

Chapter 20

Elk and Rangelands



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Abstract Elk (*Cervus canadensis*) are the second largest member of the deer family that reside in North America. Historically, the species occupied most of North America, however, today, they occupy only a small proportion of that range. Across their historical and contemporary distribution, they occupied diverse vegetation communities including both rangelands and forest ecosystems. Given this broad distribution, elk face numerous conservation and management threats including competition with wild and domestic ungulates, disease considerations, and human-elk conflicts. This chapter highlights these and other conservation and management concerns, especially as they pertain to rangelands. In closing, we identify current and future research needs that will be important for the continued persistence and expansion of elk populations across their range.

Keywords Carnivores · Climate change · Conservation · Disease · Elk-livestock · Habitat · Management

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20.1 General Life History and Population Dynamics

Elk (*Cervus canadensis*), comprised of six subspecies, were one of the most widely distributed deer species in North America (Fig. 20.1). However, since European settlement, the Eastern elk (*C. c. canadensis*) and Merriam's elk (*C. c. merriami*), have been driven to extinction. Of the remaining subspecies, the Tule (*C. c. nannodes*) and Manitoban (*C. c. manitobensis*) elk only occupy a small fraction of their historical range. In contrast, the Roosevelt (*C. c. roosevelti*), and Rocky Mountain elk (*C. c. nelsoni*) subspecies occur across much of their historical range. Of these, the Rocky Mountain subspecies is the most widely distributed and the subspecies found across most of North America rangelands today.

Elk ecology and behavior of both males (hereafter bulls) and females (hereafter cows) are driven by the energetic requirements associated with breeding and calving periods (Geist 2002; Cook et al. 2013). The courtship and breeding activity, termed the “rut”, occurs in late September. For cows, the rut is followed by an ~ 250-day gestation period, with the peak of calving occurring in early June to coincide with the high nutritional quality provided by vegetative green-up (Cook et al. 2013). After birthing, cows will track forage availability to increase fat reserves for winter while also continuing energetically expensive lactation activities into winter. Like cows, bulls will track vegetation conditions during summer to replenish fat reserves for the

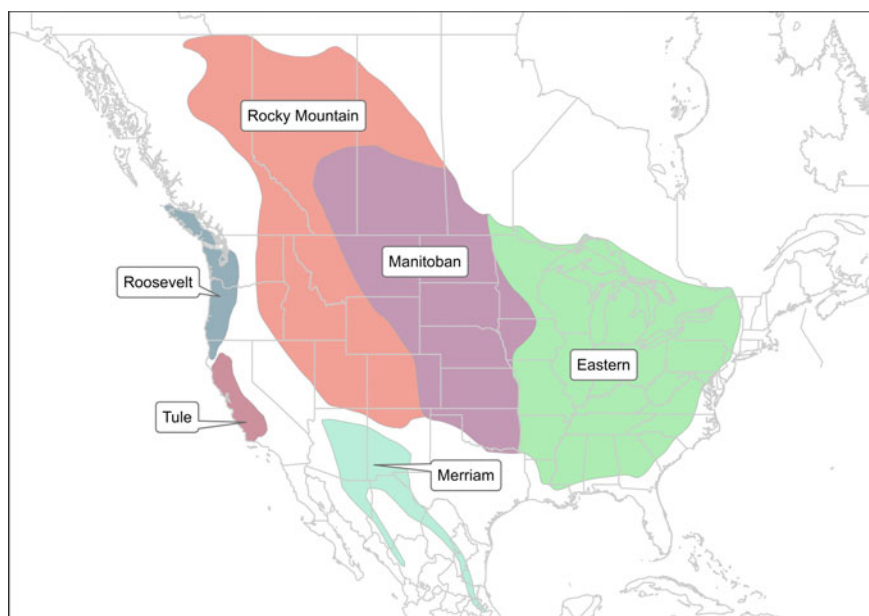


Fig. 20.1 Historical distribution of elk in North America. Adapted from figures available in Wisdom and Thomas (1996) and from Historic Elk Range Map Geographic Information System Polygon files compiled by Rocky Mountain Elk Foundation

next breeding season. Because antler shape and size are important for establishing dominance among bulls, and maintaining a harem of cows during the rut, bulls will also seek out mineral resources during the antler growth period (~ March–July). For bulls, the rut is a period of intense fat loss driven by reduced feeding and high energy expenditure. Following the rut, bulls will maximize energy conservation during winter to maintain fat reserves. Across most western rangelands, elk migrate seasonally to meet these nutritional requirements. Elk will typically move up in elevation to forested summer ranges during May and move down in elevation to lower-elevation rangelands between September and December where they winter. However, the spatial and temporal variability of these forage and mineral resources across populations and geographic regions results in significant variability in when and how elk use rangelands across the U.S.

When elk can appropriately track changing forage conditions, populations can undergo strong population growth. However, stochasticity in environmental conditions and predator communities likely shape annual variation in calf survival (Lukacs et al. 2018), and thus, overall population size. A review of 37 studies reported annual calf survival estimates ranged from 6 to 72% suggesting that calf survival is a prominent driver of elk population growth rate (Raithel et al. 2007). In contrast, adult female survival was relatively constant across populations (Raithel et al. 2007). Moreover, human harvest is the primary source of mortality in most hunted populations, for both cows and bulls, suggesting that management objectives strongly influence elk abundance (Keller et al. 2015). In a study of 45 different elk populations across the western U.S. and Canada, cow elk survival was 85 and 95% (Brodie et al. 2013) and bull elk survival was 56 and 79% in harvested and unharvested populations, respectively (Unsworth et al. 1993; Lubow et al. 2002).

20.2 Current Species and Population Status

Following the market hunting period, only 60,000 elk, distributed across 7 western states, remained in North America (Jackson 1944). However, by 2021, large-scale reintroductions and conservation actions have led to an estimated 1.18–1.22 million wild elk distributed across 27 U.S. states and five Canadian provinces, based on a collation of state and provincial elk management reports and media statements (Fig. 20.2; Table 20.1). Because of continued restoration and management efforts, elk continue to increase in abundance and distribution in most portions of their range. The species *Cervus canadensis* is ranked “least concern” by the International Union for the Conservation of Nature and “globally secure” by NatureServe. State- and province-level ranks in North America also indicate secure populations except in Ontario (critically imperiled).

In areas of established elk populations, surveys are common. Surveys have predominantly been conducted via fecal pellets (Rowland et al. 1984) and road- or aerial-based sampling surveys (Samuel et al. 1987), collecting data on the observed number of bulls and cows and approximate age class (juvenile, sub-adult, adult).

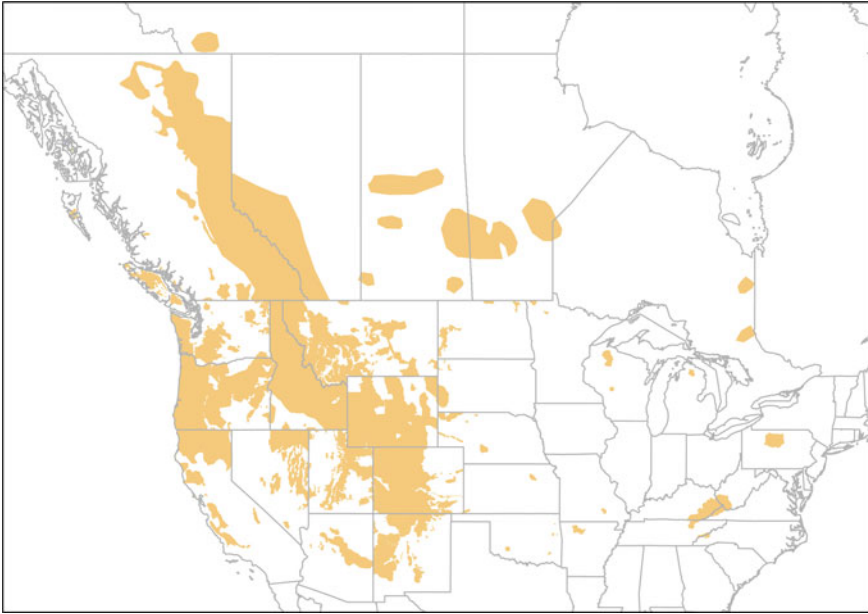


Fig. 20.2 Current distribution of elk in North America. State- or province-specific distribution data were obtained from state websites, by georeferencing habitat mapping documents (e.g., state elk management plans), or replicated from data compiled by Rocky Mountain Elk Foundation. Distribution in Alaska not shown. Elk residing in National Parks or within Tribal or First Nations boundaries are not shown as they are not included in Table 20.1

Additionally, information on age of harvest obtained via check stations and phone surveys has been used to determine population structure (Bender and Spencer 1999). Traditional survey methodology is comprehensively reviewed in Toweill and Thomas (2002).

In recent years, thermal imaging has been used to increase detection probabilities during rangeland aerial surveys (Dunn et al. 2002) and to assess vegetation impacts by elk (Biederbeck et al. 2016). Unmanned aerial surveys are also seeing increased use, providing both thermal imaging and real-time, spatially explicit population information (Witczuk et al. 2018; Graves et al. 2022). Remote cameras are also now being used to estimate elk abundance (Moeller et al. 2018). The vast data collected using traditional and contemporary survey methods, and advances in computer processing capabilities have facilitated corresponding improvements for estimating elk abundance and assessing harvest management scenarios (Eacker et al. 2017; Bender and Spencer 1999) and habitat use (Sawyer et al. 2007; Boyce et al. 2003).

The significance of diseases in elk has emerged in the last half century as game-farming and winter-feeding grounds have exposed elk and facilitated the spread of a variety of diseases. More recently, the emergence of management-oriented epidemiological investigations has expanded our understanding of these diseases within free-ranging elk populations and their consequences on population performance. Thus,

Table 20.1 Elk population estimates for U.S. states and Canadian provinces. Estimates are unlikely to include elk abundance within national parks or on Tribal or First Nations lands

Location	Elk estimate	Source	Date
<i>U.S.A</i>			
AK	1300–1500	S	2021
AZ	35,000–45,000	W, M ¹	2021
AR	450	S	2021
CA	12,900	P	2018
CO	292,760	P	2019
ID	> 120,000	W	2021
KS	450–500	M ¹	2018
KY	15,876	P	2020
MI	930–1462	M ¹	2019
MN	259	M ¹	2020
MO	> 200	M ¹	2020
MT	136,151	P	2020
NE	2500–3000	S	2021
NV	13,500	P	2018
NM	70,000–90,000	M ¹	2021
NC	150–200	W	2021
ND	700–1000	U ²	2021
OK	> 5000	M ¹	2019
OR	126,646	P	2019
PA	1350	W	2020
SD	7682–10,076	P	2020
TN	> 400	W	2020
TX	3500	O3	2014
UT	81,000	P	2020
WA	46,150–53,150	W	2021
WI	400	W	2021
WV	85	W	2021
WY	112,900	M ¹	2020
<i>Canada</i>			
AB	26,000	U ²	2021
BC	43,000–43,500	W	2021
MB	6500	W	2021

(continued)

Table 20.1 (continued)

Location	Elk estimate	Source	Date
ON	600–1000	M ¹	2020
SK	7350	O ⁴	2014
Total	1,183,939–1,225,865		

Source M—Media reports (refers to agency biologist statements in news articles), O—Other, P—Elk management plan or population estimate, S—Wildlife agency staff, U—Unconfirmed, W—Wildlife agency website

¹ “Media reports” refer to agency biologist statements within news articles

² Third party websites (e.g., state-specific hunting organizations)

³ Texas Tech University fact sheet

⁴ University of Saskatchewan thesis

disease surveillance and management are now important components of many elk management programs.

20.3 Habitat Associations

Historically, North American elk occupied a diverse mix of habitats to meet basic ecological needs for forage, water, and security from weather and predators (i.e., both human and nonhuman). This diversity reflected the broad distribution of elk across the continent prior to European settlement (Murie 1951). Nearly all major vegetation types were occupied by elk other than the humid forests of the southeastern U.S. and hot desert communities of the Southwest (Murie 1951; Skovlin et al. 2002). Different subspecies of elk exploited this habitat mix (Fig. 20.1). For example, the extirpated Merriam’s elk occurred in dry forests and chaparral of the Southwest (Skovlin et al. 2002), where its distribution may have been limited by water. By contrast, Roosevelt elk were the most forest-associated taxon, occurring primarily in coastal rainforests but with seasonal use of open meadows (Murie 1951). The Tule elk of California were the subspecies most adapted to plains environments, occasionally inhabiting even chaparral or woodlands (Murie 1951; McCullough 1969); however, their habitat associations were little studied before their near extirpation. Populations of Eastern elk were widely distributed in the plains of the midwestern U.S., (e.g., Iowa and Illinois), where they lived year-round and co-occurred with bison (Murie 1951). These habitat associations continue today across the geographic range of elk, apart from those elk extirpated in plains states (Murie 1951).

The broad range of habitat associations for elk reflects their status as mixed feeders of intermediate selectivity, consuming a wide variety of graminoids, forbs, and woody plants (Cook 2002). As a result, rangelands provide key seasonal habitats for elk, primarily through their provisioning of non-woody forage (Cook 2002). Winter diets of elk are also dominated by graminoids (Christianson and Creel 2007), but some elk herds rely on woody browse more frequently in winter than in other seasons

(Rowland et al. 1983; Cook 2002). Today, rangelands remain an important habitat component for many elk populations (Sawyer et al. 2007), particularly those that migrate between forested summer range to more open rangeland in winter. The seasonal use of rangelands has become increasingly common in the Western U.S. with elk selecting bedding sites in sage-steppe biomes in Washington (McCorquodale et al. 1986), foraging sites in agricultural lands in Manitoba, Canada and Montana, USA (Proffitt et al. 2013; Brook 2010), and spatial refugia in urbanized landscapes (Polfus and Krausman 2012).

Forested stands, especially with low-moderate canopy cover, offer additional foraging opportunities for elk in late summer and early fall as vegetation senesces in open habitats (Cook 2002). Additionally, forested communities may benefit elk by reducing predation risk due to increased visual obstruction (Skovlin et al. 2002; Lowrey et al. 2020). However, forests are not a required habitat component for elk if rugged topography offers visual obstruction (Lehman et al. 2016) and sufficient forage. Land ownership and its associated management may also influence habitat selection such that elk behaviors diverge from traditional habitat associations as elk attempt to minimize predation risk from human hunting (Proffitt et al. 2010).

As human populations and their footprint have expanded into historical elk winter range, some of these habitat associations have been altered due to changes in forage characteristics and predation risk. For example, conversion of winter range to croplands has led to elk selecting for areas of increased forage potential (Brook 2010). In cases of high forage availability, elk may select forage over the thermal cover provided in adjacent forested landscapes that they would have historically used (Long et al. 2014). This transition has altered forage preferences to more non-traditional food sources available in urban settings, such as golf courses, subdivisions, and the wildland-urban interface (WUI; Tucker et al. 2004; Skovlin 2002). Further, the spread of exotic species, such as spotted knapweed (*Centaurea stoebe*), into rangelands has altered elk diets and forage availability (Kohl et al. 2012).

The attractiveness of higher forage quality and availability from urbanization of elk winter range has been exacerbated by reduced predation risk as predators may avoid humans, and because hunter harvest is usually not allowed (Berger 2007). Thus, elk in these situations have ample, high-quality forage with reduced or absent predation risk, increasing residency time on adjacent rangelands (Cleveland et al. 2012) and potential loss of traditional migratory behavior (Hebblewhite et al. 2006). For example, elk migratory behavior has been altered or lost in Banff, Alberta, Canada; Estes Park, CO; Sequim, WA; and Jackson Hole, WY. The resulting, burgeoning elk populations in urban and WUI settings have negative impacts on rangeland condition that are largely beyond managerial control (Haggerty and Travis 2006) and have led to corresponding increases in human/elk conflict.

Although conflicts between ranchers and elk have developed on rangelands and croplands adjacent to forest preserves and urbanized rangelands (Tucker et al. 2004), parallel opportunities have emerged to improve range condition for elk. For example, in cooperation with cattle ranchers, wildlife managers can “pre-condition” rangelands for elk via cattle grazing, thus improving winter range condition (Clark et al. 2000). Additionally, advanced, interactive tools are being developed to provide site specific

recommendations for range management on agricultural lands (<https://tinyurl.com/54fu93cb>). Further work on habitat associations of urbanizing landscapes, predation risk, migration and crop depredation remain important contemporary issues for elk management and research.

20.4 Rangeland Management

Shared grazing management of elk with other wild and domestic ungulates has been controversial for over a century (Miller 2002). This controversy centers on how the perceived competitive advantages of elk (e.g., their broad diet, large body size, tendency to form large herds, aggressive behavior toward smaller ungulates) may negatively impact other ungulates on co-occupied rangeland (Miller 2002). However, the shared use of rangelands by elk with other ungulates does not automatically indicate competition. Multi-ungulate grazing systems can be complementary, indifferent, or beneficial. Thus, many factors must be considered (Ager et al. 2004; Hughey et al. 2021), with effects that are season- and area-specific and often requiring formal monitoring or research.

20.4.1 *Elk-Cattle Competition*

It is unlikely that elk will compete with other native wild ungulates, however elk may compete with cattle because of the following reasons (Wisdom and Thomas 1996; Clark et al. 2017): (1) the two ungulates co-occupy millions of ha of rangelands across the western U.S. and Canada, among the largest areas of shared range of ungulates in North America; (2) their diets can converge when either or both graze at high population density during seasonal forage limitations, such as senescence of herbaceous forage during late summer-fall; and (3) some seasonal ranges (e.g., winter) that are co-occupied by elk and cattle may have limited space and forage availability. Under each scenario, there is potential for elk and cattle to compete directly for food. Furthermore, elk-cattle dietary overlap can be high within and across seasons (Torstenson et al. 2006), and both ungulates readily adapt to available forages seasonally (Scasta et al. 2016). In turn, both ungulates can substantially reduce available biomass of nutritious forages, altering the abundance, composition, and structure of plant communities under moderate to high grazing use (Endress et al. 2016; Rhodes et al. 2018), affecting each other and potentially other rangeland species.

20.4.2 Cattle Grazing Prescriptions that Benefit Elk

In many cases, livestock grazing systems are likely compatible with elk. However, it may also be either positive or negative. For example, grazing prescriptions can be designed and used to condition grasses for nutritional benefit of elk, and to maintain desired elk distributions. This was demonstrated by research from Montana in which grazing intensity, duration, rotation, and rest periods was manipulated to maximize foraging efficiency and dietary quality for elk (Alt 1992; Frisina 1992). Rest-rotation cattle-grazing systems in Oregon were also documented to support extended elk use of grazing lands by providing desired nutritional benefits (Anderson et al. 1990). Similar benefits to elk are possible from traditional, deferred and rest-rotation cattle grazing systems in more productive rangelands (Vavra and Sheehy 1996; Crane et al. 2016). However, the benefits are not always realized when beef cattle production is the primary goal (Chaikina and Ruckstuhl 2006; Tolleson et al. 2012). Cattle grazing in many arid and semi-arid rangelands also is not likely to provide nutritional benefits to the other ungulates under moderate or high stocking rates (Hobbs et al. 1996; Krausman et al. 2009; Damiran et al. 2019).

20.4.3 Elk Competition with Other Ungulates

The potential for feral equid-elk competition has become an increasing management concern, and yet, elk and feral equids share less than 4.5% of their distributions across the western U.S. (Stoner et al. 2021). It should be noted that where these species overlap, feral equids can have substantial impacts on elk habitat. Beyond equids, a notable and emerging grazing management controversy is the potential for elk to compete with mule deer. Elk may displace mule deer (Johnson et al. 2000; Stewart et al. 2002) and can substantially reduce biomass of high-quality mule deer forages, particularly during late-summer and fall (Findholt et al. 2004). In addition to mule deer, concerns regarding the potential for elk-bison competition are increasing as bison reintroduction efforts continue throughout North America. To date, research on bison-elk competition has been limited and inconclusive. In Wind Cave National Park, bison and elk had moderate spatial overlap, however differences in food habitats limited overall competition (Wydeven and Dahlgren 1985). In contrast, Coughenour (2005) suggested that at high densities, bison and elk may compete for available forage.

20.4.4 Estimating Elk and Ungulate Competition

We summarized conditions under which the potential for elk-ungulate competition may be low, high, or uncertain on co-occupied rangelands, based on 12 generalizations developed and reviewed extensively in Wisdom and Thomas (1996; Fig. 20.3). These generalizations have been supported by contemporary research and still apply today (Clark et al. 2017). Although specific to elk-cattle competition, similar approaches could be applied to better understand competition between elk and other ungulates. Our summary is not intended to replace field assessments, monitoring, or research, but could be used as a first step to prioritize areas and times in which greater attention may be warranted to address the potential for competitive interactions. Figure 20.3 could be used, for example, to identify grazing periods when formal methods of “forage allocation” may help mitigate undesired grazing impacts and potential competitive interactions. In this context, forage allocation represents the desired proportional availability of nutritional resources across space and time for each type of ungulate grazer.

Traditional methods for estimating forage allocation, based on stocking rate of cattle and elk, are reviewed in Wisdom and Thomas (1996). More recent applications (Riggs et al. 2015) further documented the challenges of applying these methods at landscape scales, owing to the diversity and data accuracy that must be considered (Clark et al. 2017). Fine-scale, spatially- and temporally-dynamic forage allocation methods such as use of linear programming (e.g., Cooperrider and Bailey 1984;

Competition Potential	Specific Conditions	Grazing Context	Specific Conditions	Competition Potential
 LOW	Late-spring and early summer ranges support high forage biomass and quality (peak productivity of forbs and grasses) over large areas.	Competition varies by season and extent of spatial overlap.	Winter and spring-fall ranges have limited grazing area and low forage biomass and quality.	 HIGH
 LOW	Cattle and elk are temporally separate on more productive, mesic rangelands where spring-summer grazing by one ungulate facilitates regrowth of grasses to benefit the other.	Grazing effects on forage can be beneficial or competitive.	Grazing on less productive, xeric rangelands does not facilitate regrowth of grasses, increasing competition for limited forage following peak forage production.	 HIGH
 LOW	Cattle and elk distribute themselves separately based on different responses to environmental conditions, with independent spatial forage use.	Elk and cattle are spatially separate.	Elk avoid cattle, which may or may not restrict elk grazing choices or limit cattle conditioning of grasses to benefit elk after cattle are moved from a pasture.	UNCERTAIN 
 LOW	High precipitation results in abundant forage of sufficient quality, with full expression of dietary differences and low dietary overlap, regardless of spatial overlap.	Forage quality and quantity vary by timing and extent of drought.	Prolonged drought, often during late summer and fall, results in low forage quantity and quality and convergence of elk-cattle diets when using same areas.	 HIGH
 LOW	Productive, mesic rangelands historically grazed by multiple ungulate species, such as tall- and mid-grass prairie systems, have high resilience to fire and grazing.	Range site productivity drives competition.	Less productive, xeric rangelands have low resilience to fire and grazing, especially for areas with a declining range trend and high use by cattle or elk.	 HIGH
UNCERTAIN 	Rangelands have highly variable seasonal climate regimes, resulting in low predictability of herbaceous forage dynamics.	High number of unknowns due to insufficient data.	Perceptions are the basis for inferring competitive interactions.	UNCERTAIN 

Fig. 20.3 Potential for competition between elk and cattle (high, low, or uncertain) based on grazing context on western rangelands, summarized from Wisdom and Thomas (1996), as estimated for arid and semi-arid rangelands (areas receiving < 50 cm of annual precipitation)

Johnson et al. 1996) and foraging simulation models (Ager et al. 2004; Riggs et al. 2015) have been used successfully in research but required data are often lacking for effective management applications. Regardless of method, estimating forage allocation requires four major inputs (Ager et al. 2004): (1) biomass of key forages available to each ungulate; (2) allowable use of those forages for each ungulate; (3) percent spatial overlap between ungulates; and (4) percent dietary overlap between ungulates as offset by degree of spatial overlap.

Reasonable estimates of biomass of key forage species available to each ungulate often can be obtained from past monitoring conducted in an area or from published sources for the associated ecoregion (Ager et al. 2004) or using remote-sensed products (Garrouette et al. 2016; Allred et al. 2021). Establishing the allowable use of key forages for each ungulate is a major management decision best made in relation to the ecological resilience (i.e., capacity to survive and recover) of key forages under a specified level of grazing use by each ungulate. Data on range condition and trend can often be used as the basis for making decisions about grazing use for each ungulate, which are typically available on most public grazing allotments. Estimating spatial overlap involves mapping the expected spatial distributions of each ungulate in relation to the environmental features shown in the literature to have consistent and measurable influence on each ungulate type's use of a landscape, independent of the other. For example, geographic information systems and extensive, widely-available, spatial data could provide efficient mapping of elk and cattle spatial distributions to evaluate spatial overlap (Stewart et al. 2002). Lastly, the main dietary items (i.e., key forages) must be identified to estimate biomass available to each ungulate within areas of shared spatial overlap (Wisdom and Thomas 1996), which, in some cases, can now be done at landscape scales with DNA metabarcoding (Nichols et al. 2016).

20.5 Impacts of Disease

Elk can host a suite of viral, bacterial, prion, and nutritional diseases that have varying levels of impact on elk populations (Table 20.2). While disease surveillance and management often focus on the diseases that influence elk population performance, much of the focus of elk diseases relate to their consequences for livestock. The transmission of disease from elk to livestock or livestock to elk, which we refer to as spillover, can have important consequences for both elk and domestic livestock health. For example, bacterial diseases such as bovine tuberculosis or anthrax can be transmitted between livestock and elk and result in animal health concerns and/or death. The risk of spillover to livestock can create conflict, as disease spillover has the potential to adversely affect livestock health, economic activity, and support for elk conservation. Below we detail two of the most important and contemporary diseases affecting elk, brucellosis (Cross et al. 2010a) and chronic wasting disease (CWD; Williams and Young 1980).

Brucellosis is a global zoonotic disease caused by the bacteria *Brucella abortus* that infects cattle, elk, and bison (Olsen 2010). Brucellosis was nearly eradicated

Table 20.2 Bacterial, viral, prion, and parasitic diseases that affect elk

Diseases or Condition	Description	Primary references
<i>Bacterial</i>		
Anaplasmosis (gall sickness)	Disease of blood cells primarily affecting domestic cattle that is caused by <i>Anaplasma</i> bacteria and transmitted by ectoparasite	Kuttler (1984), Zaugg et al. (1996)
Anthrax	Zoonosis afflicting animals and humans globally, caused by the spore-forming, environmentally-maintained bacterium <i>Bacillus anthracis</i>	Turnbull (2008), Blackburn et al. (2014)
Bovine Tuberculosis	A zoonotic disease, due to <i>Mycobacterium bovis</i> , classically carried by cattle and spilling over into wildlife reservoirs	Rhyan and Saari (1995), Brook et al. (2013)
Brucellosis	A highly infectious zoonosis affecting animals and humans worldwide caused by <i>Brucella abortus</i>	Cheville et al. (1998), Rhyan et al. (2013)
Leptospirosis spp.	An infective serological group of bacteria that can infect nearly all mammals	Bender and Hall (1996), Lilenbaum and Martins (2014)
Necrotic Stomatitis	A bacterial infection in the mouth which causes abscesses, necrosis, and loss of teeth	Murie (1930), Murray et al. (1996)
Paratuberculosis (Johne's Disease)	An infectious granulomatous enteritis caused by <i>Mycobacterium avium</i> paratuberculosis causing significant economic losses in livestock	Williams et al. (1983), Carta et al. (2013)
<i>Viral</i>		
Hemorrhagic Disease	Transmitted by biting midges in the <i>Culicoides</i> spp. and other arthropods, causing acute and frequently fatal hemorrhagic disease in domestic and wild ungulates	Howerth et al. (2001), Ruder et al. (2015)
<i>Prion</i>		
Chronic Wasting Disease	Transmissible spongiform encephalopathy caused by prion-induced folding of proteins in the brain	Williams and Young (1980), Williams et al. (2002)
<i>Parasites and Parasitic Diseases</i>		
External parasites: Mange Mites and Winter tick	Common part of the normal biology of most animals; however, some external parasites including mange mites (<i>Psoroptic</i> spp.) and winter tick (<i>Dermacentor albipictus</i>) may cause morbidity and mortality in elk	Samuel et al. (1991), Corn and Nettles (2001)
Internal parasites: Lungworm, <i>Ecchinoccus granulosus</i>	Common part of the normal biology of most animals; however, some internal parasites, e.g., lungworm (<i>Dictyocaulus viviparus</i>) or <i>Ecchinoccus granulosus</i> , may cause morbidity and mortality in elk	Foreyt et al. (2000), Thompson (2008)

from the U.S. in the early 2000's, but the disease persists in elk and bison populations in the Greater Yellowstone Area (GYA; Rhyan et al. 2013). Brucellosis prevalence within GYA elk populations ranges from 0–53% (Rayl et al. 2019; NASEM 2020), and is increasing in many herds (Cross et al. 2010b; Brennan et al. 2017). *B. abortus* concentrates in the reproductive system and typically causes abortion during the third trimester (Cheville et al. 1998). Transmission occurs when individuals ingest *B. abortus* bacteria from infected fetuses or birthing fluids on tissues, soil or vegetation which may persist for 21–81 days depending on conditions (Aune et al. 2012).

Elk are responsible for transmitting the disease to livestock in multiple recent outbreaks (Kamath et al. 2016). Because transmission from elk to livestock occurs where livestock may contact and ingest the elk-aborted fetus or birthing fluids, disease management programs focus on maintaining spatial separation between elk and livestock during this transmission risk period. In addition, the controversial elk winter feed grounds in Wyoming are used in part to reduce comingling between elk and livestock. Management to reduce transmission risk may also include non-lethal and lethal actions aimed at redistributing elk away from livestock (Jones et al. 2021).

CWD is a transmissible spongiform encephalopathy caused by abnormal folding of proteins that accumulate in brains of infected animals and eventually lead to central nervous system failure and death. As CWD may infect members of the cervid family, including elk, deer, and moose, it has critical implications for elk population performance and management on rangelands and elsewhere. CWD was first recognized in the 1970's at a captive deer research facility in northwestern Colorado (Williams and Young 1980), and since has spread throughout captive and free-ranging elk, deer, and moose populations across North America (Mysterud and Edmunds 2019). Control efforts to date have largely been unsuccessful at reducing the spatial spread and prevalence of CWD in free-ranging elk populations (Uehlinger et al. 2016).

Clinical signs of CWD include severe weight loss, and behavioral changes such as stumbling, tremors, and teeth grinding (Miller et al. 1998). CWD has an incubation period lasting for several months to several years, during which an infected elk may show few signs of illness but still shed prions in urine, feces, and saliva. Transmission to susceptible animals may occur directly through contact with an infected animal or indirectly through environmental contamination (Williams et al. 2002). There is no evidence that infected elk can transmit CWD to domestic livestock (Williams 2005).

The effect of CWD on elk population demography is primarily due to reduced adult female survival rates, as infected individuals will continue to reproduce (Mysterud and Edmunds 2019). Depending on the prevalence and other factors interacting to influence adult female survival rate, CWD may have variable effects on elk population performance (Monello et al. 2014; Mysterud and Edmunds 2019). For example, in the Rocky Mountain elk population, CWD prevalence rates exceeding 13% have the potential to decrease population growth (Monello et al. 2014). It should be noted that recent work suggests that natural resistance to CWD may be increasing in wild cervid populations (Monello et al. 2017).

20.6 Ecosystem Threats

A primary threat to elk across western rangelands stems from continued human population growth and its contribution to urban, suburban, and exurban growth. The result has been increased development and associated infrastructure leading to habitat alteration, fragmentation, and destruction. Beyond direct reduction in available habitat, residential expansion and development also contributes to shifts in elk behavior that contribute to changing elk use of rangelands (Polfus and Krausman 2012). In some places, human development has led to fragmented and diminished habitat quality with elk demonstrating avoidance of small ownership parcels (Wait and McNally 2004) and faster movements in areas close to houses (Cleveland et al. 2012). In other cases, elk may select for developed areas because of increased forage opportunities (e.g., manicured lawns, irrigated fields), reduced snow depth, and reduced predator densities that may potentially contribute to increased human-wildlife conflicts (Thompson and Henderson 1998).

Beyond residential development, human population growth requires substantial infrastructure (Soulard 2006) including road and energy development, much of which is occurring on elk winter and transitional ranges. Generally, elk avoid roads open to public motorized use (Rowland et al. 2000; Sawyer et al. 2007; Frair et al. 2008), a behavior that is particularly evident for hunted populations during fall and winter (Beck et al. 2013) and during daylight and twilight hours (Prokopenko et al. 2017). It should be noted, however, that elk response to roads in refuge areas are less predictable (Wisdom et al. 2018). While there is little evidence that elk-vehicle collisions are a significant influence on elk survival, roads provide a means of incidental mortality from legal and illegal harvest by humans (McCorquodale et al. 2003; Frair et al. 2007). Through such mortality, the road network has the possibility to influence elk population dynamics (Frair et al. 2008).

As human population continues to grow, there is an ever-expanding energy development network that is required (Kiesecker and Naugle 2017), much of which overlaps with ungulate winter range in North America (Hebblewhite 2011). Previous research has demonstrated that these surface disturbances (e.g., wells, access roads, etc.) negatively affect elk, however the magnitude of those effects has varied across studies. For example, elk in northeastern Wyoming altered their behavior in response to the development of a coalbed natural gas field (Buchanan et al. 2014). Compared to pre-development years, elk selected areas with greater cover, increased terrain ruggedness, and farther from roads post-development, leading to a decrease in preferred habitat use for the population (Buchanan et al. 2014). Despite these displacement behaviors, the size of this elk population has remained stable (Buchanan et al. 2014) or increased since the development (Bureau of Land Management 2015). In contrast, the risk of mortality for elk in New Mexico and Southern Colorado decreased for elk in proximity to energy development disturbance (Dzialak et al. 2011). More research is necessary to clarify how elk respond to energy development, and studies in North Dakota and Wyoming are underway.

Concomitant to human population growth, interest in recreational activities is also increasing leading to concerns about its impact on elk behavior and demography. For example, increased recreational use (e.g., all-terrain vehicle use, hiking, horseback riding, mountain biking) has been shown to increase movement rates (Wisdom et al. 2004) and reduce feeding time (Naylor et al. 2009) by elk, translating to higher energetic costs which may contribute to lower vital rates (Phillips and Alldredge 2000).

Land ownership changes are becoming increasingly common, and in turn, posing significant challenges to elk populations and to wildlife managers (Haggerty and Travis 2006). When land ownership changes result in a shift away from traditional ranching activities, and toward restricted hunting access, elk use of private lands may intensify due to increases in high quality forage (Barker et al. 2019a) or due to enhanced security relative to neighboring hunted areas (Conner et al. 2001; Vieira et al. 2003). This has contributed to overabundant elk populations in states such as Wyoming and Montana. Importantly, reactivation of hunting on these private lands can quickly reverse elk behaviors (Sergeyev et al. 2022).

Long-term climate change poses one of the most significant threats to elk populations across western rangelands. Through its alteration of the environment, climate change has the potential to influence elk distribution, migration, and population sizes via changes in seasonal forage availability and quality. The West is experiencing lower snowpack, earlier snowmelt, and an increase in both drought frequency and the rate of spring green-up (Marshall et al. 2019). Temperature and other weather patterns are less predictable, with increased frequency of large storms, and the dry periods between them (Groisman and Knight 2008). These changes in climate are also affecting broad scale forest disturbance (e.g., bark beetle outbreak) and fire regimes, both with impacts on elk habitat use and management (Lamont et al. 2020; Spitz et al. 2018; Proffitt et al. 2019). Each of these factors will continue to influence availability of high-quality forage on both summer and winter range, and during migration (Rowland et al. 2018). Moreover, these changes may particularly impact elk spring migrations, which are closely tied to the phenology of snow melt and plant green-up (Hebblewhite et al. 2008) and fall migrations that are tied to the timing and amount of snow (Rickbeil et al. 2019). Significant mismatches in timing between migration and plant phenology can negatively influence reproductive rates and overwinter survival (Middleton et al. 2018; Cook et al. 2004).

20.7 Conservation Actions

Generally, elk populations are stable or increasing, precluding the need for explicit conservation actions. One exception is Tule elk which are the focus of diverse conservation actions following its near extirpation in the 1800s. Despite this history some herds have grown exponentially resulting in conflict with livestock producers, especially in protected areas (Watt 2015). Given their high genetic diversity and relatively low allelic diversity and heterozygosity, transplants among existing Tule elk

herds may be the best strategy to conserve this subspecies (Williams et al. 2004). However, removal of elk or contraception may be needed where populations remain above objective (e.g., Howell et al. 2002). Due to the location of their habitat, future conservation of Tule elk will require management in a socioecological context (Ciriacy-Wantrup et al. 2019; Denryter and Fischer 2022).

Transplants can restore elk populations extirpated or dramatically reduced by market hunting, habitat loss, or other stressors, with successful reintroductions occurring in many locales (Sargeant and Oehler 2007; O'Neil and Bump 2014). This is particularly evident in eastern North America, where elk reintroductions have led to establishment of ~ 20,000 elk across nine states and two Canadian provinces (Table 20.1). Most reintroductions have been aimed at providing hunting opportunity, but conflicts with landowners must also be addressed when reintroduced elk extend onto private lands. In rare cases, translocations may also help alleviate problems associated with overabundant elk (Walter et al. 2010). Translocation options are increasingly limited by state policies due to the potential of spreading diseases such as CWD (Corn and Nettles 2001).

Large-scale habitat alteration from wildfires, leading to habitat loss and fragmentation, can pose special conservation challenges for elk, especially in more arid regions. Habitat restoration in such sites is challenging given high spatial and temporal variability in precipitation patterns and forage resources (Chambers et al. 2014). Although fire can improve the nutritional landscape for elk, especially in higher elevations (Proffitt et al. 2019), realized benefits depend on fire intensity, size, pattern, and affected vegetation community. Moreover, forage may be limited in the short term as fires can damage shrublands that are used seasonally by elk (McCorquodale et al. 1986) and may require decades to become reestablished (Davies et al. 2012). Additionally, exotic herbaceous plants often predominate following fire in shrublands and supplant native species, diminishing resources for elk and often require active restoration through seeding and other practices (Chambers et al. 2014).

Climate change may also alter elk habitat and migratory patterns and these relationships have primarily been studied in forested and alpine habitats, although Denryter and Fischer (2022) assessed movements in non-forested habitat. The complexities of climate change interactions with migration, disease ecology, and harvest will challenge elk conservation into the future, although elk have exhibited plastic behaviors that can partially compensate for these changes (Rickbeil et al. 2019). Where elk are considered vulnerable or below objective, protecting special habitat features such as calving areas, migratory corridors, or security areas from human disturbance or outright loss, while engaging collaboration across all relevant stakeholders, is recommended (Shively et al. 2005; Middleton et al. 2019).

20.8 Management Actions

Elk receive significant management attention in most areas they occur, from harvest to habitat management, and in some cases human conflict issues can become prominent. In some areas predators that prey on elk are also considered an integral part of elk management. While state and provincial wildlife agencies often take the lead on elk management, many other entities have significant involvement including federal land management agencies, research institutions, conservation groups, sportsman interests, livestock producers, and others.

20.8.1 *Harvest Management*

In general, most elk management programs seek to maintain the size and distribution of elk populations at socially acceptable levels compatible with other land uses while meeting recreational demands, including harvest. Harvest is an important management tool for manipulating the distribution and abundance of elk, given they are among the most iconic species of the American West and are highly valued by sportsmen and women. Harvest management is complex, integrating biological objectives and reflecting political, economic, and social considerations. Elk have important influences on vegetation (Wisdom et al. 2006), which can create conflicts with private landowners (Hobbs et al. 1996; Walter et al. 2010). After objectives for managing elk populations are determined for a population and/or management unit, specific harvest regulations can be designed to achieve those objectives. Because population management objectives vary widely across western populations, harvest strategies also vary widely (Stalling et al. 2002).

Elk population management objectives and associated harvest regulations are usually defined in state Elk Management Plans. These plans guide annual regulations that determine the allocation of hunting licenses and specify the number, age, and sex of animals allowable for harvest, the hunting period and areas of harvest, and allowable weapon types. Tribal harvest of elk, whether on lands ceded as treaty hunting areas or on reservations, is regulated by each tribe and is primarily “need-driven” (McCorquodale 1997). Tribal harvest likely contributes only marginally to the total harvest of elk in rangelands given the relative paucity of tribal members participating in elk hunts (McCorquodale 1997); nonetheless, elk remain an important cultural resource in much of the US, where they are considered a “First Food” (Long and Lake 2018).

As elk populations increased and recovered in the mid-1900s, conservative hunting regulations only allowed for harvest of males. Elk harvest management has changed as populations have largely recovered, and in some cases exceeded socially tolerable levels. For overabundant elk populations, regulations that allow for antlerless harvest and/or prolonged hunting periods may be implemented to reduce cow survival rates and corresponding population growth rates. Conflicts on private lands

related to crop depredation are increasing and may be related to the abundance or distribution of elk (Walter et al. 2010). To alleviate these conflicts, harvest regulations that apply to specific parcels of land and/or outside of traditional hunting season dates may also be implemented. Conversely, to manage small or declining elk populations, restrictive regulations may be applied to increase cow survival rates and population growth rates.

20.8.2 *Habitat Management*

The overarching management objective for elk habitat is to provide for a mix of seasonal habitats that include adequate nutrition while minimizing risk of disturbance from predators and humans. By emphasizing both vegetation conditions and disturbance risk, managers will be best equipped to optimize distribution and abundance of elk. Within this context, habitat management is often targeted toward shifting elk distributions from private to public lands to reduce damage on the former and increase hunting and viewing opportunities on the latter. Enhancing forage production for elk in natural systems can help meet these goals (Barker et al. 2019a, b). A special consideration of elk habitat is vulnerability to harvest, given the gentle topography and lower tree canopy cover common in rangeland systems (Edge and Marcum 1991; Wisdom and Thomas 1996).

In habitats with abundant non-native plants or encroachment of shrublands or woodlands, active restoration through seeding and/or prescribed fire can reduce invasive plant abundance and improve nutritional conditions, assuming precipitation is adequate and competition from invasive plant species is reduced (Chambers et al. 2014). For elk, this situation is most common on winter ranges, where invasive plant species like cheatgrass (*Bromus tectorum*) and knapweeds (*Centaurea* spp.) can be common. However, elk may consume these species in moderate amounts, especially during winter and spring (Kohl et al. 2012).

Elk feed grounds constitute a unique management tool, typically occupying traditional elk winter ranges. They can be effective in alleviating damage on private lands thus improving social tolerance of elk and landowner-wildlife agency relations, however, they can lead to degraded ranges and disease transmission, such as brucellosis or CWD (Maichak et al. 2009; Thorne et al. 1991).

20.8.3 *Carnivore Management*

Declines in some elk populations have been attributed to the restoration and recovery of large carnivore populations such as mountain lions (*Puma concolor*), grizzly bears (*Ursus arctos horribilis*), and wolves (*Canis lupus*) (Lehman et al. 2018;

Horne et al. 2019; Proffitt et al. 2020). Management tools to limit carnivore abundances and impacts on elk populations may be limited by state or federal legislation, lack of public support for carnivore harvest or carnivore population reductions (Mitchell et al. 2018), and disagreements within the scientific community regarding the effectiveness of carnivore control. As carnivore populations expand and increase, wildlife managers will need to employ integrated programs to effectively achieve both carnivore and elk population objectives (Proffitt et al. 2020).

20.9 Research/Management Needs

Future research to support management of elk can be summarized in four priority topics: competitive interactions with other ungulates, ongoing and emerging diseases and pathogens, effects of climate change, and socio-ecological effects of changing population distributions.

20.9.1 *Competitive Interactions with Other Ungulates*

Elk exhibit a variety of perceived competitive advantages over other ungulates, particularly mule deer and cattle, and all three co-occupy vast areas of western rangelands. Competitive interactions remain highly controversial and major sources of uncertainty remain. Study priorities include the need for:

- Manipulative landscape experiments to evaluate the behavioral, distributional, dietary, and population responses of mule deer to reductions in elk density in areas of historical mule deer range where populations have declined while elk populations have increased. Designs such as before-after-control impact (BACI) studies would be optimal.
- Observational landscape studies of mule deer diet, habitat-use, distribution, and individual and population performance across a gradient of elk densities (zero to high) under similar background environmental conditions. Data from these descriptive landscape studies could be used to validate predictions developed from the manipulative landscape experiments.
- Diet and spatial overlap of elk with cattle, and associated levels of biomass reduction and changes in nutritional quality of diets of both ungulates under high or moderate densities of both ungulates to assess potential for exploitative competition and effects on animal performance of each ungulate at specified densities of each.
- New decision support tools to accurately assess and model the spatio-temporal interactions of elk, deer, and cattle and the potential for interference and exploitative competition under varying densities of each ungulate, and under different

cattle grazing systems and practices across the xeric to mesic gradient of grassland, shrubland, woodland, and forested rangelands.

20.9.2 Diseases and Pathogens

Much has been learned about diseases and pathogens that affect elk, with new diseases emerging as climate change and other factors affect elk and their habitats (Rayl et al. 2019). Today, the expansion of CWD across elk populations is a primary concern of state wildlife agencies, as CWD is being found in new herds annually (Galloway et al. 2021). Spillover of brucellosis between elk and livestock remains a special challenge as transmission from elk to livestock continues (Kamath et al. 2016). Research to further investigate the spatial and temporal extent of disease transmission risk would inform management approaches to reduce disease spread in elk. For farmed elk, further research on disease outbreaks in confined herds is needed to broaden understanding of the risk of transmission to wild elk. Synthesizing this knowledge to develop comprehensive and systematic disease surveillance protocols would help state agencies decide when and what management actions (e.g., increased harvest, culling) to implement.

20.9.3 Climate Change

Studies that document changes in forage phenology under changing temperature and precipitation regimes are among the highest of elk research and management needs, given their cascading effects on all other reproductive phases of elk life history and potential for dramatic shifts in population distributions, including migration (Middleton et al. 2013; Rickbeil et al. 2019). Effects of climate change include those during winter, such as from diminished snowpack and more rapid snowmelt, and during summer, such as from more extended drought and higher temperatures. Similarly, research is needed to understand how altered fire regimes, facilitated by climate change, fire management, and land uses (Loehman et al. 2018; Chambers et al. 2019), affect forage phenology, dynamics, and nutrition, and subsequently affect spatial distributions and performance of elk populations. Study topics of high priority to evaluate changing climate and fire regimes include:

- Effects on herbaceous forage phenology related to timing and rate of green up and brown down, and duration of high photosynthetic activity.
- Resultant changes in timing and duration of forage biomass and quality in relation to potential mismatches with calf birth dates and their lactation needs.
- Potential cascading effects on body fat dynamics of lactating females from mismatched forage dynamics with birth dates and subsequent increase in alternate-year productivity.

- Possible shifts in population distribution from increasingly xeric habitats, often associated with public rangelands, to more mesic habitats on private lands.
- Changes in timing, routes, and predictability of migration and demographic consequences.
- Effects of altered fire regimes (intensity, scale, frequency) on forage phenology and nutritional resource dynamics in arid and semi-arid rangelands, and subsequent effects on spatial distributions and performance of elk populations.
- Restoration of desired native forages of high nutritional value in the face of increasing competition with exotic plants following wildfires in arid and semi-arid rangelands.

20.9.4 Socio-Ecological Research

Elk are one of the most widely studied wildlife species in the world, but management conflicts persist. Thus, integrated socio-ecological solutions to issues such as elk distributions on private versus public lands are required (Carter et al. 2014). All stakeholders should be at the table, including state wildlife, tribal, and public land management agencies, private landowners, the public, and local governing bodies (White and Ward 2010). Knowledge gaps exist about the social tolerance of stakeholders for elk, which could be addressed through structured, qualitative interviews and listening sessions designed by social scientists in a knowledge co-production framework. This process could elucidate why landowners do or do not desire elk on their properties and help explain apparent contradictions in the mutual desire of some for-hunter opportunity on public lands coupled with opposition to road closures. In addition, the economic value of elk has not been well-documented and most research on this topic is decades old, generally not from rangeland systems, and primarily based on consumptive use (Bolon 1994; Fried et al. 1995; Chapagain et al. 2020).

Although a broad understanding of how elk respond to management actions such as road closures or timber thinning has been gained by a wealth of published studies (Spitz et al. 2018; Wertz et al. 1996), a formal meta-analysis could help answer questions such as: how large an area must be treated to attract elk to a seasonal range and hold them there? What habitat features do elk seek on private versus public lands and how does that differ across rangeland systems? How does human disturbance interact with elk response to vegetation treatments? Finally, more adaptive management experiments employing hunting regulations, e.g., general season antlerless elk damage tags as recently piloted by Oregon Department of Fish and Wildlife (<https://myodfw.com/articles/general-season-antlerless-elk-damage-tag>) or multiple, targeted hunts (Cleveland et al. 2012; Sergeyev et al. 2022), will advance knowledge about best practices to mitigate elk depredation issues on private lands.

20.10 Summary

Human interest in elk is well documented in indigenous culture and after European settlement. With settlement came the extirpation of Eastern and Merriam's elk, the near extirpation of Tule elk, and significant reduction of Roosevelt and Rocky Mountain elk populations. Through expansive wildlife conservation and management efforts, Roosevelt and Rocky Mountain elk populations have largely recovered. Initial regulations focused on bull harvest to increase calf and cow survival, leading to burgeoning Rocky Mountain and Roosevelt elk populations across the U.S. and Canadian rangelands. With little exception, notably in New Mexico and Ontario, elk populations are at, or above objectives established by state and provincial agencies, leading to a shift in strategy toward cow harvest to curtail population growth.

As elk populations have recovered, habitat associations closely tied to rangelands have emerged, and research demonstrates the importance of seasonal (e.g., summer and winter) ranges to maximize calf recruitment and cow and bull overwinter survival (Murie 1951; Cook et al. 2013). There has also been an increased appreciation for the importance of balancing the cumulative impacts of human development, specifically roads, which can increase elk harvest rates (Polfus and Krausman 2012). Further, as the human population grows and development of historic winter ranges expands, the need for conservation easements and cooperative grazing plans has emerged as an important management strategy. The realization that human development has disrupted migratory elk behavior and altered historical habitat associations continues to be a point of conservation concern for the long-term management of elk populations.

These alternations contribute to changes in forage quality and availability, predator–prey interactions, and at times, a reduction or loss of migratory corridors that all facilitate increased human/elk conflict, specifically in rangelands near urbanized areas or areas in which hunter access is restricted (Brook 2010; Proffitt et al. 2013). To mitigate these conflicts, cooperative grazing management has been implemented (Wisdom and Thomas 1996) that can benefit both elk and livestock, thus reducing competition for forage resources. The forage allocation strategy can also lead to improved rangeland management for a variety of sympatric rangeland species of concern, such as mule deer. Still, other rangeland management challenges remain. Feral horses and burros lack sufficient predators and population control measures and can lead to deleterious impacts on rangeland resources and potential competition between ungulate species, both domestic and wild (Stoner et al. 2021).

The spatial overlap of elk, other wild ungulates, and domestic livestock may also pose disease transmission concerns. Elk transmission of brucellosis to domestic livestock has resulted in increased conflict and at times reduced support for elk conservation. In addition, the emergence of CWD and its increasing spread throughout elk populations is a rapidly growing concern across occupied elk range (Uehlinger et al. 2016).

Energy development has become an area of increasing concern in rangelands. The development of oil and gas fields and their corresponding road networks can alter elk

habitat use, potentially increasing vulnerability and possibly impacting population dynamics (Hebblewhite 2011). Further, “Green Energy” expansion of wind farms and solar energy arrays in rangelands will likely lead to additional habitat alterations and impacts on population distribution and dynamics. However, this relationship is poorly understood and proper siting guidelines and best management practices for wind and solar energy development are currently limited or lacking.

Climate change is altering the timing of spring green-up and the duration and accumulation of snow in winter, both of which impact elk recruitment and survival (Cook et al. 2004). Further, the expanse and intensity of fire in rangelands, as was evident in the unprecedented duration and longevity of fires in 2020 across the Western US, is attributable to climate change. Beyond direct habitat alterations in the immediate aftermath of these fires, invasive species, such as cheatgrass and spotted knapweed, are expanding into rangelands through habitat disturbance such as fire, further altering historical elk-forage relationships.

Given this breadth of challenges facing elk populations, additional elk conservation and management actions are warranted. The focus on connected, unaltered rangelands to preserve existing habitat associations and migratory behaviors must continue. These large, connected and intact areas help bolster elk populations against the impacts of climate change and slow energy development-induced land alterations. Given their high behavioral plasticity, elk will likely be able to adapt to these stressors if proper rangeland management and conservation efforts continue into the future (Rickbeil et al. 2019).

As elk have been and remain the focus of both indigenous cultural traditions and recreational harvest and viewing, continued support for elk conservation in rangelands is needed. Despite significant challenges such as invasive species, landscape alteration, disease emergence, and climate change, continued focus is critical for managing rangelands for multiple use and multiple species. Research and management are needed that focus on competitive interactions of elk with sympatric ungulates, emerging diseases and pathogens, interactive effects of climate change, and the socio-ecological effects of shifts in population distribution. Addressing these contemporary issues is a pressing management need and will require broad and diverse partnerships to ensure the viability of elk populations across North American rangelands into the future.

References

- Ager AA, Johnson BK, Coe PK, et al (2004) Landscape simulation of foraging by elk, mule deer, and cattle on summer range. In: Transactions, North American Wildlife and Natural Resource Conference, vol 69, pp 687–707
- Allred BW, Bestelmeyer BT, Boyd CS et al (2021) Improving Landsat predictions of rangeland fractional cover with multitask learning and uncertainty. *Methods Ecol Evol* 12:841–849
- Alt KL, Frisina MR, King FJ (1992) Coordinated management of elk and cattle, a perspective-Wall Creek Wildlife Management Area. *Rangelands* 14:12–15

- Anderson EW, Franzen DL, Melland JE (1990) Forage quality as influenced by prescribed grazing. In: Severson KE (ed) Can livestock be used as a tool to enhance wildlife habitat? RM-194. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, pp 56–70
- Aune K, Rhyan JC, Russell R et al (2012) Environmental persistence of *Brucella abortus* in the Greater Yellowstone Area. *J Wildlife Manage* 76:253–261
- Barker KJ, Mitchell MS, Proffitt KM (2019a) Native forage mediates influence of irrigated agriculture on migratory behaviour of elk. *J Anim Ecol* 88:1100–1110
- Barker KJ, Mitchell MS, Proffitt KM et al (2019b) Land management alters traditional nutritional benefits of migration for elk. *J Wildl Manage* 83:167–174
- Beck JL, Smith KT, Flinders JT et al (2013) Seasonal habitat selection by elk in north central Utah. *West N Am Naturalist* 73:442–456
- Bender LC, Hall PB (1996) *Leptospira interrogans* exposure in free-ranging elk in Washington. *J Wildl Dis* 32:121–124
- Bender LC, Spencer RD (1999) Estimating elk population size by reconstruction from harvest data and herd ratios. *Wildl Soc B* 27:636–645
- Berger J (2007) Fear, human shields and the redistribution of prey and predators in protected areas. *Biol Lett*. <https://doi.org/10.1098/rsbl.2007.0415>
- Biederbeck HH, Jackson DH, VandeBergh DJ (2016) Aerial high resolution digital imagery elk survey. Wildlife Technical Report, vol 006. Oregon Department of Fish and Wildlife, Corvallis, OR
- Blackburn JK, Van Ert M, Mullins JC et al (2014) The necrophagous fly anthrax transmission pathway: empirical and genetic evidence from wildlife epizootics. *Vector-Borne Zoonotic Dis* 14:576–583
- Bolon NA (1994) Estimates of the values of elk in the Blue Mountains of Oregon and Washington: evidence from the existing literature. General Technical Report. U.S. Forest Service, Pacific Northwest Research Station, PNW-GTR-316, Portland, Oregon, USA
- Boyce MS, Mao JS, Merrill EH et al (2003) Scale and heterogeneity in habitat selection by elk in Yellowstone National Park. *Ecoscience* 10:421–431
- Brennan A, Cross PC, Portacci K et al (2017) Shifting brucellosis risk in livestock coincides with spreading seroprevalence in elk. *PLoS ONE* 12(6):e0178780
- Brodie J, Johnson H, Mitchell M et al (2013) Relative influence of human harvest, carnivores, and weather on adult female elk survival across western North America. *J Appl Ecol* 50:295–305
- Brook RK (2010) Habitat selection by parturient elk (*Cervus elaphus*) in agricultural and forested landscapes. *Can J Zool* 88:968–976
- Brook RK, Vander Wal E, van Beest FM et al (2013) Evaluating use of cattle winter feeding areas by elk and white-tailed deer: implications for managing bovine tuberculosis transmission risk from the ground up. *Prev Vet Med* 108:137–147
- Buchanan CB, Beck JL, Bills TE et al (2014) Seasonal resource selection and distributional response by elk to development of a natural gas field. *Rangeland Ecol Manag* 67:369–379
- Bureau of Land Management (2015) Fortification creek planning area annual monitoring report 2015. Buffalo, Wyoming
- Carta T, Álvarez J, de la Lastra JP et al (2013) Wildlife and paratuberculosis: a review. *Res Vet Sci* 94:191–197
- Carter NH, Viña A, Hull V et al (2014) Coupled human and natural systems approach to wildlife research and conservation. *Ecol Soc* 19:43
- Chaikina NA, Ruckstuhl KE (2006) Native ungulates: the good, the bad, and the ugly. *Rangelands* 28:8–14
- Chambers JC, Bradley A, Brown CS et al (2014) Resilience to stress and disturbance, and resistance to *Bromus tectorum* L. invasion in the cold desert shrublands of western North America. *Ecosyst* 7:360–375
- Chambers JC, Brooks ML, Germino MJ et al (2019) Operationalizing resilience and resistance concepts to address invasive grass-fire cycles. *Front Ecol Evol* 7:185

- Chapagain BP, Poudyal NC, Warkins C (2020) A travel cost analysis of elk-viewing opportunity generated from an elk reintroduction project in Tennessee. *Hum Dimens Wildlife*. <https://doi.org/10.1080/10871209.2020.1864067>
- Chevill NF, McCullough DR, Paulson LR et al (1998) *Brucellosis in the greater Yellowstone area*. National Academies Press
- Christianson DA, Creel S (2007) A review of environmental factors affecting elk winter diets. *J Wildl Manage* 71:164–176
- Ciriacy-Wantrup SV, Bishop RC, Andersen SO (2019) Conservation of the California Tule Elk: a socioeconomic study of a survival problem. *Natural Resource Economics. Selected Papers*, pp 231–246. Routledge
- Clark PE, Krueger WC, Bryant LD et al (2000) Livestock grazing effects on forage quality of elk winter range. *J Range Manag* 53:97–105
- Clark PE, Johnson DE, Ganskopp DC et al (2017) Contrasting daily and seasonal activity and movement of sympatric elk and cattle. *Rangel Ecol Manage* 70:183–191
- Cleveland SM, Hebblewhite M, Thompson M et al (2012) Linking elk movement and resource selection to hunting pressure in a heterogeneous landscape. *Wildl Soc B* 36:658–668
- Conner MM, White GC, Freddy DJ (2001) Elk movement in response to early-season hunting in northwest Colorado. *J Wildl Manage* 926–940
- Cook JG (2002) Nutrition and food. In: Toweill D, Thomas JW (eds) *North American elk: ecology and management*. Smithsonian Institution Press, Washington, DC, pp 259–350
- Cook JG, Johnson BK, Cook RC et al (2004) Effects of summer-autumn nutrition and parturition date on reproduction and survival of elk. *Wildl Monogr* 155(1):1–61
- Cook RC, Cook JG, Vales DJ et al (2013) Regional and seasonal patterns of nutritional condition and reproduction in elk. *Wild Mon* 184:1–45
- Cooperrider AY, Bailey JA (1984) A simulation approach to forage allocation. Developing strategies for rangeland management. Westview Press, Boulder, CO, USA, pp 525–560
- Corn JL, Nettles VF (2001) Health protocol for translocation of free-ranging elk. *J Wildlife Dis* 37:413–426
- Coughenour MB (2005) Bison and elk in Yellowstone National Park—linking ecosystem, animal nutrition, and population processes. Part 3 of a Final Report to U.S. Geological Survey, Bozeman, MT
- Crane KK, Mosley JC, Mosley TK et al (2016) Elk foraging site selection on foothill and mountain rangeland in spring. *Rangeland Ecol Manage* 69:319–325
- Cross P, Ebinger MR, Patrek V et al (2010a) *Brucellosis in cattle, bison, and elk: management conflicts in a society with diverse values*. Knowing Yellowstone Taylor Trade Publishing, Lanham, Maryland, USA, pp 80–93
- Cross PC, Cole E, Dobson AP et al (2010b) Probable causes of increasing brucellosis in free-ranging elk of the Greater Yellowstone Ecosystem. *Ecol Appl* 20:278–288
- Damiran D, DelCurto T, Findholt SL et al (2019) The effects of previous grazing on the subsequent nutrient supply of ungulates grazing late-summer mixed-conifer rangelands. *Sustain Agric Res* 8. <https://doi.org/10.5539/sar.v8n4p13>
- Davies GM, Bakker JD, Dettweiler-Robinson E et al (2012) Trajectories of change in sagebrush steppe vegetation communities in relation to multiple wildfires. *Ecol Appl* 22:1562–1577
- Denryter K, Fischer K (2022) Mitigating anthropogenic barriers to facilitate distributional shifts helps reduce vulnerability of a large herbivore to climate change. *Animal Conserv*. <https://doi.org/10.1111/acv.12776>
- Dunn WC, Donnelly JP, Krausmann WJ (2002) Using thermal infrared sensing to count Elk in the Southwestern United States. *Wildl Soc B* 30:963–967
- Dzialak MR, Webb SL, Harju SM et al (2011) The spatial pattern of demographic performance as a component of sustainable landscape management and planning. *Landscape Ecol* 26:775–790
- Eacker DR, Lukacs PM, Proffitt KM et al (2017) Assessing the importance of demographic parameters for population dynamics using Bayesian integrated population modeling. *Ecol Appl* 27:1280–1293

- Edge WD, Marcum C (1991) Topography ameliorates the effects of roads and human disturbance on elk. In: *Proceedings of a symposium on elk vulnerability*. Montana State University, Bozeman, MT, pp 132–137
- Endress BA, Naylor BJ, Pekin BK et al (2016) Aboveground and belowground mammalian herbivores regulate the demography of deciduous woody species in conifer forests. *Ecosphere* 7:e01520
- Findholt SL, Johnson BK, Damiran D et al (2004) Diet composition, dry matter intake, and diet overlap of mule deer, elk, and cattle. In: *Transactions, North American wildlife and natural resources conference*, vol 69, pp 670–686
- Foreyt WJ, Hunter D, Cook JG et al (2000) Susceptibility of elk to lungworms from cattle. *J Wildl Dis* 36:729–733
- Frair JL, Merrill EH, Allen JR et al (2007) Know thy enemy: experience affects elk translocation success in risky landscapes. *J Wildl Manage* 71:541–554
- Frair JL, Merrill EH, Beyer HL et al (2008) Thresholds in landscape connectivity and mortality risks in response to growing road networks. *J Appl Ecol* 45:1504–1513
- Fried BM, Adams RM, Berrens RP et al (1995) Willingness to pay for a change in elk hunting quality. *Wildl Soc B* 23:680–686
- Frisina MR (1992) Elk habitat use within a rest-rotation grazing system. *Rangelands* 14:93–96
- Galloway NL, Monello RJ, Brimeyer D et al (2021) Supporting adaptive management with ecological forecasting: chronic wasting disease in the Jackson Elk herd. *Ecosphere* 12:e03776
- Garrouette EL, Hansen AJ, Lawrence RI (2016) Using NDVI and EVI to map spatiotemporal variation in the biomass and quality of forage for migratory elk in the Greater Yellowstone Ecosystem. *Remote Sensing* 8(404):1–25
- Geist V (2002) Adaptive Behavioral Strategies. In: Toweill DE, Thomas JW (eds) *North American elk: ecology and management*, vol 1. Smithsonian Institution Press. Washington D.C, USA, pp 389–433
- Groisman PY, Knight RW (2008) Prolonged dry episodes over the conterminous United States: New tendencies emerging during the last 40 years. *J Climate* 21:1850–1862
- Graves TA, Yarnall MJ, Johnston AN et al (2022) Eyes on the herd: quantifying ungulate density from satellite, unmanned aerial systems, and GPS collar data. *Ecol Appl* e2600
- Haggerty JH, Travis WR (2006) Out of administrative control: absentee owners, resident elk and the shifting nature of wildlife management in southwestern Montana. *Geoforum* 37:816–830
- Hebblewhite M (2011) Effects of energy development on ungulates. In: Naugle DE (ed) *Energy development and wildlife conservation in Western North America*. Island Press/Center for Resource Economics, Washington, DC, pp 71–94
- Hebblewhite M, Merrill EH, McDermid G (2008) A multi-scale test of the forage maturation hypothesis in a partially migratory ungulate population. *Ecol Monogr* 78:141–166
- Hebblewhite M, Merrill EH, Morgantini LE et al (2006) Is the migratory behavior of montane elk herds in peril? The case of Alberta's Ya Ha Tinda elk herd. *Wildlife Soc B* 34:1280–1294
- Hobbs NT, Baker DL, Bear GD et al (1996) Ungulate grazing in sagebrush grassland: mechanisms of resource competition. *Ecol Appl* 6:200–217
- Horne JS, Hurley MA, White CG et al (2019) Effects of wolf pack size and winter conditions on elk mortality. *J Wildl Manage* 83:1103–1116
- Howell JA, Brooks GC, Semenoff-Irving M et al (2002) Population dynamics of Tule Elk at point Reyes national seashore, California. *J Wildl Manage* 66:478–490
- Howerth EW, Stallknecht DE, Kirkland PD (2001) Bluetongue, epizootic hemorrhagic disease, and other orbivirus-related diseases. *Infect Dis Wild Mamm* 3:77–97
- Hughey LF, Shoemaker KT, Stewart KM et al (2021) Effects of human-altered landscapes on a reintroduced ungulate: Patterns of habitat selection at the rangeland-wildland interface. *Biol Cons* 257:109073
- Jackson HHT (1944) Big game resources of the United States. PNW-325. U.S. Dept Inter Bur Sport Fish Wildlife Res

- Johnson BK, Ager, Crim SA et al (1996) Allocating forage among wild and domestic ungulates—a new approach. In: Edge WD, Olson-Edge SL (eds) Proceedings of the sustaining rangeland ecosystems symposium, Oregon State University, Corvallis. OR, pp 166–169
- Johnson BK, Kern JW, Wisdom MJ et al (2000) Resource selection of mule deer and elk during spring. *J Wildl Manage* 64:685–697
- Jones JD, Proffitt KM, Paterson JT et al (2021) Elk responses to management hunting and hazing. *J Wildl Manag* 85:1721–1738
- Kamath PL, Foster JT, Drees KP et al (2016) Genomics reveals historic and contemporary transmission dynamics of a bacterial disease among wildlife and livestock. *Nat Comm* 7:1–10
- Keller BJ, Montgomery RA, Campa HR III et al (2015) A review of vital rates and cause-specific mortality of elk *Cervus elaphus* populations in eastern North America. *Mamm Rev* 45:146–159
- Kiesecker JM, Naugle DE (2017) Energy sprawl solutions: balancing global development and conservation. Island Press, Washington DC
- Kohl MT, Hebblewhite M, Cleveland SM et al (2012) Forage value of invasive species to the diet of Rocky Mountain elk. *Rangelands* 34:24–28
- Krausman PR, Naugle DE, Frisina MR et al (2009) Livestock grazing, wildlife habitat, and rangeland values. *Rangelands* 31:15–19
- Kuttler K (1984) Anaplasma infections in wild and domestic ruminants: a review. *J Wildl Dis* 20:12–20
- Lamont BG, Kauffman MJ, Merkle JA et al (2020) Bark beetle-affected forests provide elk only a marginal refuge from hunters. *J Wildl Manage* 84:413–424
- Lehman CP, Rumble MA, Rota CT et al (2016) Elk resource selection at parturition sites, Black Hills, South Dakota. *J Wildl Manage* 80:465–478
- Lehman CP, Rota CT, Raithel JD et al (2018) Pumas affect elk dynamics in absence of other large carnivores. *J Wild Manage* 82:344–353
- Lilenbaum W, Martins G (2014) Leptospirosis in cattle: a challenging scenario for the understanding of the epidemiology. *Transbound Emerg Dis* 61:63–68
- Loehman R, Flatley W, Holsinger L et al (2018) Can land management buffer impacts of climate changes and altered fire regimes on ecosystems of the southwestern United States? *Forests* 9:192
- Long JW, Lake FK (2018) Escaping social-ecological traps through tribal stewardship on national forest lands in the Pacific Northwest, United States of America. *Ecol Soc* 23. <https://doi.org/10.2307/26799109>
- Long RA, Bowyer RT, Porter WP et al (2014) Behavior and nutritional condition buffer a large-bodied endotherm against direct and indirect effects of climate. *Ecol Monogr* 84:513–532
- Lowrey B, Devoe J, Proffitt KM et al (2020) Hiding without cover? Defining elk security in a beetle-killed forest. *J Wildl Manage* 84:138–149
- Lubow BC, Singer FJ, Johnson TL et al (2002) Dynamics of interacting elk populations within and adjacent to Rocky Mountain National Park. *J Wildl Manage* 66:757–775
- Lukacs PM, Mitchell MS, Hebblewhite M et al (2018) Factors influencing elk recruitment across ecotypes in the Western United States. *J Wildl Manage* 82:698–710
- Maichak EJ, Scurlock BM, Rogerson JD et al (2009) Effects of management, behavior, and scavenging on risk of Brucellosis transmission in elk of western Wyoming. *J Wildl Dis* 45:398–410
- Marshall AM, Abatzoglou JT, Link TE et al (2019) Projected changes in interannual variability of peak snowpack amount and timing in the Western United States. *Geophys Res Lett* 46:8882–8892
- McCorquodale SM (1997) Cultural contexts of recreational hunting and native subsistence and ceremonial hunting: their significance for wildlife management. *Wildl Soc B* 25:568–573
- McCorquodale SM, Raedeke KJ, Taber RD (1986) Elk habitat use patterns in the shrub-steppe of Washington. *J Wildl Manage* 50:664–669
- McCorquodale SM, Wiseman R, Marcum CL (2003) Survival and harvest vulnerability of elk in the Cascade Range of Washington. *J Wildlife Manage* 67:248–257

- McCullough D (1969) The tule elk: its history, behavior, and ecology, vol 88. University of California Press, Berkeley
- Middleton AD, Kauffman MJ, McWirth DE et al (2013) Animal migration amid shifting patterns of phenology and predation: lessons from a Yellowstone elk herd. *Ecol* 94:1245–1256
- Middleton AD, Merkle JA, McWhirter DE et al (2018) Green-wave surfing increases fat gain in a migratory ungulate. *Oikos* 127:1060–1068
- Middleton AD, Sawyer H, Merkle JA et al (2019) Conserving transboundary wildlife migrations: recent insights from the greater yellowstone ecosystem. *Front Ecol Environ* 18:83–91
- Miller W (2002) Elk interactions with other ungulates. In: Toweill DE, Thomas JW (eds) North American elk: ecology and management. Smithsonian Institution Press, Washington, D.C., USA, pp 435–447
- Miller MW, Wild MA, Williams ES (1998) Epidemiology of chronic wasting disease in captive Rocky Mountain elk. *J Wildl Dis* 34:532–538
- Mitchell MS, Cooley H, Goode JA, et al (2018) Distinguishing values from science in decision making: setting harvest quotas for mountain lions in Montana. *Wildlife Soc B* 42:13–21
- Moeller AK, Lukacs PM, Horne JS (2018) Three novel methods to estimate abundance of unmarked animals using remote cameras. *Ecosphere* 9:e02331
- Monello RJ, Powers JG, Hobbs NT et al (2014) Survival and population growth of a free-ranging elk population with a long history of exposure to chronic wasting disease. *J Wildl Manage* 78:214–223
- Monello RJ, Galloway NL, Powers JG et al (2017) Pathogen-mediated selection in free-ranging elk populations infected by chronic wasting disease. *P Natl Acad Sci USA* 114:12208–12212
- Murie OJ (1930) An epizootic disease of elk. *J Mammal* 11:214–222
- Murie OJ (1951) The elk of North America. Stackpole Books
- Murray R, Downham D, Clarkson M et al (1996) Epidemiology of lameness in dairy cattle: description and analysis of foot lesions. *Vet Rec* 138:586–591
- Mysterud A, Edmunds DR (2019) A review of chronic wasting disease in North America with implications for Europe. *Eur J Wildl Res* 65:26
- National Academies of Sciences, Engineering, and Medicine [NASEM] (2020) Revisiting brucellosis in the greater Yellowstone area. National Academies Press
- Naylor LM, Wisdom MJ, Anthony RG (2009) Behavioral responses of North American elk to recreational activity. *J Wildl Manag* 37:328–338
- Nichols RV, Åkesson M, Kjellander P (2016) Diet assessment based on rumen contents: a comparison between DNA metabarcoding and macroscopy. *PLoS ONE* 11:e0157977
- O'Neil S, Bump J (2014) Modeling habitat potential for elk expansion in Michigan, USA. *Wildl Bio in Pract* 10:111–131
- Olsen S (2010) Brucellosis in the United States: role and significance of wildlife reservoirs. *Vaccine* 28:F73–F76
- Phillips GE, Alldredge AW (2000) Reproductive success of elk following disturbance by humans during calving season. *J Wildl Manage* 64:521–530
- Polfus JL, Krausman PR (2012) Impacts of residential development on ungulates in the Rocky Mountain West. *Wildl Soc B* 36:647–657
- Proffitt KM, Grigg JL, Garrott RA et al (2010) Changes in elk resource selection and distributions associated with a late-season elk hunt. *J Wildl Manage* 74:210–218
- Proffitt KM, Gude JA, Hamlin KL et al (2013) Effects of hunter access and habitat security on elk habitat selection in landscapes with a public and private land matrix. *J Wildl Manage* 77:514–524
- Proffitt KM, DeVoe J, Barker K et al (2019) A century of changing fire management alters ungulate forage in a wildfire-dominated landscape. *For Int J For Res* 92:523–537
- Proffitt KM, Garrott R, Gude JA et al (2020) Integrated carnivore-ungulate management: a case study in west-central Montana. *Wildl Monogr* 206:1–28
- Prokopenko CM, Boyce MS, Avgar T (2017) Characterizing wildlife behavioural responses to roads using integrated step selection analysis. *J Appl Ecol* 54:470–479

- Raithel JD, Kauffman MJ, Pletscher DH (2007) Impact of spatial and temporal variation in calf survival on the growth of elk populations. *J Wildl Manage* 71:795–803
- Rayl ND, Proffitt KM, Almberg ES et al (2019) Modeling elk-to-livestock transmission risk to predict hotspots of brucellosis spillover. *J Wildl Manage* 83:817–829
- Rhyan J, Saari D (1995) A comparative study of the histopathologic features of bovine tuberculosis in cattle, fallow deer (*Dama dama*), sika deer (*Cervus nippon*), and red deer and elk (*Cervus elaphus*). *Vet Pathol* 32:215–220
- Rhyan JC, Nol P, Quance C et al (2013) Transmission of brucellosis from elk to cattle and bison, Greater Yellowstone Area, USA, 2002–2012. *Emerg Inf Dis* 19:1992
- Rickbeil GJ, Merkle JA, Anderson G et al (2019) Plasticity in elk migration timing is a response to changing environmental conditions. *Glob Change Biol* 25:2368–2381
- Riggs RA, Keane RE, Cimon N et al (2015) Biomass and fire dynamics in a temperate forest-grassland mosaic: Integrating multi-species herbivory, climate, and fire with the FireBGCv2/GrazeBGC system. *Ecol Model* 296:57–78
- Rhodes AC, Larsen RT, Clair SBS (2018) Differential effects of cattle, mule deer, and elk herbivory on aspen forest regeneration and recruitment. *Forest Ecol Manag* 422:273–280
- Rowland MM, Alldredge AW, Ellis JE et al (1983) Comparative winter diets of elk in New Mexico. *J Wildl Manage* 47:924–932
- Rowland M, White G, Karlen E (1984) Use of pellet-group plots to measure trends in deer and elk populations. *Wildl Soc B* 12:147–155
- Rowland MM, Wisdom MJ, Johnson BK et al (2000) Elk distribution and modeling in relation to roads. *J Wildl Manage* 64:672–684
- Rowland MM, Wisdom MJ, Nielson RM et al (2018) Modeling elk nutrition and habitat use in western Oregon and Washington. *Wildl Monogr* 199:1–102
- Ruder MG, Lysyk TJ, Stallknecht DE et al (2015) Transmission and epidemiology of bluetongue and epizootic hemorrhagic disease in North America: current perspectives, research gaps, and future directions. *Vector-Borne Zoonot* 15:348–363
- Samuel MD, Garton EO, Schlegel MW et al (1987) Visibility Bias during Aerial Surveys of Elk in Northcentral Idaho. *J Wildl Manage* 51:622–630
- Samuel W, Welch D, Smith B (1991) Ectoparasites from elk (*Cervus elaphus nelsoni*) from Wyoming. *J Wildl Dis* 27:446–451
- Sargeant GA, Oehler MW Sr (2007) Dynamics of newly established elk populations. *J Wildl Manage* 71:1141–1148
- Sawyer H, Nielson RM, Lindzey FG et al (2007) Habitat selection of Rocky Mountain elk in a nonforested environment. *J Wildl Manage* 71:868–874
- Scasta JD, Beck JL, Angwin CJ (2016) Meta-analysis of diet composition and potential conflict of wild horses with livestock and wild ungulates on western rangelands of North America. *Rangeland Ecol Manage* 69:310–318
- Sergeyev M, McMillan BR, Hall LK et al (2022) Reducing the refuge effect: using private-land hunting to mitigate issues with hunter access. *J Wildl Manage* 86:e22148
- Shively KJ, Alldredge AW, Phillips GE (2005) Elk reproductive response to removal of calving season disturbance by humans. *J Wildl Manage* 69:1073–1080
- Skovlin JM, Zager P, Johnson PK (2002) Elk habitat selection and evaluation. In: Toweill DE, Thomas JW (eds) *North American elk: ecology and management*. Smithsonian Institution Press, Washington DC, p 531–556
- Soulard CE (2006) Land cover trends of the central basin and range ecoregion. U.S. Geological Survey, Reston, Virginia
- Spitz DB, Clark DA, Wisdom MJ et al (2018) Fire history influences large-herbivore behavior at circadian, seasonal, and successional scales. *Ecol Appl* 28:2082–2091
- Stalling DH, Wolfe GJ, Crockett DK (2002) Regulating the hunt. *North American elk: ecology and management*. Smithsonian Institution Press, London, U.K., pp 749–791
- Stewart KM, Bowyer RT, Kie JG et al (2002) Temporospatial distributions of elk, mule deer, and cattle: resource partitioning and competitive displacement. *J Mammal* 83:229–244

- Stoner DC, Anderson MT, Schroeder CA et al (2021) Distribution of competition potential between native ungulates and free-roaming equids on western rangelands. *J Wildl Manage* 85:1062–1073
- Thompson R (2008) The taxonomy, phylogeny and transmission of *Echinococcus*. *Exp Parasitol* 119:439–446
- Thompson MJ, Henderson RE (1998) Elk habituation as a credibility challenge for wildlife professionals. *Wildl Soc B* 26:477–483
- Thorne E, Herriges Jr JD, Reese AD (1991) A Bovine brucellosis in elk: conflicts in the greater Yellowstone area. In: *Proceedings of the elk vulnerability symposium*, Bozeman, Montana, pp 296–291
- Tolleson D, Halstead L, Howery L et al (2012) The effects of a rotational grazing system on elk diets in Arizona piñon–juniper rangeland. *Rangelands* 34:19–25
- Torstenson WLF, Mosley JC, Brewer TK et al (2006) Elk, mule deer, and cattle foraging relationships on foothill and mountain rangeland. *Rangeland Ecol Manage* 59:80–87
- Toweill DE, Thomas JW (2002) *North American Elk: Ecology and Management*. Smithsonian Institution Press, Washington and London
- Tucker DG, Gardner ES, Wakeling BF (2004) Elk habitat use in relation to residential development in the Hualapai Mountains, Arizona. In: Van Riper C, Cole KL (eds) *The Colorado Plateau: cultural, biological, and physical research*. University of Arizona Press, Tucson, AZ, pp 89–96
- Turnbull PCB (2008) *Anthrax in humans and animals*. World Health Organization
- Uehlinger F, Johnston A, Bollinger T et al (2016) Systematic review of management strategies to control chronic wasting disease in wild deer populations in North America. *BMC Vet Res* 12:1–16
- Unsworth JW, Kuck L, Scott MD et al (1993) Elk mortality in the Clearwater drainage of northcentral Idaho. *J Wildl Manage* 57:495–502
- Vavra M, Sheehy DP (1996) Improving elk habitat characteristics with livestock grazing. *Rangelands* 18:182–185
- Vieira ME, Conner MM, White GC et al (2003) Effects of archery hunter numbers and opening dates on elk movement. *J Wildl Manage* 67:717–728
- Wait S, McNally H (2004) Selection of habitats by wintering elk in a rapidly subdividing area of La Plata County, Colorado. In: *Proceedings of the fourth international symposium on urban wildlife conservation*. University of Arizona, Tucson, Arizona, USA, pp 200–209
- Walter WD, Lavelle MJ, Fischer JW et al (2010) Management of damage by elk (*Cervus elaphus*) in North America: a review. *Wildl Res* 37:630–646
- Watt LA (2015) The continuously managed wild: Tule Elk at point Reyes national seashore. *J Int Wildl Law Pol* 18:289–308
- Wertz TL, Blumton A, Erickson LE et al (1996) Strategies to keep wildlife where you want them - do they work? INT-GTR-343 In: Evans KE (ed) *Sharing common ground on western rangelands: Proceedings of a livestock/big game symposium*. U.S. Forest Service, Intermountain Research Station, Ogden, UT, pp 70–72
- White PCL, Ward AI (2010) Interdisciplinary approaches for the management of existing and emerging human–wildlife conflicts. *Wildl Res* 37:623–629
- Williams E (2005) Chronic wasting disease. *Vet Pathol* 42:530–549
- Williams E, Young S (1980) Chronic wasting disease of captive mule deer: a spongiform encephalopathy. *J Wildl Dis* 16:89–98
- Williams ES, Snyder SP, Martin KL (1983) Experimental infection of some North American wild ruminants and domestic sheep with *Mycobacterium paratuberculosis*: clinical and bacteriological findings. *J Wildl Dis* 19:185–191
- Williams ES, Miller MW, Kreeger TJ et al (2002) Chronic wasting disease of deer and elk: a review with recommendations for management. *J Wildl Manage* 66:551–563
- Williams CL, Lundrigan B, Rhodes OE Jr (2004) Microsatellite DNA variation in tule elk. *J Wildl Manage* 68:109–119
- Wisdom MJ, Thomas JW (1996) Elk. In: Krausman PR (ed) *Rangeland wildlife*. Society for Range Management, Denver, CO, pp 157–181

- Wisdom MJ, Ager AA, Preisler HK et al (2004) Effects of off-road recreation on mule deer and elk. In: Transactions of the 69th North American wildlife and natural resources conference 2004, pp 531–550
- Wisdom MJ, Vavra M, Boyd JM et al (2006) Understanding ungulate herbivory—episodic disturbance effects on vegetation dynamics: knowledge gaps and management needs. *Wildl Soc B* 34:283–292
- Wisdom MJ, Preisler HK, Naylor LM et al (2018) Elk responses to trail-baised recreation on public forests. *For Ecol Manage* 411:223–233
- Witczuk J, Pagacz S, Zmarz A (2018) Exploring the feasibility of unmanned aerial vehicles and thermal imaging for ungulate surveys in forests - preliminary results. *Int J Remote Sens* 39:5503–5520
- Wydeven AP, Dahlgren RB (1985) Ungulate habitat relationships in Wind Cave National Park. *J Wildl Manage* 49:805–813
- Zaugg JL, Goff WL, Foreyt W et al (1996) Susceptibility of elk (*Cervus elaphus*) to experimental infection with *Anaplasma marginale* and *A. ovis*. *J Wildl Dis* 32:62–66

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