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Mineral licks as a potential nidus for parasite transmission

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ABSTRACT

Discrete landscape features can concentrate animals in time and space, leading to non-random interspecific encounters. These encounters have implications for predator-prey interactions, habitat selection, intraspecific competition, and transmission of parasites and other pathogens. The lifecycle of the parasitic nematode *Parelaphostrongylus tenuis* requires an intermediate host of a terrestrial gastropod. Natural hosts of *P. tenuis* are white-tailed deer, and an aberrant host of conservation concern is moose, which are susceptible to high levels of mortality as a naive host to the parasite. Intermediate hosts become infected when *P. tenuis* larvae are shed in deer feces, then consumed or enter the gastropod through the foot. Incidental (or perhaps intentional) ingestion of infected gastropod intermediate hosts by aberrant or dead-end hosts often results in mortality of that animal. We present photographic evidence depicting a potential mechanism for transmission from infected white-tailed deer to moose, heretofore not examined in the literature. We deployed remote cameras at mineral licks around Grand Portage Indian Reservation in northeastern Minnesota, USA. We observed white-tailed deer defecating at mineral lick sites and geophagous moose at the same sites. We hypothesize that mineral licks may act as a nidus for *P. tenuis* transmission between deer and moose in this system and call for further research into the potential role of mineral licks in parasite transmission.

The Grand Portage Band of Lake Superior Chippewa is a federally recognized Indian tribe in extreme northeastern Minnesota, USA, and proudly exercises its rights to food sovereignty through subsistence hunting and fishing. Mooz (Moose) are a primary subsistence food used by the Anishinaabeg (people) of Grand Portage Band historically and presently. Management for and research on maintaining this moose population as a vital subsistence species thus sets the context for this paper examining potential for disease transmission between white-tailed deer and moose through shared use of mineral licks.

The declining moose (*Alces alces*) population in northeastern Minnesota, USA, and the surrounding region is of concern to indigenous communities that rely on moose as a subsistence food, as well as to wildlife watchers, sports groups, and tourism-centered economies. Moose are particularly vulnerable to mortality caused by a parasitic nematode, *Parelaphostrongylus tenuis*, meningeal worm (Lankester, 2010). Up to 25% of natural deaths of adult moose in northeastern Minnesota have been caused directly or indirectly by *P. tenuis* infection (Carstensen et al., 2017; Oliveira-Santos et al., 2021). Meningeal worm is a natural parasite of white-tailed deer (*Odocoileus virginianus*), but can infect other ungulates via ingestion of various terrestrial gastropod species that act as intermediate hosts (Anderson, 1963; Keane et al., 2022; Lankester, 2010).

In general, parasites have been an overlooked link in food webs (Byers, 2009; Lafferty et al., 2006, 2008; Marcogliese and Cone, 1997), but the lifecycle of *P. tenuis* and the physical mode of transmission among hosts is well studied (Lankester, 2001). First-stage larval *P. tenuis* (L1) are shed in deer fecal pellets and exist on a thin surface layer of mucus (Lankester and Anderson, 1968). To develop into L2 and infectious L3 stages, larvae must penetrate a terrestrial gastropod and molt within the foot tissue (Lankester, 2001). Infection is assumed to occur when gastropods contact fecal pellets or L3 free living in the soil (larvae readily leave pellets when immersed in water and are likely to also do so with rain or snow). The infectious L3 are released when the gastropod tissues are digested after ingestion by white-tailed deer or an aberrant host. L3 then enter the body cavity from the gastrointestinal tract and

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migrate to the central nervous system (CNS). Within deer CNS, larvae continue to molt to the fourth and then subadult (fifth) stages. Adult females release unembryonated eggs into venous blood, which are carried to the heart and lungs. The eggs lodge in alveolar capillaries and develop into L1, where they are coughed up and swallowed, passing unharmed through the gastrointestinal tract on fecal surfaces (Lankester, 2001). In aberrant hosts, adult worms may enter and cause damage to other parts of the CNS, including cranial nerves, as well as eyes. This damage can manifest in moose as swaying and weakness in hindquarters, circling, blindness, inability to stand, and various other neurological pathologies (Lankester, 2001).

White-tailed deer pellets collected in Grand Portage Indian Reservation exhibited a 66% shedding prevalence of *P. tenuis* larvae (Escobar et al., 2019), yet terrestrial gastropods surveyed on the reservation, and elsewhere in the region, exhibited low infection rates (generally <0.1%) (Lankester, 2001, 2018; Nankervis et al., 2000; Platt, 1989; Severud et al., 2023). Ingestion of infected gastropods by deer is therefore required for the *P. tenuis* lifecycle to persist, so deer must consume large numbers of gastropods. Several mechanisms have been hypothesized to explain the apparent disconnect between low infection of gastropods and high infection of deer (McCoy and Nudds, 2000). Hypotheses with little support include deer becoming more likely to be infected as they age (Anderson and Prestwood, 1981) and *P. tenuis* manipulating behavior of gastropods to make them more likely to be ingested (Cyr, 2015; McCoy and Nudds, 2000). Several species of terrestrial gastropod are more arboreal than others (McCoy and Nudds, 1997), perhaps leading to relatively higher levels of consumption. Deer and other cervids may actively and selectively forage for gastropods as a source of protein (Furness, 1988; Pietz and Granfors, 2000), but whether cervids intentionally consume gastropods has not been fully examined. These aforementioned mechanisms are not mutually exclusive and may contribute to *P. tenuis* infections, yet there is no requirement of congregating the necessary hosts in space or time.

We posit that deer and moose co-occur at discrete landscape features such as mineral licks, natural springs, and seeps, that create opportunities for high density contacts among deer, moose, and gastropods based on the photograph presented here (Risenhoover and Peterson, 1986; Wiles and Weeks, 1986). Mineral licks are ephemerally or permanently wetted areas that contain various minerals and are visited by wildlife to drink water or consume soil (geophagy) (Ayotte et al., 2006). Potential benefits provided to ungulates include supplemental sources of sodium and carbonates to help stabilize rumen pH associated with changes in spring diets (Ayotte et al., 2006). We initially observed movements of Global Positioning System (GPS)-collared moose and deer that centered on discrete locations on the reservation. On-the-ground investigations confirmed some of these locations were mineral licks with visible terrestrial gastropods present (others were assumed to be mineral licks but were not confirmed via cameras). We placed remote cameras at several of these sites to further characterize their use by deer and moose. Several cameras recorded moose and deer using the same mineral licks, with photographs and videos capturing instances of simultaneous use (Fig. 1).

A permanent moist environment could allow infected gastropods to increase in abundance over time (Severud et al., 2023). Infected deer defecate near these mineral licks (also captured by our camera traps), allowing gastropods to be exposed to *P. tenuis* larvae. Moose may subsequently use these mineral licks and ingest soil and surrounding vegetation that may contain infected gastropods. Research at Grand Portage Indian Reservation is ongoing into which species of gastropods are ingested by moose (Garwood et al., in press). We further plan to sample terrestrial gastropods at these licks and analyze them for signs of infection by *P. tenuis*. Based on highly localized concentrations of deer paired with microclimatic conditions favorable to snails and slugs (Lankester, 2001), we expect gastropods at mineral licks to exhibit higher infection rates than found in surrounding areas (e.g., 0%, Severud et al., 2023).

Fig. 1. White-tailed deer (*Odocoileus virginianus*; foreground) and moose (*Alces alces*; background) simultaneously captured by remote cameras at a mineral lick on Grand Portage Indian Reservation, northeastern Minnesota, USA, June 2022.

Discrete hotspots on the landscape for disease transmission has been studied via many mechanisms in various systems, such as watering holes, feeding operations, and scrapes (Blake et al., 2011; Egan et al., 2023; Plummer et al., 2018; Sorensen et al., 2014). Mineral licks as sites of intense species interactions among moose, elk (*Cervus canadensis*), white-tailed and mule deer (*O. hemionus*) have been described (Brochez et al., 2020). Roadside mineral licks have been decommissioned to mitigate moose-vehicle collisions (Rea et al., 2021). Mineral licks in and near the Grand Portage Indian Reservation could act as an ecological trap or nidus for parasitic transmission from deer to moose. Identification of sites as relatively high risk for moose (high visitation by deer and moose) could perhaps lead to mitigation of *P. tenuis* transmission by targeted removal of deer at those locations or decommissioning of those licks. The time and effort required to do so would need to be evaluated along with unintended consequences resulting from excluding cervids from mineral licks. Further research into the role of mineral licks in *P. tenuis* transmission is warranted.

Declaration of Competing Interest

The authors have no conflicts of interest to declare. Funding was provided by the Boon and Crockett Program at Michigan State University and South Dakota Agricultural Experiment Station at South Dakota State University.

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