Introduction:

The winter tick, *Dermacentor albipictus* (Packard), is a unique hematophagous ectoparasite of large ungulates with a distribution stretching across much of North America. Its primary hosts include wild cervids such as moose (*Alces alces*), wapiti (*Cervus elaphus*), and mule deer (*Odocoileus hemionus*) as well as domesticated ungulates such as horses and cattle (Welch 1990, Samuel 1980, 1989). There are several key characteristics about the winter tick's life history that make it unique among tick species relevant to human and animal health, the primary concerning its life cycle. Like all hard ticks (Order Ixoidea), the winter tick has 3 parasitic life stages which it will progress through sequentially: larva, nymph, then adult. Most hard ticks will drop off a host after taking a blood meal then quest for a new host once they've molted into the next life stage, but winter ticks will stay on their host while molting from larva-to-nymph and nymph-to-adult; ticks that use this life strategy are known as 'one-host' ticks.

Image 1: Winter tick (*Dermacentor albipictus*) adult female on a moose captured in Wilson, WY.

This life strategy likely protects winter ticks from adverse environmental conditions or predatory threats by insulating them against the stable temperature and humidity conditions of their host's skin (Samuel 2004, 2007). Protection specifically from the harsh cold temperatures of North American winters allowed this tick to molt through its life stages throughout the winter, making it one of the few tick species capable of developing reproductively in this season, explaining why the name 'winter' tick is so appropriate. In early spring female winter ticks will engorge on their hosts and finally drop off after parasitizing them for roughly 8 months. This begins the period when winter ticks are finally vulnerable to environmental conditions such as temperature and humidity which can impact female survival, egg clutch size, hatching success, and larval activation success (Samuel 2000, 2004, McPherson 2000, Addison 2016, Drew 1985). These females are relatively immobile, only moving <60 cm from their original drop-off point, so the environmental conditions they are exposed to are heavily influenced by their host's movement patterns and habitat use in the spring (Drew 1986).

Winter ticks are also unique because of the specific threat they pose to wildlife health. As one-host ticks, winter ticks have relatively fewer opportunities during their life cycle to pick-up pathogens from blood meal hosts and transmit to a host later on in its life cycle. The process of vectoring pathogens from one host species to another is the primary concern ticks pose to human, wildlife, and domesticated animal health. If the winter tick stays on its host throughout all 3 life stages, it will only be able to transmit the host's own pathogens back into the host repeatedly but is unlikely to, say, transmit a rodent or bird pathogen to its host. Instead, this tick threatens health through the sheer, overwhelming power of numbers. Moose (*Alces alces*) are the most commonly known host for the winter tick because they suffer severe mortalities to winter tick epizootics in which individual moose can have >100,000 individual ticks infesting them at a single time (DelGiudice 1997, Samuel 2004). Other ungulates such as elk and mule deer have been documented with high winter tick infestations causing winter tick dermatitis, but this pathology seems rare for these species and not as serious a population threat as it is for moose (Calvante 2020, Welch 1991). The underlying pathology behind winter tick dermatitis and how it leads to morbidity and mortality in moose is not entirely clear, but common symptoms include anemia, hair loss due to excess rubbing, and depleted fat stores likely due to reduction in foraging time budget and increased effort in thermoregulation and circulation (Welch 1990, Samuel 2004, Drew 1989, Addison 1994, 1998). For moose calves experiencing their first winter, these symptoms can lead to severe condition deterioration during a time of nutritional stress and result in mortalities (Addison 1998, Drew 1989).

Winter ticks and moose:

In the Northeastern US, winter tick epizootics can lead to >80% mortality in first-winter calves (Jones 2017, 2019). Oftentimes winter tick infestations will not directly result in mortality, especially for adult moose, but high infestations (>30,000 ticks/moose) can occur on moose coinfected with other parasites such as *Elaeophora schneideri*, *Fascioloides magna*, and *Paralaphostrongylus tenuis*, which seems to be a major mortality threat for moose in the Midwestern US (Carstensen 2013, Wuenschmann 2015). Even if moose survive the late winter season and shed their engorged ticks, their fat stores have been seriously reduced which may impact their reproductive potential (DelGiudice 1997). Winter ticks threaten moose across the southern extent of their range and the distribution and ecology of winter ticks and their effects on moose populations in the Midwest and Northeast US has been described before, but little is known about winter ticks and the Shiras moose (*Alces alces shirasi*) which ranges across the Northern Rocky Mountains in the US and into Alberta, Canada (Aalongdong 1994, Terry 2015).

Shiras moose is the smallest of the 3 North American moose subspecies and occurs at notably lower densities than *Alces alces americanus* populations in the Midwest and Northeast. This subspecies is characterized by its partially migratory populations which typically migrate from low elevation riparian habitats on their winter range up to high elevation alpine lakes and forests on their summer range. Moose populations in Alaska and Scandinavian moose in Europe display similar migratory behavior, but this movement pattern is unique among the moose populations currently threatened by winter ticks. Since winter tick fecundity is known to be affected by the microclimate conditions of the habitats moose use in early spring, it is possible that fully-migratory Shiras moose could either be dropping winter ticks in drier, high elevation habitats or disperse their winter ticks across a greater range of habitats thus reducing the chances they will drop all their ticks in suitable habitats. Also notable for the Shiras moose subspecies is its overlap with a higher diversity of ungulates and, in the Greater Yellowstone Ecosystem particularly, high densities of ungulates which may also influence winter tick distribution and abundance across the landscape.

Winter ticks and the Jackson Moose Herd:

Recent studies have suggested that the Jackson Moose Herd, a Shiras moose herd of <500 individual moose, may be impacted by winter tick epizootics (Dewey 2017). Ranging from the residential areas surrounding Jackson, WY, into Grand Teton National Park (GTNP), and northward into the Bridger-Teton National Forest (BTNF) and Yellowstone National Park, this partially migratory moose population has been associated with human developments in the area for decades and is locally admired and relatively well-studied. Extreme fire events and increases in predator densities likely contributed to Jackson moose decline from >10,000 moose in the early 1980’s to its current historic lows, but the impacts of parasite threats such as winter ticks have been understudied (Oates 2016, Vartanian 2011, Becker 2008). The low population size of this highly visible moose population has driven NPS-GTNP and Wyoming Game and Fish Department (WGFD) ungulate managers to investigate the population threats, including those from parasites, and status of Jackson moose and develop sustainable management plans for their future. In 2012 biologists with NPS-GTNP began monitoring hair loss on moose, a common metric for inferring winter tick infestation intensities, and in 2017 noted that >80% of moose in the southern region of GTNP displayed some degree of early spring hair loss vs <5% of moose in the northern region (Dewey 2017). Northern and southern Jackson moose also vary in the degree to which they migrate, which may influence their exposure risk to winter ticks.

Image 2: Two moose calves in Wilson, WY.

Wildlife managers operate with limited resources and in order to accurately prioritize the threat posed by winter ticks alongside other population threats and the statuses of other managed species, managers need to know 1) how winter ticks are impacting moose health, 2) how these impacts compare to other population threats, and 3) what are the projected population consequences for this threat? Since winter ticks are highly vulnerable to climatic conditions like temperature and humidity, climate change and specifically hotter, drier summers and warmer, shorter winters will dramatically modify the frequency and intensity of winter tick epizootics. Field experiments on winter ticks have shown that temperatures above 15 C in early spring increase female survival and clutch sizes and relative humidity above 75% during the summer will increase egg hatching success and larval questing activation rates (Bergeron 2013, 2014, Drew 1985, 1986, Addison 2016). Coarse weather station data correlated with winter tick epizootic years (as determined with hair loss observations) revealed high levels of correlation between winter tick epizootics and 1) onset of winter with first accumulation of snow >3” and 2) onset of spring with first major snow melt event reducing pack below 6” (Samuel 2004, Jones 2019). These climatic factors are further influenced by habitat characteristics like canopy closure, understory vegetation assemblages, hydrology, and duff/soil composition which are completely controlled by host movement and space use patterns. Precise estimations of the severity of winter tick epizootics in the future relies upon accurate descriptions for distribution and abundance across habitat types, studies which have yet to be conducted for winter ticks in the Western US.

Methods:

1. Sampling time period

During late spring and early summer, fed adult female winter ticks (engorged females i.e. EFs) will drop off their host and move <60 cm to lay their eggs. Once laid, these eggs will stay dormant all summer until a mixture of environmental cues encourages larvae to emerge typically around late July and early August. These larvae will be inactive for 1-2 weeks and begin questing for a host by ascending nearby vegetation and congregating in clumps on vegetation tips, typically between .5-1.5 m above the ground (ideal height for attaching to large ungulates). Winter tick larvae do not ascend and descend vegetation diurnally to avoid desiccation or predation while questing. Larvae will remain clumped on vegetation, moving only to avoid high winds, until they find a host or die due to desiccation in dry conditions or when they are buried with the first major snow. The first major snow event in northwest WY is typically in late October or early November, so sampling for winter ticks from **early August - late October** (August 1st-October 31st) should encompass the entire larval questing period.

2. Sampling locations

500 m square sampling plots will be randomly distributed across the ~ 2,000 sq km Jackson moose herd range that encompasses the areas where moose have been documented during EF drop off times (late April-early May). 30 plots will be located in 'high moose density' areas as noted by GPS collaring initiatives undertaken 2005-2010 and 30 plots will be randomly distributed across habitat types. Available habitat will be split into the main habitat types of shrubland/meadow, willow-dominated riparian area/wetland, aspen/deciduous forest stand, coniferous forest stand, mixed residential use, and agricultural plots. Each sample plot will be designated as having between 1 and 6 of the principal habitat types and the number of sample plots with each combination of habitat types will be distributed based on proportion of available habitat in the entire study area. Two 250 m drag transects will be located within each sample plot in an orientation that optimizes the number of habitat types crossed by the transects. Each sample plot will be sampled repeatedly every 3 weeks from early August to late October.

3. Sampling technique

Upon the start of each transect the surveyor will record:

- Date and time
- Relative humidity, wind speed, and temperature via Kestrel at 2 m, 1 m, and ground-level
- GPS location
- Weather and vegetation characteristics

The surveyor will drag a 1 square meter flannel cloth attached to a wooden dowel via a bound cord across the 250 m transect at roughly 1 m/s. The surveyor will check both sides of the cloth for larvae every 2 minutes. Upon larvae detection, the surveyor will extract larvae and place into a vial labeled with a specific ID for that location and record the vegetation characteristics for the detection. The surveyor will then begin a circular drag with a 90 m radius centered on the GPS location for the detection.

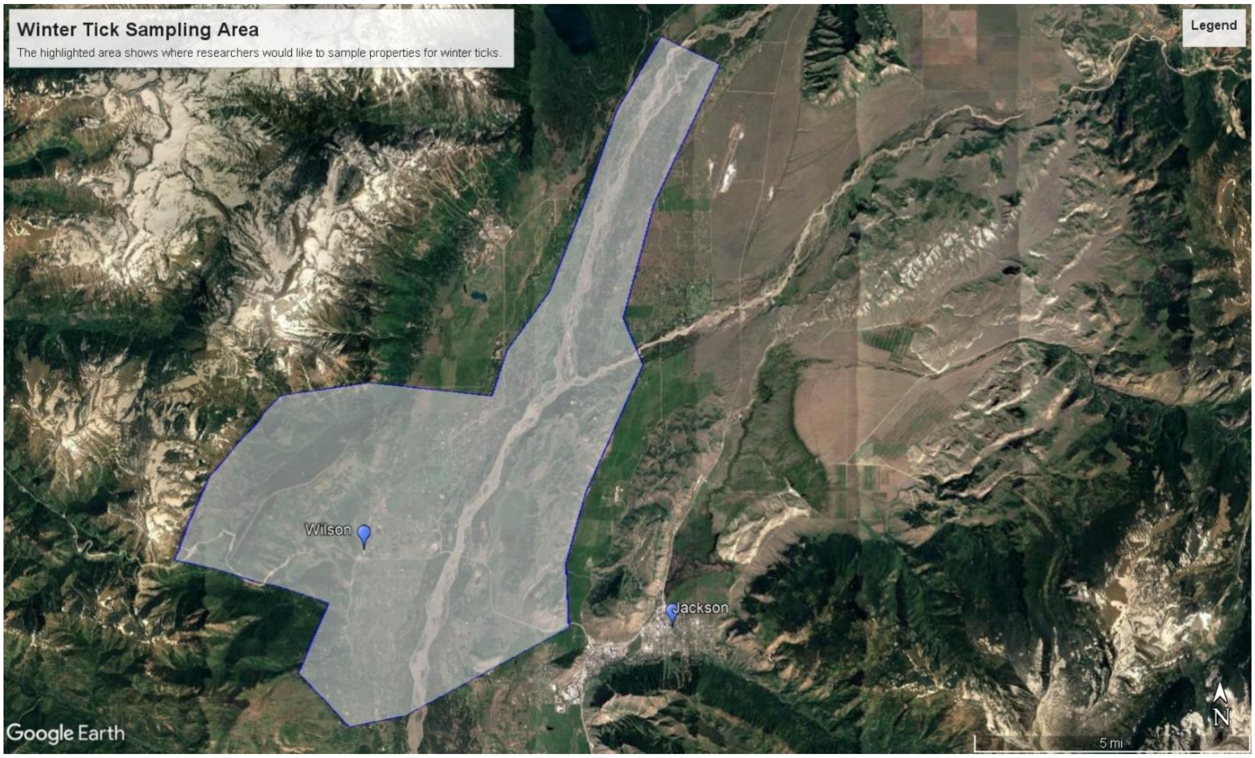

Image 3: Area of interest for sampling winter ticks in the Jackson/Wilson area south of GTNP.

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