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Livestock Parasite Management on High-Elevation Rangelands: Ecological Interactions of Climate, Habitat, and Wildlife

John Derek Scasta[1]

Department of Ecosystem Science and Management, University of Wyoming, Agriculture C 2004, Laramie, WY 82071.
[1]Corresponding author, e-mail: jscasta@uwyo.edu.

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ABSTRACT. Livestock parasitism on high-elevation rangeland (>1,800 m (6,000′)) may not be as well documented as parasitism is at lower elevations because producers assume elevation limits parasite persistence and exposure of livestock to parasites. Certain parasites, such as horn flies, *Haematobia irritans* (L.) (Diptera: Muscidae), and biting midges, *Culicoides* spp. (Diptera: Ceratopogonidae), a vector of bluetongue virus, are restricted to lower elevations. However, some parasites are endemic to high elevations, such as the Rocky Mountain wood tick, *Dermacentor andersoni* (Stiles) (Acari: Ixodidae), a vector of many diseases. Multiple horse fly and mosquito species persist at various elevation gradients, with some having preference for lower or higher elevations. For example, the horse fly, *Hybomitra laticornis* (Hine) (Diptera: Tabanidae), occurred from 1,700–3,035 m (5,577′–9,957′), *Hybomitra phaenops* (Osten Sacken) (Diptera: Tabanidae) only occurred above 2,499 m (8,198′), and the western horse fly, *Tabanus punctifer* (Osten Sacken) (Diptera: Tabanidae), only occurred below 2,250 m (7,381′). This variable elevation range is also expressed by several mosquito species, with six of 12 known mosquito species that transmit West Nile virus at or above 1,750 m (5,740′). Furthermore, gastrointestinal roundworms can survive > 1 yr at high elevations, use larvae inhibition to survive winter, and lungworm infection may increase with elevation. Evidence suggests changing weather patterns, climate variability, and animal movements could shift some parasites and diseases into higher elevations, such as mosquitoes and biting midges. Moving livestock to high-elevation ranges may also increase the opportunity for livestock–wildlife interactions, parasite and disease transmission, and exposure. Producers should develop high-elevation integrated pest management strategies, such as delaying or avoiding parasite treatment to optimize efficacy and reduce input costs, monitoring closely during wet years and periods of livestock–wildlife interactions, using elevation to avoid certain parasites, and not assuming that elevation is capable of preventing livestock parasitism.

Key Words altitude, cattle, disease, grazing, sheep

Livestock parasitism is a global problem, especially at low-elevation regions with a humid, tropical climate where temperature almost always favors hatching and larval development (Waller 1997, Maldonado-Simán et al. 2006). Issues with livestock parasitism on high-elevation rangeland can occur, but remain to be fully understood or addressed by industry, academia, or the public. This lack of understanding is explained, at least in part, because producers with livestock grazing at high elevations assume that the harsh climate will limit parasite persistence and infestations, a relationship that is sometimes true (Lloyd 1973, Kaufman et al. 1999). Unfortunately, this misconception is not always true across all parasite species (Table 1). Furthermore, a 2006 working group report by livestock entomologists suggests a crisis with declining research and extension resources addressing livestock parasite and veterinary entomology issues in the western United States, many of which have unique high-elevation livestock parasite problems (Blodgett and Lanier 2006).

These issues are particularly prominent in Colorado, Utah, and Wyoming—the three states in the United States with highest mean elevations of greater than 1,800 m (6,000′; Fig. 1). In these states, animal agriculture on high-elevation rangeland is an important socioeconomic attribute for the rural agricultural communities (U.S. Department of Agriculture [USDA] Census of Agriculture 2012). As of 2012, 1.7 million head of beef cows and 1.0 million head of sheep and lambs were located within these three states, and Wyoming is ranked 15th nationally for beef cattle production, with 61% of farm receipts coming from cattle sales (USDA Census of Agriculture 2012). Other states with mean elevations lower than 1,800 m that also have high-elevation livestock production include New Mexico, Nevada, Idaho, Arizona, Montana, Oregon, Hawaii, and California (Fig. 1). In several of these arid states, high-elevation grasslands are a critical grazing resource for the local livestock industry, and subsequently producers in these states have similar high-elevation livestock parasite problems. Similar high-elevation livestock production and parasitism scenarios also occur in Canada, Australia, Europe (Spain, Switzerland, and Scotland), Asia (Nepal), Africa (Kenya and Ethiopia), and South America, among other places (Bekele and Mukasa-Mugerwa 1994, Panadero et al. 2000, Steinman et al. 2003, Bishop et al. 2004, Cagienard et al. 2006, Kaufmann et al. 2012). Much of the grazing land in these states and other countries occurs at high elevations where livestock spend a high proportion of their time and are susceptible to parasites that can affect their productivity. Therefore, livestock producers operating on high-elevation rangelands need to be aware of the ecology and exposure risk of parasites that are unique to their situation.

High-elevation rangelands are also unique from lower elevations due to wildlife and climatic dynamics. First, grazing livestock on high elevation may increase the opportunity for livestock–wildlife interactions and parasite transmission (Blood 1963, Foreyt et al. 2000, Green et al. 2005). This increased opportunity for the interaction between livestock and wildlife has been raised as a concern for a number of parasite and disease transmission issues (Kilpatrick et al. 2009). Secondly, high-elevation ecosystems may be more sensitive to climate warming due to a reduction in area and unprecedented warming rates that will also accelerate fire cycles (Diaz et al. 2003, Randin et al. 2009). Furthermore, the role of fire in altering parasite habitat, animal movements, and parasite infestation is a novel research area, especially for internal and external dung-dependent parasites (Barger 1978, Seip and Bunnell 1985, Scasta et al. 2012, Polito et al. 2013, Scasta et al. 2014, Scasta et al. 2015). In the northern Rocky Mountains, temperatures are expected to increase with elevation, a result that is expected to lead to earlier spring expression (Westerling et al. 2006). In Scotland, it has been inferred that tick populations and associated disease pathogens may become more abundant at higher elevations in response to climate warming

Table 1. Livestock parasitism risk associated with elevation

Parasite species	Effect of elevation	Risk at high elevations
External parasites		
Face fly—*Musca autumnalis*	Generally not a problem at high elevations but can persist at northern latitudes	Low[a]
Stable fly—*Stomoxys calcitrans*	Generally not a problem at high elevations; an issue at round hay bale feeding sites	Low[a]
Horse fly—*Hybomitra laticornis*	Can persist across elevational gradient from 1,700–3,035 m	High
Horse fly—*Tabanus gilamus*	Can persist across elevational gradient from 1,700–3,035 m	High
Horse fly—*Hybomitra phaenops*, *Tabanus eurycerus*	Only occurred above 2,499 m	High
Horse fly—*Tabanus abditus*, *T. punctifer*	Only occurred below 2,250 m	Low
Horn fly—*Haematobia irritans*	Occur at high elevations, may not reach economic levels most years at $>$2,400 m	Low
Black fly—*Simulium spp.*	May occur at high elevations, not well understood, can disperse long distances	Moderate[a]
Mosquitoes—*Culex restuans*, *Culiseta incidens*, *Ochloerotatus atropalpus*	Found exclusively at 1,750–2,600 m; WNV vector	High
Mosquitoes—*Culiseta impatiens*, *Cu. inornata*	Found 50% of time or more at 1,750–2,600 m; WNV vector	High
Mosquitoes—*Culex tarsalis*	Typically at low elevations but may be expanding elevational range; WNV vector	Low, possibly increasing
Mosquitoes—*Aedes vexans*, *Anopheles earlei*, *An. freeborni*, *Coquilletidia perturbans*, *Culex erythrothorax*, *Cu.pipiens*, *C. territans*, *Ochlerotatus dorsalis*, *Oc. hendersoni*, *Oc. melanimon*, *Oc. trivittatus*	Typically at low elevations less than 1,730 m with the exception of *O. hendersoni*; (all are known WNV vectors except *An. earlei, An. freeborni, Cx. territans, Oc. hendersoni*)	Low
Biting midge—*Culicoides sonorensis*	Generally does not occur above 1,200 m	Low
Rocky Mountain Wood Tick—*Dermacentor andersoni*	Endemic to mountain regions from 1,200–3,000 m; risk increases above 2,100 m and with presence of sagebrush	High
Winter tick—*Dermacentor albipictus*	Extends further north than other ticks; problematic for wildlife that use high elevations; not well understood	Moderate[a]
Spinose ear tick—*Otobius megnini*	Not well understood but common on mountain sheep that use high elevations	Moderate[a]
Cattle grubs—*Hypoderma lineatum*, *H. bovis*	Can be problematic at high elevations of 1,524 m; persist in colder mountain areas internationally	High
Sheep keds—*Melophagus ovinus*	Common at elevations of 2,280 m; not well understood due to host dependency	Moderate[a]
Bot flies—*Oestrus ovis*	Common in Colorado and Wyoming but not well understood; international studies suggest that high elevation may buffer against exposure	Low
Lice and mites—*Psoroptes spp.*, *Bovicola longicornis*, *Solenopotes ferrisi*	Not well quantified for livestock but elk at 1,981 m were highly infected	High
Black blow flies/maggots—*Phormia regina*	Increase with elevation	High
Green blow flies/maggots—*Lucilia sericata*	Decrease with elevation	Low
Secondary screwworm—*Cochliomyia macellaria*	Not able to survive extreme winters	Low
Internal parasites		
Cooperia roundworms—*Cooperia oncophora*, *C. bisonis*	Survival optimized in cooler weather due to larval inhibition	High
Ostertagia roundworms—*Ostertagia osteragi*, *O. bisonis*	Survival optimized in cooler weather due to larval inhibition; *O. ostertagi* is the dominant species of concern	High
Trichostrongylus roundworms—*Trichostrongylus axie*	Occurred in 28% of Wyoming cattle	Moderate
Lungworms—*Dictyocaulus vivipaurus*	Common in elk and mountain sheep; potentially pathogenic between livestock and wildlife; potentially exacerbating BHMD; clinical parasitism not common	Moderate

[a] Lacking empirical data that quantifies the response to elevation.

trends (Gilbert 2010). Similar concerns have been expressed in the western United States and globally due to outbreaks of bluetongue virus in livestock and wildlife (Miller et al. 2010, Maclachlan and Mayo 2013). Given the unique problems and drivers of parasite problems at high elevations and the wildlife and climate dynamics, livestock producers will have to consider innovative adaptations and develop situational awareness as conditions develop. The following information and recommendations will assist in developing integrated pest management (IPM) strategies that are timely, effective, and economical for high-elevation livestock production and parasitism. Furthermore, information on changes in latitudinal distributions of parasites may reflect potential elevation distribution changes due to colder climates.

External Parasites

Flies. Many species of flies cause losses to livestock production in the United States. Stable flies, *Stomoxys calcitrans* (L.) (Diptera: Muscidae), and face flies, *Musca autumnalis* (De Geer) (Diptera: Muscidae), are known to occur at northern latitudes in the United States; however, these fly species are generally not a major threat to livestock in higher elevation states (Blodgett and Lanier 2006). Face flies can occur at northern latitudes, are known to occur in high-elevation states, and have expanded into southern Canada (Krafsur and Moon 2008). However, face flies tend to be less abundant in dry pastures and more abundant in areas with shade and water (Depner 1969). Furthermore, much of the research on face flies has occurred in states with lower elevations. The annual development of face fly populations at high elevations is likely constrained by temperature, as they require 70 degree days of $>12^{\circ}$C and subsequently would have very few seasonal generations at high elevations (Krafsur and Moon 1997). Stable flies can also occur at northern latitudes but are generally associated with concentrated animal feeding areas, and no research has assessed how they respond to elevation gradients. Stable flies have been reported in the sandhills of Nebraska at 1,097 m (3,600'), but no records of stable fly parasitism in mountain areas of the United States exist in the

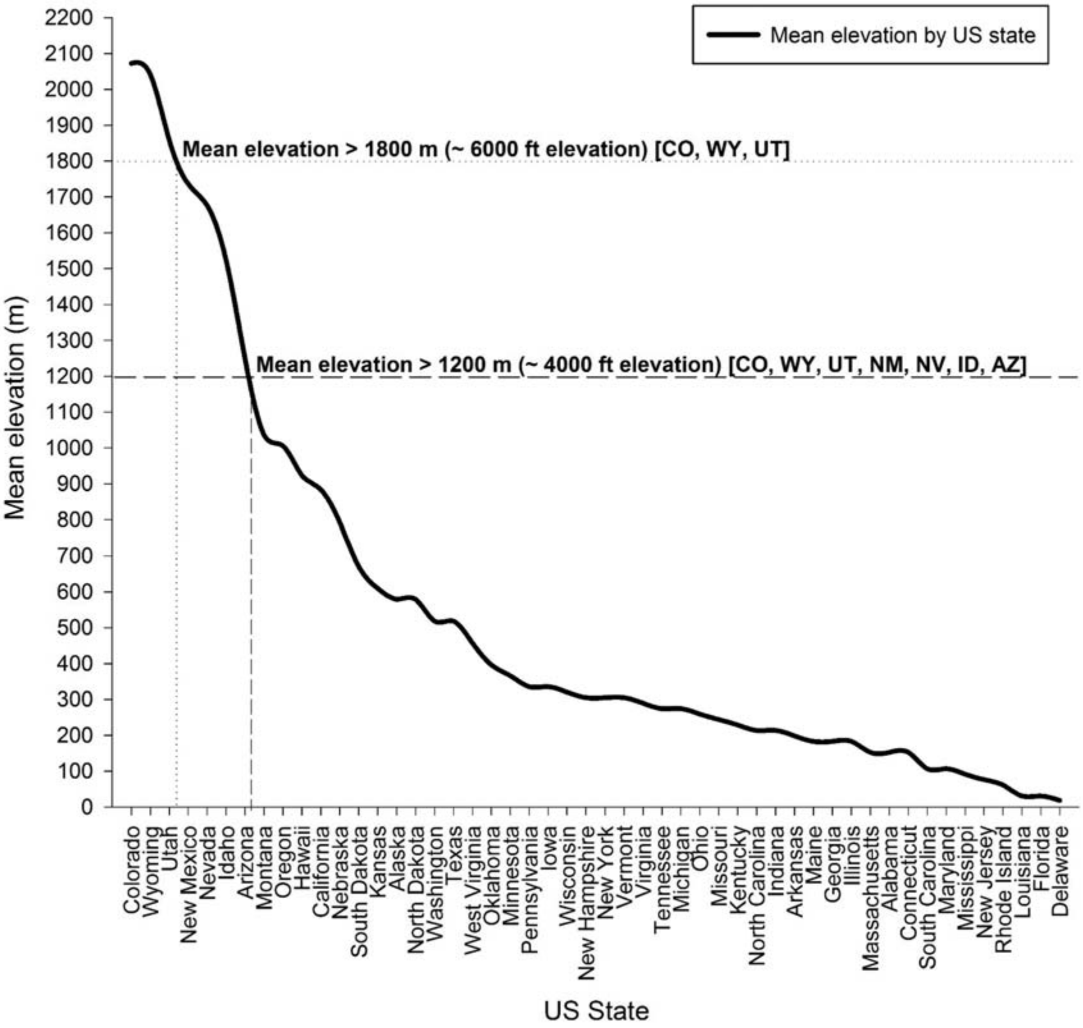

Fig. 1. Mean elevation of all 50 states in the United States of America.

literature (Campbell et al. 1987). However, a study in Madagascar suggests that stable fly abundance is not correlated with elevation up to 1,600 m (5,249') or climate, and farm management practices may be the most important explanatory variable (Gilles et al. 2008).

The horn fly, *Haematobia irritans* (L.) (Diptera: Musciade), is considered to be one of the most damaging external parasites of cattle. Horn fly densities were compared at three elevations (800, 1,800, and 2,400 m (2,624', 5,905', 7,874')) in Wyoming, and cattle on the high-elevation location (2,400 m (7,874')) had the lowest number of horn flies as compared with cattle infestations at lower elevations, and were below the economic threshold for the duration of the study (Kaufman et al. 1999). The authors of this study suggested that producers operating at high elevations may not need to use insecticides every year, which ultimately reduces costs for insecticidal control and decreases the development of insecticidal resistance in horn fly populations. This strategy maintains a population of horn flies that would be susceptible to insecticides should they need to use them during a heavy fly population year. Thus, producers need to assess horn fly presence and population on a regular basis to detect population increases and strategically treat as needed.

Black flies, *Simulium* spp. (Diptera: Simuliadae), occur across the intermountain west and may create localized problems for livestock on sites with running water (Blodgett and Lanier 2006). The response to elevation gradients is not well understood, and black flies can disperse several miles from breeding habitats, making control difficult. Producers should be aware that they cause annoyance that results in loss of weight gain, potentially transmit vesicular stomatitis, and may be able to survive at high elevations (Blodgett and Lanier 2006, Iowa State University 2008).

Horse flies and deer flies (Diptera: Tabanidae) can occur seasonally throughout the west and attack humans and livestock. The immature stages are generally associated with water, and the adults are one of the most free living livestock parasite species with large dispersal ranges, making them difficult to monitor and manage. A study in New Mexico assessed horse fly communities in response to elevation ranging from 1,700–3,035 m (5,577'–9,957'; Clark and Hibler 1973). The dominant horse fly species, *Hybomitra laticornis* (Hine), accounted for 90% of the 15,223 flies captured and occurred across the entire elevation gradient. *Tabanus gilanus* (Townsend) also occurred across the entire elevation gradient. At the highest elevations (2,377–3,035 m (7,667'–9,957')), *Hybomitra tetrica rubrilata* (Phillip) accounted for 30% of the collections, and this species only occurred above 2,377 m (7,667'). *Hybomitra phaenops* (Osten Sacken) only occurred above 2,499 m (8,198') and has been known to occur in a narrow elevation band between 2,499–2,743 m (8,198'–8,999'). *Tabanus eurycerus* (Phillip) occurred only below 2,499 m (8,198'), and *Tabanus abditus* (Phillip) and the western horse fly, *Tabanus punctifer* (Osten Sacken), occurred only below 2,250 m (7,381'). Thus, elevation may provide a buffer for some horse fly species, but some species can persist at all elevations, and some only occur at the highest elevations. Given that horse flies are vectors of viral, bacterial, protozoan, and helminthic diseases, the economic impact beyond blood feeding should be kept in mind

(Krinsky 1976). Producers should be aware that livestock are still at risk for horse fly exposure, even when grazing at high elevations.

Mosquitoes. Mosquitoes (Diptera: Culicidae) transmit numerous viral diseases to cattle and can cause severe weight loss due to the repeated biting, leading to annoyance and avoidance behavior (Blodgett and Lanier 2006). Mosquitoes have also been noted to occur broadly across western U.S. rangelands and elevations (Blodgett and Lanier 2006). A study from the front range of Colorado assessed mosquito species composition along an elevation gradient from 1,500–2,400 m (4,921'–7,874'; Eisen et al. 2008). Mosquito species richness was the highest in the plains (11 species at 1,510–1,560 m (4,954'–5,118'), decreased as elevation increased through foothills–low montane (6 species at 1,610–1,730 m (5,282'–5,675') and mid-range montane areas (3 species at 1,750–2,220 m (5,740'–7,283'), but rebounded in high montane elevations (6 species at 2,360–2,600 m (7,742'–8,530')). This pattern is the result of some species reaching the "cool end" of their range while others at high elevations are considered more cold-adapted. Species richness, however, is not an indication of population densities, which seasonally are a concern. The greatest abundances of any single species were at the lowest elevation, and the highest densities at the highest elevation were an order of magnitude lower (Eisen et al. 2008).

Of the 27 mosquito species assessed in this study, 12 are known to experimentally transmit West Nile virus (WNV). Three of the 12 mosquito species that transmit WNV were found exclusively at high montane or mid-range montane sites. These included the white-dotted mosquito or *Culex restuans* (Theobald), the cool weather mosquito or *Culiseta incidens* (Thomson), and *Ochlerotatus atropalpus* (Coquillett). *Culiseta impatiens* (Walker) and *Culiseta inornata* (Williston) were two of the 12 species found at these types of sites >50% of the time. There is also potential for a species to expand its range as warming trends change in a region. For example, the western encephalitis mosquito, *Culex tarsalis* (Coquillett), was found at higher elevations (Eisen et al. 2008). In a similar case, malaria has been detected in mosquito species in Hawaii at 1,900 m (6,233'), indicating that changes in a vector species distribution due to changes in climate can change disease risk (Freed et al. 2005). Producers should be aware that mosquito species may exist at both lower and higher elevations and may affect livestock populations that are maintained in their regions.

Biting Midges. Biting midges or gnats, primarily *Culicoides sonorensis* (Wirth & Jones) (Diptera: Ceratopogonidae), can be a problematic vector of bluetongue virus (BTV) to cattle, sheep, and pronghorn antelope in the United States (Green et al. 2005). Historically, BTV has been more of a problem in sheep than cattle, but producers that export either sheep or cattle to Canada are subject to testing. BTV is noted to be endemic in many countries between 40° N and 35° S (Cagienard et al. 2006). Biting midges also transmit epizootic hemorrhagic disease to livestock and wildlife with subclinical symptoms typically in sheep and cattle but severe mortality in native wildlife such as deer and pronghorn (Bengis et al. 2002). BTV and epizootic hemorrhagic disease are diseases of great concern globally due to the complex livestock–wildlife–parasite interactions, barriers to effective eradication schemes, and economic losses (Bengis et al. 2002). Generally, *C. sonorensis* does not occur on sites above 1,200 m (4,000'), as the higher elevations do not provide the appropriate habitat for survival of midge populations (Walton et al. 1992, Blodgett and Lanier 2006). A study in Wyoming indicated that ewe sheep pastured in the mountains were not exposed to BTV until they returned to lower elevations in the fall because the high-elevation range had cooler temperatures that are less favorable for maintenance of midge life cycles and "rapid virus amplification" (Miller et al. 2010). In contrast, rams had a near 100% infection rate likely because they did not go to the mountains and were pastured at lower elevations. The site in this study (1,280–1,340 m (4,200'–4,400')) was surrounded by mountains (3,048 m (10,000')) which acted as a natural barrier. However, in 2007, this BTV outbreak in Wyoming was attributed to the movement of infected livestock or wildlife and changes in the *Culicoides*' distribution as a result of warmer than average temperatures during the summer months. In addition, the summer in this area was longer and warmer than average (Miller et al. 2010).

A study in the Great Plains demonstrated that risk of BTV seropositive cattle increased as elevation increased up to 1,260 m (4,260'), but cattle populations moving northward in latitude had a decreased risk of acquiring BTV (Schmidtmann et al. 2011). Several international studies found that *Culicoides* species were only present in low numbers above 800 m (2,624') in Israel and Australia (Steinman et al. 2003, Bishop et al. 2004). Incidentally, research in Switzerland indicate that there are no biting midge-free zones in this country, including alpine summer pastures, but that the BTV vectoring species complex *Obsoletus* (a species group of five closely related species) is predominant below 1,200 m (3,937'). The *Pulicaris* species complex (a species group of 15 closely related species), whose vector competency for BTV is largely unknown, prevails above 1,500 m (4,921'; Cagienard et al. 2006, Kaufmann et al. 2012). There is great concern about the changing climate and subsequent effects on biting midge distribution and disease transmission globally (Maclachlan and Mayo 2013).

Ticks. Hard ticks (Acari: Ixodidae) are obligatory parasites that require bloodmeals from hosts, often infest livestock at high elevations, and transmit many viral and bacterial diseases. The Rocky Mountain wood tick, *Dermacentor andersoni* (Stiles), is a known vector for Colorado tick fever, Rocky Mountain spotted fever, tularemia, and inducing tick paralysis (Geissler et al. 2014). *D. andersoni* feeds on a variety of animals including deer, livestock, dogs, coyotes, and humans. The Rocky Mountain wood tick is endemic to mountainous regions of western North America at elevations from 1,219–3,048 m (4,000'–10,000'; Geissler et al. 2014). A study in western Wyoming found that *D. andersoni* attached to humans more frequently in areas with sagebrush and at elevations around 2,133 m (7,000'). In this study, 37 of 174 adult ticks removed from humans (21%) tested positive for Colorado tick fever (Geissler et al. 2014). Given the prevalence of *D. andersoni* at high elevations and preference for sagebrush-type habitats, producers with these landscape features should be particularly aware of the risk of tick exposure and monitor key tick attachment locations on cattle, such as inner ears, abdomen, and tail heads.

Winter ticks, *Dermacentor albipictus* (Packard), are also an ectoparasite of livestock and are referred to as a "one-host tick" because the larval and nymphal stages remain on the same host until reaching the adult stage. Winter ticks are a common pest of horses, elk, mule deer, moose, and other wildlife species in the United States, in addition to occasionally infesting cattle (Wilkinson 1967, Samuel et al. 1991). These *Dermacentor* species extend much further north than other *Dermacentor* species and are able to use a much broader seasonal window for development than other species (Wilkinson 1967). Although no information has quantified the ability of *D. albipictus* populations to persist at higher elevations, this species is present at higher latitudes and commonly found on a variety of wildlife that are adapted to higher elevations. This suggests *D. albipictus* should be considered a potential pest in these environments. *D. albipictus* is not known to be a primary vector for any disease pathogens, and the primary negative consequence is associated with heavy infestations causing anemia and death.

The spinose ear tick, *Otobius megnini* (Dugès) (Acari: Argasidae), is a soft tick that was once considered a pest of warmer climates such as California, Florida, and Texas, but recently has become a concern for livestock owners in Colorado and Wyoming (Lloyd 1973, Colorado State University Veterinary Diagnostic Lab 2014). *O. megnini* is not known to be a primary vector for any disease pathogens but can cause secondary bacterial infections, destruction of the ear canal and tympanic membrane, and death in livestock in severe infestations (Colorado State University Veterinary Diagnostic Lab 2014). Currently, no studies have quantified the ability of *O. megnini* to persist at high elevations, but this species has been found on mountain sheep which are known to prefer high-elevation habitats (Allen 1955, Blood

1963). Additionally, interactions between native sheep and cattle are not uncommon (Blood 1963).

Other Ectoparasites. Cattle grubs, in the genus *Hypoderma* (Diptera: Oestridae), were a major economic problem in North America until the development of parasiticides (Colwell 2000). Currently, cattle grubs are considered clinically nonexistent but sero-surveillance across the four western Canadian provinces suggests this may not be the case (Colwell 2013). Furthermore, the response of cattle grubs to elevation, specifically the northern cattle grub or *Hypoderma bovis* (L.) and the common cattle grub or *Hypoderma lineatum* (Villers), has been studied on high-elevation rangeland in Arizona at 1,524 m (5,000'; Collins and Dewhirst 1971). A strategic management strategy has been to synchronize calving during a fly-free period after the oviposition activity of *H. lineatum* had ceased, generally from the beginning of April through the beginning of May (Collins and Dewhirst 1971). An ecological study in Spain suggested that *Hypoderma* presence, and the development of the external life stages, were highly correlated with certain climate types (Panadero et al. 2000). The highest occurrence of cattle grubs was in the interior areas of Spain with cold maritime climate (95.4%; mountainous areas at 800 m or 2,625') and the lowest occurrence was in the warmer maritime climate (49.7%; coastal areas; Panadero et al. 2000). This suggests that cattle at higher elevations may be at greater risk to cattle grub infestations and if cattle grubs return to clinical levels, integrated management techniques will be warranted (Scholl et al. 1986, Kunz et al. 1990).

Sheep keds, *Melophagus ovinus* (L.) (Diptera: Hippoboscidae), are parasites primarily of domestic sheep that have been noted to occur at 2,280 m (7,480'; Legg et al. 1991). An unusual feature of keds is they spend their entire life on the sheep host and do not interact directly with the environment independent of the host. There are very few studies on the influence of elevation on ked life cycles, disease transmission, or infestation rates on hosts. This suggests that an inventory of sheep ked infestations from flocks raised at different locations could be warranted to determine if the complete lack of host independence translates into the lack of an elevation influence.

Bot flies, *Oestrus ovis* (L.) (Diptera: Oestridae), are a common problem in domestic sheep in Wyoming, Montana, and Colorado, with an estimate in 1973 that >90% of sheep in Wyoming were infested (Lloyd 1973, Capelle 1966). There are currently no studies on the influence of elevation on bot fly life cycles and infestations of hosts within the United States; however, there are a number of records that are of relevance. In particular, *O. ovis* has been found not only in domestic sheep but also in native bighorn sheep in Montana that have a preference for high-elevation habitat (Capelle 1966). In Spain, elevation was identified as a potential risk factor for sheep bot fly infestation. Seroprevalence testing using an enzyme-linked immunosorbent assay for *O. ovis* antibodies suggests prevalence decreased with increasing elevation, with the lowest values occurring at >750 m (2,460'; Alcaide et al. 2005). A postmortem study of 376 sheep in Ethiopian highlands (2,800 m (9,186')) found *O. ovis* larvae in 5% of sheep at the International Livestock Center for Africa research station and 19% of sheep from local farms. The low infection rate compared with other studies was attributed to the high elevation and cooler temperatures (Bekele and Mukasa-Mugerwa 1994). Infections have also been noted in Brazil at 768 m (2,578'; Silva et al. 2012).

Lice and mites can also be problematic ectoparasites for livestock and wildlife. Elk from the National Elk Refuge in Wyoming (1,981 m (6,500')) assessed in January and February were found to be highly infested with scab mites, *Psoroptes* spp. (Acari: Psoroptidae), chewing lice, *Bovicola longicornis* (Nitzsch) (Phthiraptera: Trichodectidae), and sucking lice, *Solenopotes ferrisi* (Fahrenholz) (Phthiraptera: Linognathidae) (Samuel et al. 1991). Steers from southeastern Wyoming were infected with cattle chewing lice, *Bovicola bovis* (L.) (Phthiraptera: Trichodectidae), short-nosed cattle lice, *Haematopinus eurysternus* (Nitzsch) (Phthiraptera: Haematopinidae), long-nosed cattle lice, *Linognathus vituli* (L.) (Phthiraptera: Linognathidae), and the little blue cattle louse, *Solenopotes capillatus* (Enderlein) (Phthiraptera: Linognathidae) (Watson et al. 1997). Currently, there are no studies that have quantified the influence of elevation on lice and mite infestations of hosts. However, the sheep biting louse nymphs, *Bovicola ovis* (Shrank) (Phthiraptera: Trichodectidae), survived more than three times longer at 36.5°C (97.7°F) than at 4°C (39.2°F; Crawford et al. 2001). Thus, lice can occur at high elevations and if temperatures trend warmer, survival and exposure could be greater.

Wool maggots are the feeding larvae of certain species of blow flies (Diptera: Calliphoridae) that can cause severe irritation and damage to sheep in the spring and early summer. These filth parasites are known to use decaying animal tissue and water sources for reproduction. Three blow fly species were assessed in April at distinct ecological sites with varying elevations in Arizona including black blow flies, *Phormia regina* (Meigen), green blow flies, *Lucilia sericata* (Meigen), and secondary screwworm, *Cochliomyia macellaria* (F.) (Deonier 1942). The ecological sites assessed were at elevations of 40 m (130'), 355 m (1,165'), 631 m (2,072'), and 1,158 m (3,800'). Green blow fly density was greatest at the lowest elevation (40 m) and was two times higher than at the next highest elevation (355 m). Green blow fly density was 175 times greater at 40 m than the two highest elevations and was 80 times greater at 355 m than the two highest elevations. Thus, elevation appears to provide a buffer against green blow flies (*L. sericata*), a relationship that has also been documented in England, Scotland, Spain, and Wales (Baz et al. 2007, Bisdorff and Wall 2008). However, the opposite relationship occurs for black blow flies. Black blow fly density was 4–14 times higher at 355, 631, and 1,158 m than the density at the lowest elevation of 40 m. Thus, elevation does not appear to provide a buffer against black blow flies and may increase risk of infestation to hosts at these higher elevations. A similar relationship was documented up to 1,900 m (6,233') elevation in Spain for the blue bottle fly, *Calliphora vomitoria* (L.), and *Calliphora vicina* (Robineau-Desvoidy) where *C. vomitoria* was the most abundant blow fly species accounting for almost half of all captures (Baz et al. 2007). Furthermore, *Calliphora coloradensis* (Hough) and *Lucilia silvarum* (Meigen) were collected from a corpse at 3,350 m (11,000') in Colorado (Adair and Kondratieff 2006). In contrast, secondary screwworms are sensitive to cold temperatures and cannot survive in areas with severe and prolonged winters (Deonier 1942). Management of blow flies includes lambing as early in the spring as possible, sheering sheep before peak periods of blow fly activity in the spring, and treating wounds (Deonier 1942). It is critical to remember that elevation may provide a buffer against green blow flies and secondary screwworms, but not against black blow flies. Furthermore, additional studies on blow flies are needed at elevations above 1,158 m (3,800') to gather more data on blow fly phenology relative to elevation and temperature.

Internal Parasites

Gastrointestinal Parasites. *Cooperia* and *Ostertagia* (Strongylida: Trichostrongylidae) are common roundworms that negatively affect cattle and sheep health and production. A study in Wyoming evaluated the survival of larvae of both types at 2,225 m (7,300') and 3,011 m (9,880') elevation for winter survival (Schwink 1963). Development and survival for both species of roundworms was greatest at the highest elevation. Larvae could survive for more than a year if the moisture was above normal. Overwinter survival for both was greater in these regions with cooler temperatures and higher elevations than in lower and warmer locations, a result that has been documented in similar roundworm species in Switzerland and the Himalaya foothills of Nepal (Eckert et al. 1981, Joshi et al. 1997). Although roundworm survival may be optimal at higher elevations, these common roundworms are not typically a common concern because cases of clinical gastrointestinal parasitic infection are rare, likely due to the low stocking rates and animal density in these areas (Schwink 1963). A study of intestinal parasitic infections among highland and lowland dwellers in Ethiopia found no elevation

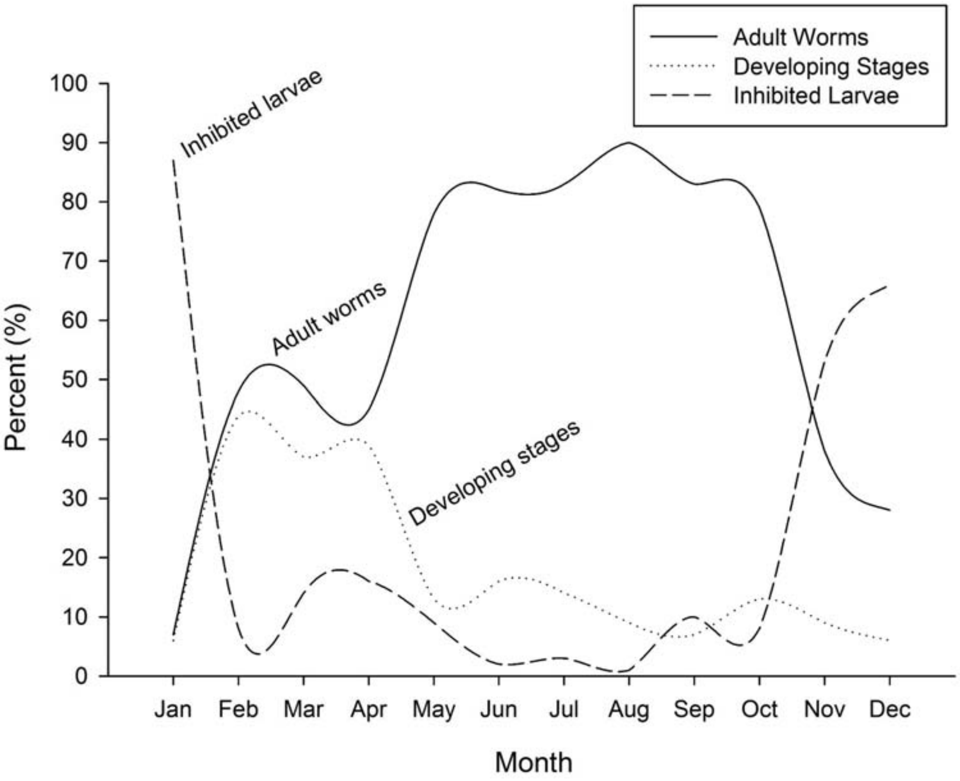

Fig. 2. Seasonal patterns of intestinal worms in the abomasum of Wyoming cattle from nonirrigated rangeland with an elevation range of 1,250–2,500 m (4,101'–8,202'). Adapted from Malczewski et al. 1996.

difference (Wegayehu et al. 2013). Producers need to be aware that wetter years may enhance winter survival of roundworms. If animals are congregated, then close observation and potential intervention could be warranted (Schwink 1963).

A state-wide assessment in Wyoming measured internal parasite composition in cattle that grazed on nonirrigated rangeland pastures at elevations from 1,250 to 2,500 m (4,101'–8,202'). In this study, all animals were infected with at least one species of *Ostertagia*. Occurrence in cattle by dominant roundworm species was 98% brown stomach worm, *Ostertagia ostertagi* (Stiles), 61% *Cooperia oncophora* (Railliet), 42% *Ostertagia bisonis* (Chapin), 34% *Cooperia bisonis* (Cram), and 28% stomach hairworm, *Trichostrongylus axei* (Cobbold) (Strongylida: Trichostrongylidae) (Malczewski et al. 1996). A study of worm-free calves on Sierra Nevada mountain ranches at elevations of 1,250 and 1,500 m (4,101'–4,921') were infected with the most common species, *Ostertagia ostertagi* and *Cooperia oncophora. Ostertagia ostertagi* larval development was inhibited between November and May, but no inhibition was observed for *Cooperia* species in these cattle (Baker et al. 1984). The ability for *Ostertagia* to suspend larval development in the abomasum as a survival mechanism during inclement weather has also been shown in the northwestern United States, Canada, Scotland, England, and Poland (Malczewski et al. 1996). This is also reflected in the larva:adult ratio and seasonality in the Wyoming study (Fig. 2). The prevalence of *Ostertagia bisonis* and *Cooperia bisonis* in cattle is of interest, as these parasites are more common in wild ruminants such as deer, bison, and pronghorn antelope. This cross transmission can operate in both directions, as *Ostertagia ostertagi* was found to be the dominant abomasal nematode in mule deer (*Odocoileus hemionus*) in Montana (Worley and Eustace 1972). These results combined suggest that the high prevalence of important livestock nematode species in wildlife, and vice versa, is likely the result of substantial parasitic interchange on shared range by domestic and wild ungulate hosts (Worley and Eustace 1972, Malczewski et al. 1996).

When considering gastrointestinal nematode parasitism of cattle on high-elevation ranges, management should focus on *Ostertagia ostertagi* infections (Malczewski et al. 1996). Producers should be cautioned that fecal egg counts may not be reliable estimates of infection, especially during periods of larval inhibition, when worm numbers may be the highest but egg counts the lowest (Malczewski et al. 1996; Fig. 2). Another roundworm species, Barber's pole worm or *Haemonchus contortus* (Strongylida: Trichostrongylidae), has been considered a problematic parasite of sheep and goats in tropical and subtropical regions of the world. Infections of *Haemonchus contortus* in small ruminants has been detected at elevations of 1,700 m (5,577') in Kenya and 1,000–1,400 m (3,280'–4,593') in New South Wales, Australia (Gatongi et al. 1998, Webb et al. 1979). A study of gastrointestinal nematodes (*Haemonchus*, *Ostertagia*, *Trichostrongylus*, *Oesophagostomum*) in llamas in Argentina had lower eggs per gram at very high elevations (2,500–4,000 m (8,202'–13,123')) than at lower elevations (24–111 m (78'–364')), but all farms were positive for coccidia (van Erp 2014). Similar coccidian of llamas has been documented in Colorado and Wyoming although no elevation data was reported (Schrey et al. 1991). Therefore, producers need to consider the seasonality of larval development, herd health history, stocking rate, and animal density.

Lungworms. Lungworms, or parasitic nematodes of the Order Strongylida, can be a problem in cattle, domestic sheep, and wildlife species such as elk and bighorn sheep due to infection of the lower respiratory tract (Blood 1963, Lloyd 1973, Blodgett and Lanier 2006). Currently, there is no research that explains how elevation influences lungworm infection although it has been suggested that lungworms could be a greater concern in mountain meadows than in desert rangeland (Maas 1996). A study from Idaho suggests that lungworms, specifically *Dictyocaulus viviparous* (Bloch) (Strongylida: Dictyocaulidae), may be marginally pathogenic between cattle and elk, and grazing cattle at higher elevations may increase the opportunity for direct interactions and parasitization (Foreyt et al. 2000). Furthermore, in a study

Table 2. IPM principles specific for high-elevation livestock operations

Principles of high-elevation livestock parasite IPM	Justification, economic thresholds[a], and references
1. Delay/avoid treating for flies	Flies may not reach economic thresholds at high elevations. Not treating will maintain a population susceptible to insecticides and reduce input costs. Delaying treatment until a threshold is reached will optimize the efficacy of the active ingredient (Kaufman et al. 1999). Economic thresholds are 100 per cow side (horn fly), 5 per cow face (face fly), 3–5 per cow leg (stable fly; Gordon et al. 1984; Campbell 2001). Economic thresholds for blood-feeding aquatic species (mosquitoes, horse flies, and black flies) and other parasites (biting midges) are largely unknown (Higley and Pedigo 1996).
2. Monitor regularly during years with above average rainfall	Many parasites are associated with stagnant water or wet conditions. Years with above average rainfall can increase flies, mosquitoes, certain larvae of blowflies, and internal parasite carryover from the previous year (Deonier 1942, Schwink 1963, Blodgett and Lanier 2006, Eisen et al. 2008).
3. Monitor regularly during periods or locations of regular wildlife interaction	Wildlife species such as elk and deer can serve as hosts to parasites that can be transmitted to livestock. In particular, ticks, lice, mites, and internal parasites (Allen 1955, Blood 1963, Berstrom 1975, Samuel et al. 1991, Foreyt et al. 2000).
4. Move livestock to high elevations to avoid some of the most damaging parasites	Some species are not able to persist at high elevations such as horn flies, and certain larvae of horse flies, mosquitoes, or blowflies; biting midge, or bot flies (Deonier 1942, Clark and Hibler 1973, Kaufman et al. 1999, Blodgett and Lanier 2006, Eisen et al. 2008).
5. Move away from hay feeding sites	Stable fly infestations have been correlated with round hay bale feeding sites. Because high-elevation ranges are not grazed year round, there has been no hay bale feeding and should generally be free of stable flies (Broce et al. 2005). Moving away from these feeding areas should be an effective strategy.
6. Be wary and/or avoid sites where animals congregated at high densities	The congregation of cattle and concentration of feces could deposit roundworm that can survive for more than a single year. Although clinical parasitism is not common at high elevations due to low animal density, congregation areas such as pens could be an area recurring exposure (Scwink 1963).
7. Treat for *Ostertagia ostertagi*	This is the dominant roundworm of cattle, and it can survive at high elevations by inhibiting larvae development. Be aware of the inhibited larvae stage when infestations may be least detectable but at the highest levels and apply anthelmintics strategically (Malczewski et al. 1996). Economic thresholds for endoparasites are more difficult to quantify without the assistance of a laboratory. The most practical threshold for gastrointestinal nematodes and lungworms has been suggested when clinical signs occur and the strategic use of preventative strategies (Vercruysse and Claerebout 2001).
8. Monitor for mosquitoes and horse flies even at high elevations	Some species of mosquitoes and horse flies occur exclusively at high elevations and some may expand upward with climate warming. Mosquitoes and horse flies vector problematic diseases such as West Nile virus and anaplasmosis and producers should be wary (Clark and Hibler 1973, Eisen et al. 2008). Monitoring should take place when weather is warm and wet.
9. Check livestock for tick infestations	Monitor livestock for ticks by looking closely at specific parts of the body where ticks are most commonly found. This may include looking at the inner ear, especially in areas above 1,200 m with high sagebrush cover for Rocky Mountain Wood Ticks (Geissler et al. 2014). If ticks are found, consider applying acaracides strategically. Economic thresholds have been recommended at 3 ticks per calf or cow, but in the case of disease-infectious ticks thresholds may be lower (Young and Haantuba 1998).
10. Do not assume that high-elevation grazing areas provide a buffer against livestock parasites	Although high-elevation grazing areas do provide a buffer to some livestock parasites, it does not buffer against all parasites. Producers need to use basic IPM practices including closely monitoring animals for problems, especially during the shorter summer periods at high altitudes. An example of this elevation buffer assumption is the *Culicoides*-borne BTV outbreak in the Big Horn Basin, Wyoming, in 2007, an area that had previously been BTV free (Miller et al. 2010)

[a] Economic thresholds for livestock parasites are considered the point where the financial loss expected at a certain level of infestation will exceed the cost to treat. These thresholds may fluctuate because as beef and lamb market prices increase, the economic thresholds for treating decrease (Gordon et al. 1984).

that documented 80% lungworm infection in bighorn sheep at an elevation of 1,524 m (5,000'), snails were suspected to be the intermediate lungworm host (Blood 1963). Fire may disrupt this snail–feces biological cycle of lungworms at high elevations as native sheep (*Ovis dalli stonei*) exposed to burned areas had 10 times lower lungworm (*Protostrongylus* spp.) infections in British Columbia, Canada (Seip and Bunnell 1985).

Lungworm prevalence in elk at the high-elevation National Elk Refuge in Wyoming (1,981 m (6,500')) was highest in the spring (32–70%), and declined through the summer (30–47%), fall (21–39%), and winter (8–19%; Bergstrom 1975). Sheep and goats in high-elevation areas of Ethiopia (considered 1,500 m (4,921')) had a higher prevalence of lungworm infection (*Dictyocaulus filarial* and *Muellerius capillaris* (Muller) (Strongylida: Protostrongylidae)) than sheep and goat populations at lower elevations, and scientists are emphasizing the need for prevention and treatment of livestock at these high elevations (Alemu et al. 2006).

There is an increasing concern about transmission of lungworms from livestock to native wildlife and that climate warming may soon eliminate temperature-related constraints to northward range expansion (Jenkins et al. 2006, Foreyt et al. 2009). Lungworm infections can also increase pulmonary hypoxia, pulmonary arterial hypertension, and elevate the risk of bovine high-mountain disease (BHMD) in cattle (Neary 2014). BHMD, also known as brisket disease or high altitude disease, is a common problem in cattle on ranches with elevations above 1,500 m (5,000'). Therefore, it would be prudent for livestock producers at high elevations to be aware of potential internal parasite infections in cattle and potential complications with diseases endemic to high elevations, such as BHMD (Kahn and Line 2010). Even when clinical symptoms of parasitic nematode infestation are not obvious (i.e., subclinical), intake can be reduced, milk production can be reduced, weaning weights can be lower, puberty can be delayed, pregnancy rates can be lower in mature females, and overall immune systems can be suppressed (Forbes et al. 2000, Kahn and Line 2010). The potential effects of climate change on this dynamic are unknown.

Integrated Livestock Parasite Management Strategies for High Elevations

High elevations provide natural buffers against some livestock parasites, but not all (Blodgett and Lanier 2006). Based on this review, it appears that the shorter growing season, lower animal density, lower thermal environment, and seasonal grazing all confer positive benefits to livestock parasite management for at least a subset of parasite species. However, some livestock parasite species appear to thrive at higher elevations and careful attention is warranted in determining appropriate integrated livestock pest management. Furthermore, because infestations of some parasites may be more episodic due to

Fig. 3. Livestock at high elevations can often come into contact with wildlife species. For example, grazing cattle at 2,286 m (7,500′) in southern Wyoming can be found in proximity with pronghorn antelope.

weather variation or occur in a narrower seasonal window, producers should closely monitor livestock if they choose not to treat preventatively. Gathering and treating livestock at higher elevation ranges may be more difficult due to terrain and a lack of working facilities associated with remote mountain pastures grazed in the summer months (Blodgett and Lanier 2006). Producers will need to consider alternative deployment tactics of insecticides such as fed-through products or rubs. Livestock producers that use high-elevation rangeland in the western United States should consider integrated parasite management strategies that capitalize on the benefits of high elevations and production through a decrease in insecticidal treatments (Table 2; Fig. 5).

First, producers should consider delaying or avoiding treating for flies, particularly face flies, stable flies, and horn flies. Flies may not reach economic thresholds at high elevations most years or throughout most of the year. Arguably, the economic thresholds at which the cost of animal production losses will exceed the cost of treatment may also need to be examined to ensure they apply under high-elevation scenarios. If the producer chooses not to treat their livestock with insecticides, then this will maintain a population susceptible to insecticides and strategically manage the development of long-term resistance to chemical active ingredients. This is very important, as horn flies have developed resistance to several classes of insecticides, particularly pyrethroids and organophosphates (Guerrero et al. 1997, Li et al. 2007). Efficacy of diazinon-impregnated ear tags (an organophosphate) have gone from >20 wk of control to just 1 wk of control in a 3-yr period of repeated use (Barros et al. 2001). Chemical resistance has also been a problem in mosquitoes, ticks, and mites (Foil et al. 2004, Xu et al. 2005, Van Leeuwen et al. 2010). Delaying treatment until a threshold is reached will optimize the efficacy of the active ingredient and reduce costs to the producer (Kaufman et al. 1999).

Second, it is important to monitor livestock regularly especially in years with above average rainfall because many parasites are associated with stagnant water or wet conditions. Years with above average rainfall and appropriate temperatures can lead to an increase in the population of flies, mosquitoes, certain larvae of blowflies, and internal parasite carryover from the previous year (Deonier 1942, Schwink 1963, Blodgett and Lanier 2006, Eisen et al. 2008). Depending on the parasite species of concern, it is important to monitor livestock at the physical locations on the animal where the parasite is most likely to occur. For example, ticks generally congregate near the ears and on the abdomen, face flies congregate at the corners of the eyes and nose, and horn flies congregate on the poll, sides, and abdomen.

Third, monitoring livestock regularly during periods or locations of regular wildlife interactions is important, specifically interactions with large native ruminants such as elk, deer, sheep, and pronghorn (Fig. 3). These wildlife species can serve as hosts to multiple species of parasites, such as ticks, lice, mites, and internal parasites that are capable of infesting livestock (Allen 1955, Blood 1963, Berstrom 1975, Samuel et al. 1991, Foreyt et al. 2000). Furthermore, wildlife species can serve also as a disease reservoir that can be a constraint to the disease and parasite eradication efforts (Miller et al. 2013). Scientists are predicting that wildlife will play an increasingly greater role in livestock disease transmission in the future (Siembieda et al. 2011). Therefore, producers need to be aware of wildlife that are in the area and changes in residence times and patterns that may be driven by changes in climate or changes in population management of certain wildlife species. For example, elk have been observed overwintering in western Wyoming in areas where they historically only migrated to during the spring and summer.

Fourth, it is useful to take advantage of using high-elevation ranges when possible. Some parasite species are not able to persist at high

Fig. 4. Sheep can be susceptible to a suite of parasites and diseases such as wool maggots, BTV, which is vectored by the biting midge *Culicoides sonorensis*, and sheep keds. Use of high-elevation pastures can be important for sheep (as demonstrated in this picture of Rambouillet ewes at an elevation of 2,194 m (7,200’) in Wyoming) to avoid BTV because the primary vector does not typically occur over 1,219 m (4000’).

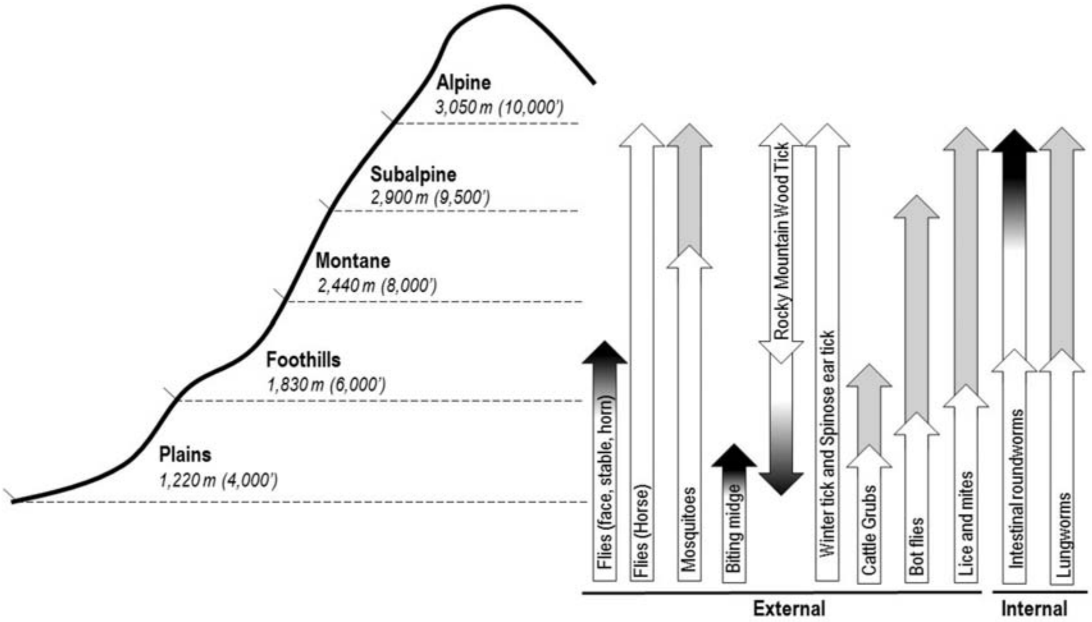

Fig. 5. Southern Rocky Mountains elevation-livestock parasite gradient model. Solid white arrows denote documented presence relative to elevation. Gradual darkening represents the extrapolation of potential range expansion based on the peer-reviewed literature. Solid gray areas represent elevations that need additional research but presence is expected. Direction of arrows denotes potential direction of expansion outside of the current documented elevation range.

elevations such as horn flies, certain horse fly and mosquito species, biting midges, bot flies, or certain larvae of blowflies (Deonier 1942, Clark and Hibler 1973, Kaufman et al. 1999, Blodgett and Lanier 2006, Eisen et al. 2008; Fig. 4). Timing movement of livestock to higher elevations could also coincide with peak periods of elevation-susceptible species. For example, in the Big Horn Basin of Wyoming, moving ewes to mountain pastures reduced the occurrence of bluetongue virus but rams that stayed at lower elevations had an almost 100% infection rate (Miller et al. 2010). In one study, high-elevation ranches had lower horn fly numbers and were always below the economic threshold when compared with lower elevation ranches (Kaufman et al. 1999). However, these scenarios may not be absolutes, especially in the context of climate change, animal movement patterns, and the influence on parasite and pathogen expansion upward in elevation and latitude (Estrada-Peña et al. 2012).

Fifth, it is important to separate hay feeding sites from grazing areas. Stable fly infestations have been correlated with round hay bale feeding sites because of the animal manure that mixes with wasted hay due to the concentration of animals at these sites (Broce et al. 2005, Talley et al. 2009). Furthermore, stable flies have not demonstrated an elevation correlation up to 1,600 m (5,249’) or climate correlation and farm management practices may be most important (Gilles et al. 2008). Therefore, moving away from these feeding areas should be an effective strategy, whether it is moving to a higher elevation or just moving locally.

Sixth, it is important to be wary of and avoid sites where animals have been congregated at high densities, perhaps for more than a year depending on moisture conditions. The congregation of livestock and concentration of feces could deposit roundworms that can survive for more than a single year, especially with above average rainfall. Although clinical parasitism is not common at high elevations due to low animal density, congregation areas such as traps (i.e., small paddocks for gathering cattle) could be areas of recurring exposure (Scwink 1963). Therefore, it is important to understand the ecology of roundworm larvae, the time interval needed for larval populations to decline, and how to optimize animal movements to minimize exposure to contaminated sites (Besier and Love 2004).

Seventh, it is essential to focus the internal parasite program to treat for *Ostertagia ostertagi*. This is the dominant roundworm pest of cattle, and it can survive at high elevations by inhibiting larvae development. Be aware that larval infestations may not be detectable at higher elevations as a result of inhibition of larval development at higher elevations (Malczewski et al. 1996). Parasitic nematodes have also developed anthelmintic resistance in small ruminants, and to a lesser degree in cattle, so it is important to use strategies to preserve efficacy such as diversifying modes of actions used, decreasing frequency of treatment, avoiding administering an inadequate dose, and using grazing management (Dobson et al. 1996, Kaplan 2004). Strategic deworming could also be incorporated based on risk assessment and integrated with multiple management strategies (Fleming et al. 2006).

Eighth, it is useful to monitor for the presence of mosquitoes and horse flies at higher elevations. Some species of mosquitoes and horse flies occur exclusively at high elevations. Mosquitoes and horse flies transmit several problematic diseases, such as WNV and anaplasmosis, and producers should be wary of outbreaks (Clark and Hibler 1973, Eisen et al. 2008). These outbreaks may be anticipated in relation to the driving climate and weather variables, primarily warmer temperatures, higher precipitation years, and stagnant water.

Finally, do not assume that high-elevation grazing areas provide an impenetrable buffer against all livestock parasites. Although high-elevation grazing areas do provide a buffer to some livestock parasites, it does not buffer against all parasites. Consequently, moving livestock to high-elevation range may increase the opportunity for livestock–-wildlife interactions, parasite and disease transmission, and exposure. Additionally, given the evidence for recent warming trends and global concern for the upward expansion of parasite elevation ranges, it is prudent to remain aware that previously nonexistent parasite issues may occur if these climate trends continue. Producers need to use basic IPM practices. IPM for livestock parasites should include closely monitoring animals for health-related problems, especially during the shorter summer periods at high elevations (Fig. 5). It is important to be aware of diseases that are specific to high elevations such BHMD and the potential complication with lungworm infestations.

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