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**Management of Sheep Pneumonia: Wild Bighorn Sheep and Domestic Sheep of the Mountainous Western United States**

Wild populations of Bighorn sheep (*Ovis canadensis*) in the mountain west region of the United States are severely impacted by pneumonia outbreaks caught from domestic sheep and other livestock (Cassirer et al. 2018). This transmission occurs when domestic livestock are taken to graze on public land and come in physical contact with wild Bighorn herds (Cassirer et. al 2018). This respiratory disease is caused by strains of bacteria that have been observed to remain in wild populations for multiple decades upon introduction (Cassirer et al. 2018). The bighorn and domestic sheep are genetically similar enough that instances of interbreeding have occurred, so the bacteria easily transfers from livestock to the wild sheep through contact (Pulling 1945, Cassirer 2018). However, domestic sheep have exhibited a much higher resilience to the infection and are less likely to develop pneumonia (Cao et al. 2020). Once the pathogens have been introduced to a wild population, it is extremely likely that the population will begin to develop pneumonia and suffer significant mortalities by the following year (Cassirer et. al 2013).

Bighorn sheep are communal ungulates native to western North America that reside on rocky mountainous land (Cassirer et al. 2013). Domestic sheep (*O. aries*) are in the same subfamily *Caprinae* as bighorn sheep, and have a long history of cultivation for human use throughout the Middle East and Asia (Reavill 2000, Chessa et al. 2009). They originated in Europe and were brought to North America by European colonizers as livestock (Chessa et al. 2009). Pneumonia in sheep originates as infections in domestic herds that are spread to wild sheep populations where bronchial disease develops (Cassirer et al. 2018). Bighorn sheep in western North America have been facing declines due to pneumonia for approximately the last century, but comprehension of how the disease operates across physical space and time has only progressed over the last few decades and is still incredibly limited. (McClintock et al. 2007, Cassirer et al. 2013).

The bronchial disease is complex and involves multiple factors including bacterial and viral infections in the lungs and immune system, which are affected by external stressors such as nutrition, competition, and environmental disturbances (McClintock et al. 2007). Symptoms of pneumonia include reduced activity and coordination, fever, coughing, and nasal discharge (Campbell and Van Metre 2018). Often domestic sheep are carriers of the contagious pneumonia-causing bacterial infection but have not developed pneumonia (Campbell and Van Metre 2018). This can be spread to other individuals, including wild Bighorn sheep that are more likely to develop the disease and be negatively impacted by it (Cassirer et al. 2018).

Pneumonia in wild bighorn sheep is associated with high mortality across all age classes, causing rapid and severe population declines (McClintock and White 2007). Outbreaks have been repeatedly observed in the United States and Canada to decrease populations by more than half (McClintock and White 2007, Hopkins). Pneumonia is a critical limiting factor in Bighorn population restoration as it causes high mortality and diminished recruitment of lambs (Cassirer et al. 2013, Sells et al. 2016).

The processes involved in sheep pneumonia contraction and spread are understudied and poorly understood, which impacts how the effects of the disease are managed (Cassirer et al. 2013). Risk of disease contraction in wild and domestic sheep has been estimated in numerous studies, but this is ineffective at informing management decisions about how to reduce risk and prevent transmission (Sells et al. 2016). Both the infection and the disease are difficult to track and to predict outbreaks, so preventative management is key (Sells et al. 2016).

Wild sheep populations are exposed to the pneumonia-causing pathogens when domestic livestock graze on public land (Cassirer et al. 2018). Wildlife managers have jurisdiction over populations living on public land, but have no control over farmers that own domestic livestock on private land (Cassirer 2022). These farmers have the right to take their herds onto the public land. Therefore, outreach and education about the detrimental effects of contact between domestic sheep and wild sheep, the intricacies of sheep pneumonia, as well as bighorn population dynamics is vital (Cassirer 2022).

Currently, government organizations and wildlife managers are seeking to prevent contact between domestic and wild sheep (Cassirer et al. 2018). This is being done by way of various strategies, including regulation of public land, outreach to private landowners and farmers, and some wildlife management techniques with limited success (Cassirer 2022).

Polymerase chain reaction (PCR) nasal swab tests have been used to discern infection rates in wild herds with some success, but it is very time- and labor-consuming and only detects the bacterial infection (Cassirer et al. 2018). Pneumonia presence is often detected during necropsies, meaning it cannot be effectively tracked in live populations (Cassirer 2022). Antibiotics and supplemental nutrition have been attempted to increase herd immunity but it is inconclusive if this is effective or efficient. Culling diseased individuals is another option with similar complications (Cassirer et al. 2018). Proposals for vaccine development have been discussed but a wildlife or domestic vaccine is not a viable option for several reasons (Cassirer 2022). Any immunity obtained from a vaccination would not protect animals from the multiple strains and variants of the bacteria that causes pneumonia. Distributing the vaccine to wild bighorn populations would pose many feasibility issues, and would be labor intensive due to inaccessible and remote locations as well as being invasive to the animals. In addition, the vaccine would have to be administered every generation, as immunity is not passed down through reproduction (Cassirer 2022).

A better understanding of how the bacterial infection can fade out of populations over time before spreading to other herds is critical for developing management strategies, including physical barriers as a form of quarantine (Cassirer et al. 2013).

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