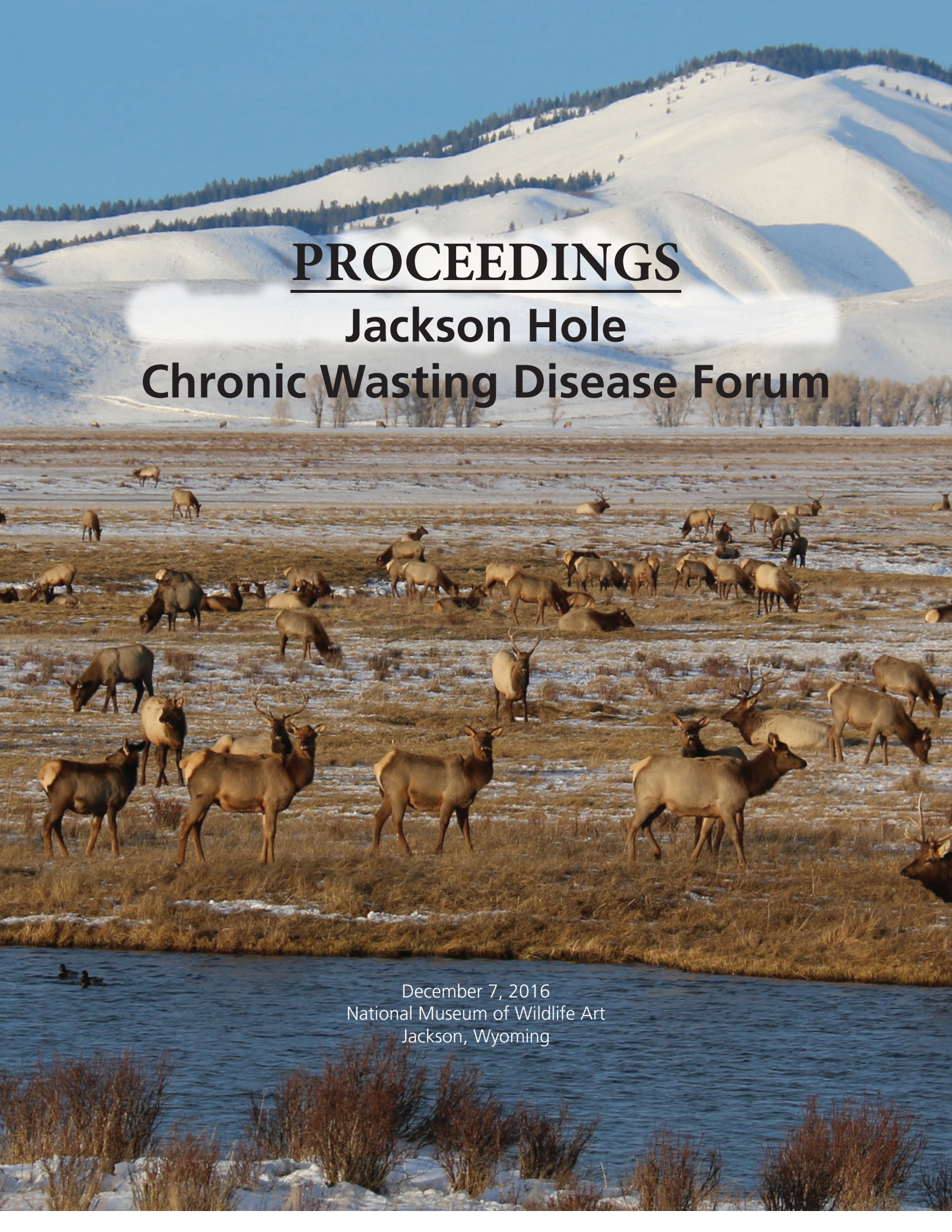

PROCEEDINGS

Jackson Hole Chronic Wasting Disease Forum

December 7, 2016
National Museum of Wildlife Art
Jackson, Wyoming

INTRODUCTION

The purpose of this Chronic Wasting Disease forum was to highlight CWD research and management considerations, with the goal to share current science-based information with the general public and all organizations concerned with the long-term health of elk and deer populations in the Jackson Hole Area.

ABSTRACTS

***Names of presenters in bold text**

Wyoming Chronic Wasting Disease Surveillance

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Chronic Wasting Disease (CWD) was first described in captive mule deer from Colorado and Wyoming in the 1970's (Williams 1980). After the initial discovery and description of this disease, the Wyoming Game and Fish Department (WGFD) began collaborative work with Dr. Elizabeth Williams in 1982 to investigate whether the disease was present in free-ranging populations (Williams 1992, Miller 2000). This was the beginning of a decades-long surveillance program to study the distribution and spread of this disease in free-ranging cervid populations.

Between 1982 and 1997 a limited number of CWD samples were collected through local check stations near Laramie and Wheatland WY. WGFD surveillance began in earnest in 1997, with peak surveillance occurring between 2003 and 2011 when federal funding was available. Currently the WGFD Wildlife Health Laboratory tests between 1500 and 3500 samples for CWD each year with over 56,000 samples tested to date in Wyoming. Surveillance includes voluntary sample collection from hunter harvested animals as well as collection from road-killed animals and targeted animals showing signs consistent with CWD. Retropharyngeal lymph nodes were sampled due to their ease of extraction and suitability as a diagnostic tissue. An enzyme-linked immunosorbent assay (ELISA) was used to analyze lymph node samples. Samples testing positive on the ELISA were then confirmed by repeating the ELISA, followed by submission to the Wyoming State Veterinary Laboratory for Immunohistochemistry (IHC). Starting in 2016, only positive samples from a hunt area where CWD has never been detected were submitted for confirmation by IHC. Results were reported to hunters in less than three weeks of sample submission, and hunters could obtain results by accessing the WGFD's website. Hunter harvested samples were used for prevalence estimates while road-killed and targeted samples helped to monitor spread. Hunter harvested deer are primarily male, while elk harvest is mixed male and female.

CWD was first identified in free-ranging mule deer in southeastern Wyoming in 1985, followed by elk in 1986. Based on early surveillance data and prevalence estimates, a small area in southeastern Wyoming containing the Laramie Mountain mule deer herd, South Converse mule deer herd, Goshen Rim mule deer herd and Laramie Peak elk herd was termed the "core endemic area" where we believe that CWD has been present for the longest period of time. Over the past 20 years, surveillance data has shown an increase in prevalence and distribution of CWD in Wyoming, particularly in deer. CWD is now found across the majority of the state, with recent new detections suggesting continued westward spread of the disease.

Using cumulative five-year estimates in the core endemic area, the Laramie Mountain mule deer herd is estimated at approximately 23% prevalence and the South Converse mule deer herd at 42% prevalence. Both herds have shown an increasing trend in prevalence over time; however, prevalence may have briefly dropped after population declines following harsh weather conditions. Prevalence levels approaching 20% or above are becoming more common in many deer hunt areas that surround the core endemic area. CWD prevalence is also increasing in many deer hunt areas of the Bighorn Basin, where prevalence is approaching or exceeding 10%. It is important to note that hunter harvest of mule deer in Wyoming is primarily male and therefore estimates only reflect male prevalence. CWD prevalence in female mule deer in Wyoming is largely unknown.

Distribution of CWD in Wyoming elk appears different than deer with most CWD in elk limited to southeastern Wyoming. The Laramie Peak elk herd overlaps the Laramie mountain mule deer herd, but five year prevalence is only estimated at 6-7%. There is robust harvest of both females and males in this population and there is no significant difference between prevalence of males and females. Elk in this herd often congregate into large groups as winter progresses and it is common to find groups of over 1000 elk in late winter. It is unknown why CWD distribution and prevalence is so different in elk, though it should be noted that behavior and management of elk and deer in the core endemic area are different. Despite the limited distribution of documented CWD in Wyoming elk, surveillance data suggests that prevalence has increased over time in Laramie Peak elk, though may have stabilized over the past 6 years. It is important to note that sample sizes for individual herds through our annual CWD surveillance are low, making it difficult to estimate prevalence with good precision, particularly when prevalence is below 10%.

To date, the WGFD has not conducted on-the-ground management for CWD, making Wyoming an example of CWD impacts in the absence of directed management. After recent research identified population declines due to CWD in Wyoming (Edmunds 2016, DeVivo 2015), the WGFD made a commitment to pursue management options. Recently the Wyoming Game and Fish Department updated its CWD management plan with expanded goals covered by four main components: Disease management, applied research, public information, and funding. The new management plan includes a stated goal to reduce the rate of spread and prevalence of CWD in Wyoming. Currently the agency is engaged in preparations to increase communication and outreach regarding CWD in the state and is looking for ways to approach management of CWD in Wyoming.

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Studies of CWD Transmission, Shedding and Environmental Contamination Using Rapid Sensitive Amplification Assays

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Chronic wasting disease affects free-ranging or captive populations of deer, elk and moose in the United States, Canada, Korea, and most recently Norwegian caribou and moose. CWD is unique in its ability to spread in wild populations, which likely occurs through environmental dissemination or direct contact with prions shed into bodily fluids or excreta. CWD is only known to affect cervid species, however, almost surely non-cervid sympatric species and other species, including humans, have been exposed. Prions are misfolded amyloid conformations of the normal, alpha-helical, cellular protein, PrP^{C}, classically designated as PrP^{Sc}. Detection of PrP^{Sc} is hampered by difficulty in distinguishing the disease specific conformation, PrP^{Sc}, from the cellular form of the PrP^{C} protein. Traditionally, the distinction has been predicated on the relative protease resistance of the disease specific form of PrP^{Sc} in western blots or enzyme-linked immunosorbent assays (ELISA). A seminal advancement in the detection of prion diseases was the discovery that the addition of PrP^{Sc} to the proper PrP^{C} substrate results in amyloid amplification under appropriate reaction conditions such as provided in the serial protein misfolding cyclic amplification assay (sPMCA).

The real-time quaking induced conversion (RT-QuIC) assay enables amyloid amplification and sensitive detection (up to attomolar concentrations of prions) by employing recombinant PrP^{C} ($rPrP^{C}$) substrate and provides increased throughput, simplified read-out, and reduced cost. Tuning of RT-QuIC conditions and enrichment methods makes it possible to detect prion seeding activity in an array of biologic and environmental samples including tissues, biologic fluids, and excreta. To help better understand, assess, and manage CWD, we have focused on RT-QuIC detection and have developed methods to concentration techniques that allow for increased sensitively and simplified detection in excreta. Prions can be extracted from excreta by exploiting the metal binding properties of prions by the addition of super-paramagnetic iron oxide beads. Prions can be extracted out of the complex and reaction-inhibiting contex associated with excreta and be detected via RT-QuIC.

These methods have enabled us to detect CWD prions in body fluids and excreta (e.g. saliva, urine, feces, cerebrospinal fluid, nasal swabs) of deer and elk and also to track the early stages of CWD infection by natural route (oral) exposure. We have used rapid seeding assayed to estimate the amount of CWD prions found in excreta, which may shed light on management of CWD as well as help to explain the spread of the disease in the wild. Using analysis of CWD prions in feces we plan to further study the environmental impact of CWD. In the future we plan to 1) Using real-time quaking induced conversion (RT-QuIC) we will estimate environmental contamination via urine and feces by CWD positive animals throughout the disease course. 2) We will apply RT-QuIC to estimate CWD incidence in populations without animal capture and assess the

persistence of prion seeding activity in feces under environmental conditions in the native range of cervid species. We have made progress to rapidly and cost-effectively detect CWD in urine and feces, which contribute substantially to environmental contamination.

In our preliminary results we estimate that deer experimentally inoculated with CWD approximately 100 (TG5037) mouse LD_{50} doses are shed in urine and about 90 (TG5037) mouse LD_{50} doses are shed in feces per day. The relative difference between a susceptible transgenic mouse lethal doses and a lethal dose in cervids remains to be determined. In the future, we will apply RT-QuIC detection of CWD in feces to estimate CWD incidence in populations without animal capture and to determine how long prion seeding activity remains active in fecal samples under potentially harsh environment conditions that exist in the native range of cervid species. This approach should advance ante-mortem detection, surveillance, and assessment of environmental contamination for CWD and other prion and protein misfolding disorders.

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Soil and the environmental transmission of chronic wasting disease

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Cervid chronic wasting disease (CWD) is progressive neurodegenerative disease affecting captive and free-ranging white-tailed deer, mule deer, elk, and moose in North America, as well as reindeer and moose in Norway (Benestad et al. 2016, Stokstad 2016) and imported elk in South Korea. Chronic wasting disease belongs to a class of diseases known as transmissible spongiform encephalopathies (TSEs) or prion disease. Substantial evidence indicates that TSEs are caused by misfolded forms of prion protein (Prusiner 1998). The central molecular event in CWD is the conformational conversion of benign, host-expressed prion protein (PrP^{C}) to pathological conformers (PrP^{TSE}) (Prusiner 1998). In addition to CWD, prion diseases include scrapie in sheep and goats, bovine spongiform encephalopathy ("mad cow" disease) in cattle, and Creutzfeldt-Jakob disease in humans.

Environmental routes are implicated in the transmission of sheep scrapie and cervid CWD (Greig 1940, Prusiner 1998, Miller et al. 2004, Mathiason et al. 2009). Reintroduction of sheep onto pastures previously holding a scrapie-infected flock led to disease transmission (Dexter et al. 2015). Further, scrapie was transmitted to naïve lambs after being housed in a sheep-house last occupied by infected animals 16 years previously (Georgsson et al. 2006). The environmental transmission of CWD has been demonstrated in controlled pen studies (Miller et al. 2004). The presence of residual excreta or decomposed carcasses from CWD-infected animals was sufficient to transmit disease to naïve mule deer (Miller et al. 2004). Infected animals shed prions in their saliva, feces, and urine (Mathiason et al. 2006, Tamgüney 2009, 2010, Pedersen and Sommerville 2012). Prions may also be released into the environment via deposition of infected carcasses and "gut piles" from hunters who dress deer in the field.

Soil represents a plausible environmental reservoir of CWD prions (Schramm et al. 2006, Pedersen and Sommerville 2012). Cervids consume soil at mineral licks to supplement mineral nutrition as well as incidentally during feeding and grooming (Arthur and Alldredge 1979). Attachment to soil particles is expected to influence the persistence, transport, and infectivity of prions in the environment. Prions remain infectious after burial in soil for at least three years (Brown and Gajdusek 1991, Seidel et al. 2007). Prions interact strongly with smectitic clay particles such as montmorillonite (Johnson et al. 2006). Vertical transport of prions through soil columns is strongly attenuated by attachment to soil particles (Jacobson et al. 2009, Jacobson et al. 2010). The attachment of prions to soil mineral surfaces as a function of solution conditions is consistent with dominant contribution of electrostatic interactions (Jacobson et al. 2013).

Adsorbed prions remain infectious (Johnson et al. 2006) and association with specific types of soil microparticles enhance oral transmission in rodent models (Johnson et al. 2007, Johnson et al. 2011). Naturally contaminated soil can transmit CWD to naïve individuals (Wyckoff et al. 2016). Mice retain fluorescent prions bound to montmorillonite longer than prions alone (Wyckoff et al. 2016). Montmorillonite promotes retention and bioavailablity of prions in a mouse model for CWD (Wyckoff et al. 2016). Montmorillonite facilitates prion transport from the stomach to macrophages and B cells (Wyckoff et al. 2016). A strong correlation was found between CWD

infection odds in mule deer in northern Colorado and soil clay content (Walter et al. 2011). Every 1% increase in soil clay content was associated with an 8.9% increase in infection odds after adjustment for age, sex and other habitat features (Walter et al. 2011).

Prions exhibit remarkable resistance to most methods of inactivation that are effective against conventional pathogens (Taylor 2000). At present, methods to reliably decontaminate pens, pastures, and rangeland are lacking. The solid-phase oxidant manganese oxide has been examined for its ability to inactivate prions (Russo et al 2009). Exposure to manganese oxide produces dose-dependent decline in pathogenic prion protein and could reduce PrP^{C}-to-PrP^{TSE} converting levels by more than a factor of 10^4 (Russo et al 2009). Recently, peroxymonosulfate, a monosubstituted form of hydrogen peroxide, was shown to rapidly degrade CWD prions (Chesney et al. 2016). Degradation was enhanced in presence of Co^{2+}; Degradation occurred in presence of competing biomolecules and was enhanced in the presence of Co^{2+} (Chesney et al. 2016). More than a 5.9 log reduction in PrP^{C}-to-PrP^{TSE} converting ability could be achieved (Chesney et al. 2016).

The transmission of CWD via contaminated plants is beginning to be studied. Prions from urine and feces adhere to plant roots and leaves (Pritzkow et al. 2015). Barley grass grown on prion-amended soil can take up prions via their roots and translocate them to above-ground tissues (Pritzkow et al. 2015). Whether the amounts translocated to above-ground tissues from soil are sufficient to initiate disease remains to be determined.
The relative importance of direct and environmental transmission of CWD has not been determined, but has important implications for the management of the disease. An improved understanding of the processes affecting the mobility, persistence and bioavailability of prions in soil is needed for the management of CWD-contaminated environments. Measurement of CWD prions in the environment would enhance our understanding of indirect disease transmission.

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Modeling the Effects of Chronic Wasting Disease on a Rocky Mountain Elk Population Using Genotype-Specific Mortality Rates

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Chronic wasting disease (CWD) is a fatal transmissible spongiform encephalopathy (TSE) of cervids caused by the misfolding of normal cellular prions. The incubation time of CWD in elk can be variable among individuals due to a methionine/leucine (M/L) polymorphism at PrP^{C} codon 132 that restricts propagation of PrP^{CWD}. Having at least one L allele provides a longer incubation time and increases the reproduction potential of an individual. The M/M genotype has been shown to have the shortest incubation time and is significantly over-represented in wild and farm raised CWD positive elk. Currently the M/M genotype has the highest frequency within elk populations. As the endemic area of CWD continues to expand, there is concern over the impact it will have on elk (*Cervus elaphus*) populations that congregate on winter feedgrounds in Wyoming. Feedgrounds have the potential to become prion sinks due to the congregation of large numbers of animals over prolonged periods. A stochastic simulation model was created to determine the effect that genotype-specific CWD mortality rates had on a hypothetical free-ranging elk population. Life table data gathered from captive elk held in a CWD-contaminated facility was used to parameterize the model. Demographic information for the modeled elk population came from the Pinedale elk herd unit. Two groups of scenarios were evaluated. One group was age-specific where the probability of death for an individual elk was based on their age and did not include information about genotypes. The second group was genotype-specific and the probability of mortality from CWD depended on an individual elk's age and genotype. Both groups included models with and without hunting. The genotype-specific group also included an antlered-only hunting model. In this exercise, prevalence was not modeled. No elk could avoid exposure, and each individual greater than one year of age, had a chance of dying each year based on their age and genotype. By modeling higher than expected CWD exposure and subsequent mortality, an upper bound was created which could be used to estimate worst-case population-level impacts. It was assumed there is no fitness disadvantage to having the L allele.

Both age-specific models resulted in extirpation or near extirpation of the elk population by year 100. With current hunting levels, the population declined sharply with a 98.5% decrease in the population by year 50. The no hunting model had a more gradual decrease but resulted in 92% fewer elk at year 100. The results were more varied within our genotype-specific scenarios. With current levels of harvest, the population decreased by 84.6% at year 25 with zero elk by year 100. The antlered-only harvest regime caused a population decline but the model suggests the population would stabilize based on the median lambda for the last 10 years of the model. The population without hunting declined initially, but rebounded by year 100 with a 32% increase in the number of elk at year 100. The genotypic frequencies changed in each genotype-specific model and showed selection for the L allele that varied with an increase of ~40 – 60%. This change increased the number of days to death and allowed population growth in the model without hunting. The models indicate elk populations exposed to CWD could respond through changes in frequency of genotypes. The models also suggest that with adaptive management, a

level of hunting may exist that is sustainable to a changing population. Selection pressure from CWD is causing changes in frequencies of genotypes with longer incubation times in white-tailed deer in Wisconsin, and in mule deer in Wyoming. However, in Colorado and elsewhere these changes have not been documented. Selection pressure may not be great enough in some areas to influence the changes seen in the modeled elk population.

Many questions exist about the effect of a changing genotype that have yet to be answered. However, genetic diversification is generally viewed as a positive component of population mixing as it can mask deleterious genes or add potentially useful genes. Many wildlife species try to maximize the heterozygosity of their offspring through mate choice. Heterozygosity has been associated with health benefits, greater body size, and increased symmetry in individuals across many animal and insect species. If there is a fitness disadvantage to elk with the L allele, we would expect to eventually see a stability of allele frequencies with the M/L genotype being the most common. This would allow the population to balance the risk of having the L allele with the benefit of increased incubation time and reproductive potential when infected with CWD. Given the potential selective pressure of CWD, we may see a change in genotype frequencies, but it is unlikely the M allele will be lost.

Williams, A. L., T. J. Kreeger, and B. A. Schumaker. 2014. Chronic wasting disease model of genetic selection favoring prolonged survival in Rocky Mountain elk (Cervus elaphus). Ecosphere 5(5):60. http://dx.doi.org/10.1890/ES14-00013.1

Endemic Chronic Wasting Disease and Mule Deer Populations Decline in Wyoming

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The effects of chronic wasting disease (CWD) on cervid demography and ecology and ultimately population sustainability are poorly understood. In southeastern Wyoming average annual CWD prevalence in mule deer (*Odocoileus hemionus*) exceeded 20% and appeared to contribute to regional population declines during the early 2000s. Free-ranging mule deer south of Douglas, Wyoming were studied to determine the impacts of CWD on survival, fecundity, genetic selection, and population sustainability. We captured adult (≥ 1.5 years old) mule deer using aerial net-gunning from 2010 – 2014. Captured deer were equipped with store-onboard global positioning system radio-collars and monitored twice weekly until study termination. We collected tonsil biopsies antemortem to test for CWD, and blood to determine pregnancy status and prion protein (*Prnp*) genotype associated with CWD susceptibility in mule deer. Marked deer were recaptured annually to test for pregnancy, and disease-negative deer retested for CWD. We observed marked does in November to count the number of fawns-at-heel, and as mortalities occurred throughout the year, we performed field investigations and necropsies to assign cause-of-death when feasible.

Our capture efforts resulted in a total of 143 mule deer (118 females and 25 males) collared and tested for CWD. Average annual CWD prevalence i.e.; the proportion of deer that test positive for CWD during a capture event ranged from 21-27%. Average annual CWD incidence i.e.; the proportion of new CWD-positive deer that occurred between capture events was 0.26 for females and 0.45 for males. An extended Cox proportional hazards model revealed CWD-positive deer were over three times more likely to die during our study compared to CWD-negative deer and males were twice as likely to die compared to females. Kaplan-Meier annual survival estimates were significantly ($\chi^2 = 40.10$, $p < 0.01$) different between CWD-negative (0.76, SE = 0.04) and CWD-positive deer (0.32, SE = 0.06). While we observed substantial differences in adult survival, we did not detect a predicted difference in fawn production based on the CWD status of deer. Mean annual pregnancy (CWD-negative = 0.99, SD = 0.11; CWD-positive = 0.94, SD = 0.24) and

fawn recruitment (CWD-negative = 0.48, SD = 0.65; CWD-positive = 0.56, SD = 0.65) were similar between CWD-negative and CWD-positive females with no effect of age, body condition, *Prnp* genotype, and observation year on these vital rates using a repeated measures analysis.

To determine the impact of CWD on population sustainability we used an age-specific, female-only, CWD transition matrix model and populated it with our estimates of survival and fawn production to evaluate the population growth rate (λ). We estimated $\lambda = 0.79$, indicating an annual population decline of 21% under current CWD prevalence levels. A model derived from the demography of only CWD-negative individuals yielded; $\lambda = 1.00$, indicating a stable population if CWD were absent. These findings support CWD as a significant contributor to mule deer population decline in this southeast WY herd.

Epidemiologic models have been used to predict population trends of free-ranging cervids in response to CWD and more recently to show genetic-selection of less-susceptible deer and elk. We developed a stochastic simulation model to determine the effect of genetic-specific CWD incidence and mortality on λ. The inclusion of genetic-specific disease metrics did not mitigate a significant decline in the simulated population, but the remaining deer were primarily of the less-susceptible genotype. This result was in contrast to model simulations that excluded genotype-specific disease indices, and genetically more susceptible deer were the last to be eliminated from the population. In both scenarios, λ remained less than one, and while the model predicted genetic selection in response to CWD, natural selection may not occur fast enough to prevent a severe reduction in the number of deer. The sustainability of a remnant population comprised of mostly less-susceptible genotyped deer remains to be determined.

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Lessons learned about chronic wasting disease in elk at Rocky Mountain and Wind Cave National Parks

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Chronic wasting disease (CWD) has been identified in elk in three national parks in Colorado, South Dakota, and Arkansas. Parks are often refugia for elk and other cervids, frequently leading to high population densities in localized areas. This is a similar situation to that observed at the National Elk Refuge. Much of what we understand about CWD ecology is derived from large studies in deer while relatively little information is available in elk; particularly in elk populations with high population densities.

Two key studies at Rocky Mountain National Park, Colorado, (RMNP) have begun to describe the population level effects of CWD in elk where densities have historically reached as high as 110 elk/km^2 on portions of their winter range. This population has been affected by CWD since at least the early 1980s and by the early 2000s a large proportion of animals found dead tested positive for CWD (~50% of female elk). The first study was initiated to evaluate rectal biopsy as an antemortem CWD diagnostic test and estimate CWD prevalence. We found that rectal biopsy, while useful to investigate disease ecology and give a relative estimate of prevalence, is not a reliable test for early detection of CWD. Immunohistochemistry of recto-anal mucosa associated lymphoid tissue had a sensitivity of ~70-85% depending on the stage of disease, prion genotype, and number of follicles observed. After including missed CWD-positive animals that died with disease within 24 months of misdiagnosis, we found a high disease prevalence of ~13% (8-19%; n=136) in 2008. Additionally, we estimated that the population growth rate in female elk was flat to declining (λ=~1.0) and that CWD can exceed natural rates of mortality, reduce adult female survival, and decrease population growth of elk by increasing mortality of infected females.

The intent of the second study was to more closely investigate disease dynamics in RMNP elk. Preliminary results support our earlier findings that CWD reduces adult female elk survival and this increased mortality decreases the population growth rate. Concurrent with our study, elk are re-distributing to areas outside of the park and now exhibit much lower densities within the park. The effects of this on CWD prevalence are unclear; movement could contribute to disease spread and a dilution effect or there may be a reduction in disease transmission pressure. We have observed a preliminary estimate of prevalence for 2012-2016 of ~8.5% (4.6-13.3%; n=138).

In an effort to more clearly understand the effects of population density on disease transmission, we are commencing research at Wind Cave National Park, South Dakota. This functionally closed population of elk exhibits high density and high mortality from CWD (~9.5%). Previous research has also shown low recruitment and projected population decline (λ=~0.94). In an effort to meet management objectives of a smaller elk population and concurrently test the hypothesis that decreasing elk density will decrease CWD prevalence, managers plan to reduce elk abundance from ~600 to ~250 in the 34,000 acre park. This lower abundance will be maintained and the

population monitored over time, allowing us to study effects on disease prevalence, vital rates and cause-specific mortality.

Finally, our earlier work examined the potential effect of selective predation on disease dynamics. Modeling indicates the absence of predator-prey interactions results in multiple alterations to disease emergence and dynamics. For diseases like CWD, disturbance to predator-prey interactions may facilitate initial establishment of disease and result in higher disease prevalence. This effect is primarily driven by predators shortening the time that infected prey remain on the landscape with the potential to transmit disease. This hypothesis needs testing through observations in a system with potentially selective predators, like coursing wolves.

Evidence suggests that surveillance for CWD in an area in which disease has not been previously observed is best targeted at animals killed by motor vehicle accidents, and theory suggests targeted surveillance should include animals killed by a selective predator. Targeted surveillance provides a greater likelihood of detecting a disease-positive individual within a sample of a given size and maximizes resources.

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Model Forecasting of the Impacts of Chronic Wasting Disease on the Jackson Elk Herd

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Chronic wasting disease (CWD) is a contagious transmissible encephalopathy that infects members of the deer family (Cervidae) in North America. Although CWD does not currently occur in the Jackson elk herd, it is present in mule deer (*Odocoileus hemionus)* 35 miles away and in elk within 160 miles. Observations from captive and free-ranging herds suggest CWD may have greater impacts on elk in relatively high-density settings or where environmental contamination may occur in a smaller area, such as those found on the National Elk Refuge (NER).

We developed a Bayesian model for the Jackson elk herd to achieve three goals; 1) Examine the potential impacts of the CWD on population dynamics of the Jackson elk herd, 2) Aid in designing future sampling for CWD in the population, and 3) Provide a proactive framework for assimilating new data on herd health to guide adaptive management of the population.
We fit the model using three sources of data on the Jackson population: total census, demographic classifications, and CWD test results and included information from a CWD-infected elk population in Rocky Mountain National Park (RMNP). The model enables predictions of the future state of the population accompanied by rigorous, statistically defensible estimates of uncertainty. These forecasts can be used to understand the short-term dynamics of the population infected with CWD before the disease actually arrives.

Analysis revealed that CWD is likely to drive the population growth rate (,\) below one, indicating a decline in elk numbers over time. A declining population becomes more probable with increasing disease prevalence. Given the predictions from this study and no hunting, the most probable threshold between an increasing and a declining population (,\ = 1) occurred when prevalence of CWD in yearling and adult females reached 7%; however, we cannot rule out a threshold as high as 23% prevalence before ,\ falls below one. The addition of CWD into the model with current hunting levels leaves little possibility that the population is growing. Note, however, that recent harvest levels are designed to decrease the population size. Although there is significant overlap in the forecasts for an infected and uninfected population, it is clear that CWD has the potential to decrease the population size.

The model framework presented here is a first step towards informing managers of the Jackson elk herd of the possible effects of CWD on the population. Our results depend in part on results of research conducted on elk populations infected with CWD in RMNP. Given that the modeled

effects were based on a smaller and presumably less concentrated elk population, CWD may lead to higher disease prevalence and larger impacts of CWD on the population growth rate due to crowded herds returning annually to the same location, as occurs on some feedgrounds.

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Role of Habitat Treatments and Related Mitigation Strategies to Offset Impacts of Altered Feedground Management

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The threat of chronic wasting disease (CWD) has prompted wildlife managers and the public to consider altering feedground management for elk (*Cervus canadensis*) on the US Fish and Wildlife Service National Elk Refuge (NER) and on other winter ranges in northwest Wyoming. These winter ranges frequently experience heavy snowfall and cold temperatures, which limits the availability of natural forage. Elk have been fed here for decades as a strategy to reduce winter mortality and lessen conflict with ranchers and communities. However, from a CWD standpoint, wildlife managers should avoid or minimize artificial feeding because it concentrates animals and increases nose-to-nose contact, which in turn facilitates disease transmission among animals. CWD is especially concerning because it is a fatal disease in elk and deer (*Odocoileus* spp.) that wildlife managers have been unable to eliminate once it becomes established in an area. The purpose of this presentation was to explore management options in the event artificial feeding is reduced or eliminated in northwest Wyoming. A common strategy employed in the West by wildlife managers in lieu of feeding is habitat treatments. In this context, habitat treatments refer to vegetative alterations, such as controlled burns or mechanical removal of mature trees, implemented to increase the quantity of higher-quality forage for ungulates. An important question facing Wyoming managers is to what extent habitat treatments can offset nutritional deficiencies associated with reduced or eliminated feeding.

In southwest Colorado, Bishop et al. (2009) compared mule deer (*O. hemionus*) recruitment and survival rates between areas provisioned with *ad libitum* feed and areas without feed. Deer receiving *ad libitum* feed experienced a 13% increase in population growth rate compared to unfed deer. Bergman et al. (2014) then conducted a similar study, except they used habitat treatments instead of feed. They conducted initial vegetation treatments and then followed up with herbicide and reseeding to help achieve desired forage responses. Deer occupying winter range areas that received these habitat treatments experienced a 14% increase in overwinter fawn survival compared to deer in winter ranges without habitat treatments. For comparison, Bishop et al. (2009) documented a 34% increase in overwinter fawn survival in response to *ad libitum* feed. Together, these studies demonstrate that habitat treatments can be an effective strategy to increase ungulate forage quality and quantity, and in turn survival, but such treatments do not provide the nutritional equivalent of commercially-produced feed supplied *ad libitum*. Studies conducted elsewhere have also demonstrated the utility of habitat treatments for increasing forage abundance and quality for ungulates. In northwest Colorado, Chuck Anderson and colleagues are investigating the utility of winter range habitat treatments for mitigating impacts of natural gas development on mule deer. This research is ongoing, although preliminary data demonstrates that habitat treatments have been an effective strategy for increasing forage quantity and quality, and in turn, winter fawn condition (personal communication). In the Pacific Northwest, Cook et al. (2016) demonstrated that early successional habitats, following logging or other disturbance, roughly doubled elk intake rate of digestible energy compared to closed canopy forests. They demonstrated that the manner in

which forest habitat is managed greatly influences its nutritional suitability for elk. In Montana, Proffitt et al. (2016) found that fire played a key role in influencing the amount and quality of forage available to elk. They found that elk with access to less nutrition on summer range had substantively lower pregnancy rates and entered winter in poorer body condition. The studies referenced above demonstrate the importance of habitat treatments and natural disturbance (e.g., fire) for producing higher-quality forage for elk and deer on summer, transition and winter range, which in turn allows the landscape to support more animals. However, the forage must be available to animals. In northwest Wyoming where feedgrounds are used, deep and/or crusted snow may drastically limit the availability of forage during many winters, even if additional habitat treatments were implemented on the landscape to increase the amount of higher-quality forage. If natural forage was largely unavailable and feeding was dramatically reduced, elk would be expected to seek out food wherever they could find it, likely on ranches and in town (e.g., Jackson Hole). Habitat treatments have often been used near ranches and towns to provide more natural forage, thereby lessening conflicts with ranchers and other citizens (e.g, Colorado Habitat Partnership Program, http://cpw.state.co.us/aboutus/pages/habitatpartnershipprogram.aspx). These treatments will not be effective, however, if they are not functionally available to the animals due to snow cover. Thus, while habitat treatments have proven beneficial across the West for increasing ungulate carrying capacity and reducing conflict, their utility is less clear for helping offset impacts of altered feedground management in northwest Wyoming where snowfall and temperatures are consistently more extreme than many other western winter ranges.

I conclude by providing recommendations in the event existing feedground management is substantively altered at NER or other feedgrounds in northwest Wyoming. First, I recommend conducting a nutrient-based assessment of the current landscape's capacity (including summer, transition and winter range) to support elk without supplemental feed. Such an assessment could draw upon existing elk data coupled with habitat and forage models. Even a qualitative assessment would be valuable in framing a decision process for how to most effectively manage elk and habitat in absence of feed. The assessment should explicitly incorporate typical and extreme snowfall relative to its impact on forage availability during fall, winter and spring. The assessment should identify areas of the landscape that may become more important in the future for elk during winter, perhaps at lower elevations, if feed were eliminated. The assessment should also identify areas where conflict with ranchers is expected to be high. Finally, the effect of wolves (*Canis lupus*) should be considered relative to anticipated effects on elk distribution and survival. Using this assessment, managers can identify additional opportunities for using habitat treatments to increase forage quantity and quality, considering all seasonal ranges. Summer and transition range can be as or more important than winter range in meeting nutritional needs of elk during winter (i.e., elk rely heavily on stored nutrients via fat and muscle to survive winter). Ultimately, managers should be able to make informed hypotheses as to the capacity of the landscape to support elk under differing feed and habitat management scenarios. These hypotheses could then be used to identify a set of management alternatives involving modification of existing feedground strategies, implementation of habitat treatments, and possibly increased hunter harvest of elk. A likely strategy might involve lessening the amount of feed provided in existing feedgrounds, and instead redistributing that feed more broadly across the landscape to redistribute elk. Ultimately, strategic placement of feed could be used to modify

existing elk space use and minimize negative impacts to ranchers and communities as elk adjust to alterations or elimination of traditional feedgrounds. In the short-term, this approach could increase operational costs associated with personnel distributing feed more widely across the landscape, but in the long-term, costs would be expected to decrease as the amount of feeding decreased. Finally, I recommend instituting any management changes in an adaptive management framework that allows evaluation of a given management strategy.

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Cover: Elk arriving on the National Elk Refuge in early winter. Photo credit- USFWS.