Fire Effects Information System (FEIS)

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Cervus elaphus

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INTRODUCTORY

Elk in the East Fork of the Bitterroot River, Montana, during August 2000.
Photo courtesy of John McColgan, Alaska Fire Service, Bureau of Land Management.

AUTHORSHIP AND CITATION:
Innes, Robin J. 2011. Cervus elaphus. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: www.fs.fed.us/database/feis/mammal/ceel/all.html [2020, March 13].

FEIS ABBREVIATION:
CEEL

COMMON NAMES:
elk
wapiti

TAXONOMY:

The scientific name of elk is *Cervus elaphus* Linnaeus (Cervidae) [210,342]. Twenty-two subspecies of elk are recognized globally, 4 of which are found in North America:

Cervus elaphus manitobensis Millais, Manitoban elk
Cervus elaphus nannodes Merriam, tule elk
Cervus elaphus nelsoni Bailey, Rocky Mountain elk
Cervus elaphus roosevelti Merriam, Roosevelt elk [210]

Subspecies are distinguished by body size, pelage color, skull form and dentition, size and shape of antlers, behavior, and geographical distribution [95,210,221]. However, the distinction of North American subspecies has been brought into question by genetic analyses. Meredith and others [198] found that Roosevelt, tule, and Rocky Mountain elk were genetically differentiated enough to warrant subspecies status, whereas Polziehn and others [227] found variation in mitochondrial DNA that supported the recognition of Roosevelt elk and tule elk as distinct subspecies, but concluded that Rocky Mountain elk and Manitoban elk should be combined. Cronin [69] found no variation in mitochondrial DNA among Manitoban, Rocky Mountain, and tule elk populations. Translocations have led to intermixing of subspecies in some areas [95,210,211], and subspecies likely interbreed where they coexist [198]. See O'Gara [210] and Geist [95] for more information about subspecies distinctions.

This review synthesizes information about elk at the species level.

SYNONYMS:
Cervus canadensis Erxleben [20,95]

ORDER:
Artiodactyla

CLASS:
Mammal

DISTRIBUTION AND OCCURRENCE

SPECIES: Cervus elaphus

- GENERAL DISTRIBUTION
- PLANT COMMUNITIES

GENERAL DISTRIBUTION:
Elk are native to North America [211]. NatureServe provides a distributional map of elk.

Elk occur in the following states and provinces (as of 2011) [205]:
United States: AR, AZ, CA, CO, ID, KS, KY, MI, MN, MT, NC, ND, NE, NM, NN, NV, OR, PA, SD, TX, UT, WA, WY
Canada: AB, BC, MB, NT, ON, SK, YT

Historically, elk occurred from northern British Columbia east to New York, south to South Carolina, and west to southern California, with disjunct populations likely extending south into Mexico [211]. Elk were extirpated from large parts of their historic range in North America by the late 1800s and early 1900s (see Status and threats) [210,211]. In the 1900s, elk were reintroduced in parts of their native range where they had been extirpated [211] and introduced in some areas outside of their known historical range in Arizona [262] and Alaska [210]. As of this writing (2011), most elk populations occur in the West, from Vancouver Island east to southern Saskatchewan, south to Texas and west to California. Disjunct populations occur in the East. Outside of North America, elk occur in Europe, Asia, and northern Africa [210].

PLANT COMMUNITIES:
Elk are "habitat generalists" and occur in a variety of habitats including grasslands, wetlands, shrublands, and forests in various stages of succession. Elk occur in communities ranging from prairie and sagebrush (*Artemisia* spp.) steppe to wet grasslands and coniferous rainforests, and from valley and riparian communities to subalpine and alpine meadows [88,95,154,184,221,231,258,275,328]. One of the only elk herds to use desert habitats winters in the breaks and sand dunes of the Little Colorado and Red deserts in southwestern Wyoming [175,210]. The few habitats apparently unoccupied by elk in North America historically were the western deserts, the humid ecosystems of the Gulf Coast states, and the large expanses of boreal forest and tundra in the northern circumpolar region [211,275].

Pacific Northwest and California: In the Pacific Northwest, elk habitats include coastal coniferous rainforests, coastal prairie, mixed-conifer forest, riparian hardwood forests and shrublands, oak (*Quercus* spp.) woodlands, sagebrush steppe, and grasslands. On the Olympic Peninsula, Washington, elk occurred in riparian habitats, including red alder (*Alnus rubra*) and red alder-willow (*Salix* spp.) communities on active floodplains and seral Sitka spruce-black cottonwood (*Picea sitchensis-Populus trichocarpa*) communities on alluvial terraces. Elk also occurred in old-growth (>200 years old) bottomland Sitka spruce-western hemlock (*Tsuga heterophylla*) forests and 5- to 15-year-old clearcuts in these habitats [107,124,136]. On the eastern slope of the Washington Cascade Range, elk occurred in wet meadows, Oregon white oak (*Quercus garryana*) woodland, and Oregon white oak-ponderosa pine (*Pinus ponderosa*) stands at low elevations; mixed-conifer forest of ponderosa pine, Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), western larch (*Larix occidentalis*), and western hemlock at mid-elevations; and forests of Douglas-fir, subalpine fir (*Abies lasiocarpa*), Pacific silver fir (*Abies amabilis*), mountain hemlock (*Tsuga mertensiana*), alpine larch (*Larix lyallii*), lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), or western redcedar (*Thuja plicata*) at high elevations [34,193,303]. In the Mount St Helens area, Washington, after the eruption of the volcano, elk selected early-successional fireweed (*Chamerion angustifolium*) communities and seeps in summer [200]. Elk occurred in big sagebrush (*Artemisia tridentata*) steppe in south-central Washington [195]. In northeastern Oregon, at the Starkey Experimental Forest and Range, elk occurred in mesic grand fir forest, xeric ponderosa pine forest, xeric onespike oatgrass-Idaho gumweed grassland (*Danthonia unispicata-Grindelia nana*), and 6- to 10-year-old logged forests [290]. In Prairie Creek Redwoods State Park, California, elk occurred in coastal redtop-slough sedge (*Agrostis gigantea-Carex obnupta*) prairie, Sitka spruce and redwood (*Sequoia sempervirens*) forests, and riparian hardwood forests and shrublands with dense stands of red alder, salmonberry (*Rubus spectabilis*), thimbleberry (*Rubus parviflorus*) and bigleaf maple (*Acer macrophyllum*) [91,109].

Rocky Mountains: In the Rocky Mountains, elk habitats include mixed-conifer forests, quaking aspen (*Populus tremuloides*) forests, grasslands, alpine meadows, stream valley shrublands, and floodplain riparian hardwood forest communities. In the Tuchodi River area of northeastern British Columbia, elk occurred in black spruce (*Picea mariana*), white spruce (*Abies glauca*), white spruce-willow, balsam poplar (*Populus balsamifera*)-quaking aspen-lodgepole pine, open balsam poplar-quaking aspen, and 6- to 20-year-old quaking aspen-balsam poplar/willow-rose (*Rosa* spp.) communities, as well as shrublands and grasslands [219]. On Alberta's eastern slope, elk occurred in alpine rough fescue-Parry's oatgrass (*Festuca altaica-Danthonia parryi*) grassland, willow bottomland, prairie Junegrass-plains reedgrass (*Koeleria macrantha-Calamagrostis montanensis*) grassland, quaking aspen groveland, white spruce-quaking aspen-lodgepole pine forest, and Engelmann spruce-subalpine fir forests with huckleberry (*Gaylussacia* spp.), mountain heather (*Cassiope* spp.), and willow understories [17]. In northern Idaho, elk occurred in Douglas-fir/mallow ninebark (*Physocarpus malvaceus*) and western redcedar/Oregon boxwood (*Pachistima myrsinites*) communities and in seral shrub fields of redstem ceanothus (*Ceanothus sanguineus*), Rocky mountain maple (*Acer glabrum*), scouler willow (*Salix scouleriana*), and serviceberry (*Amelanchier* spp.) [13,169]. In Glacier National Park, Montana, elk occurred in alpine rough fescue-Idaho fescue-bluebunch wheatgrass-timber oatgrass (*Festuca idahoensis-Pseudoroegneria spicata-Danthonia intermedia*) grasslands, big sagebrush/Idaho fescue grasslands, Engelmann spruce-white spruce forests, black cottonwood-sandbar willow (*Salix interior*) forests, and lodgepole pine/alpine rough fescue-western wheatgrass (*Pascopyrum smithii*) savannas in river floodplains. In uplands, elk occurred in quaking aspen, lodgepole pine-subalpine fir, and Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) forests, wet meadows, and Drummond's willow-sageleaf willow/beaked sedge-Nebraska sedge (*Salix drummondiana-Salix candida*/*Carex rostrata-Carex nebrascensis*) shrublands [265,272]. In the Bob Marshall Wilderness, Montana, elk occurred in bluebunch wheatgrass-Idaho fescue-shrubby cinquefoil (*Potentilla fruticosa*) grasslands; lodgepole pine-Douglas-fir/pinegrass (*Calamagrostis rubescens*) forests; closed-canopy Engelmann spruce-subalpine fir-whitebark pine (*Pinus albicaulis*) forests; burned, open-canopy Engelmann spruce-subalpine fir/beargrass-grouse whortleberry (*Xerophyllum tenax-Vaccinium scoparium*) forests; and 40- to 50-year-old burned subalpine barrens dominated by forbs, grasses, and sedges (*Carex* spp.) [226]. In Rocky Mountain National Park, Colorado, elk fed in subalpine willow parks, Engelmann spruce-subalpine fir/willow krummholz, and alpine habitats during summer [19].

Northern Great Plains and Prairie Provinces: In the northern Great Plains and Prairie Provinces, elk habitats include quaking aspen parklands, shrublands, and mixed hardwood-conifer and conifer forests. Elk in Custer State Park, South Dakota, occurred in ponderosa pine forests and in burned grasslands dominated by buffalo grass (*Buchloe dactyloides*), bluegrass (*Poa* spp.), grama (*Bouteloua* spp.) and western wheatgrass [82]. In winter in Riding Mountain National Park, Manitoba, elk occurred in grasslands, shrublands, burns, bogs, and quaking aspen-white spruce, white spruce, and jack pine (*Pinus banksiana*) forests [251].

Southwest: In the Southwest, elk habitats include shrublands, pinyon-juniper (*Pinus* spp.-*Juniperus* spp.) woodlands, ponderosa pine and Douglas-fir forests, stream valley shrublands, and floodplain riparian hardwood forest communities. In Arizona and New Mexico, elk primarily used the ecotone between pinyon-juniper woodlands and ponderosa pine forests within the Great Basin conifer woodlands biotic province as winter range and montane mixed-conifer forests, subalpine spruce-fir (*Picea* spp.-*Abies* spp.) forests, and alpine "tundra" as summer range [262]. On the Uinta North Slope region of Summit County, Utah, elk occurred in true mountain-mahogany (*Cercocarpus montanus*) communities [315]. In the Trans-Pecos region of Texas, elk selected Pinchot's juniper (*Junipers pinchotii*) woodland with lechuguilla (*Agave lechuguilla*), common sotol (*Dasylirion wheeleri*), resinbush (*Viguiera stenoloba*), and tarbush (*Flourensia cernua*) in the understory; riparian Coulter's brickelbush-honey mesquite-littleleaf sumac (*Brickellia coulteri-Prosopis glandulosa-Rhus microphylla*) woodland, and Mexican pinyon (*Pinus cembroides*)-gray oak (*Quercus grisea*)-Pinchot's juniper woodland year-round [349]. At the Cimarron National Grassland in southwestern Kansas, elk occurred in riparian plains cottonwood (*Populus deltoides* subsp. *monilifera*) and saltcedar (*Tamarix ramosissima*) communities and in adjacent sand sagebrush (*Artemisia filifolia*) prairie [31].

BIOLOGICAL DATA AND HABITAT REQUIREMENTS

SPECIES: Cervus elaphus

- BIOLOGICAL DATA
- PREFERRED HABITAT
- MANAGEMENT CONSIDERATIONS

BIOLOGICAL DATA:
Numerous reviews describing the biology of elk are available and cited frequently in this review. These include the following sources: [49,95,156,165,183,221,222,296,305,344,346]. Among these sources, this review relies most heavily on *North American Elk: Ecology and Management* (compiled and edited by Toweill and Thomas [305]), particularly the following chapters: [58,61,96,128,131,184,210,211,230,275,284,302,306]. This review does not include studies of elk outside North America. It includes information for many aspects of elk life history but focuses on those most relevant to fire.

- **Life history**
- **Diet**

Life history:

- Physical description
- Courtship and mating
- Reproduction and development
- Social behavior
- Home range and movements
- Life span and survival

Physical description: The elk is the second largest member of the deer family (Cervidae) in North America [344]. Elk vary greatly in body size depending upon latitude, habitat, and nutrition [95,210,221]. Adult female elk (cows) weigh about 80% of adult male (bull) weight [221]. Bulls weigh 778 pounds (353 kg) and cows weigh 606 pounds (265 kg) on average [210]. See Growth for more information.

Courtship and mating: Hudson and Haigh [128] described elk as polygynous, whereas other reviewers described them as polygamous [221,344]. The rut or peak breeding season may begin as early as mid-August and end as late as mid-November [230]. The rut typically lasts 10 to 12 weeks [91]. The interval between estrous periods ranges from 19 to 25 days. True estrus lasts <24 hours [128,230].

During the rut, mature males seek out female groups and gather harems of females [344]. Generally, the male with the largest antlers—the oldest and largest bull—is dominant and mates most often [128]. The dominant male generally restricts breeding opportunities of other sexually mature males by preventing them access to cows in estrus [230]. Adult bulls tolerate calves and may tolerate yearling (1.5-year-old) bulls in harems, although older bulls are not tolerated [221]. Cows in estrus exhibit a preference for older bulls and may not allow mounting by yearlings if older bulls are present. However, in the absence of older bulls, yearling bulls may breed. Yearling bulls are physiologically capable of breeding (see Growth), but they are sexually active about 1 month later than older bulls [230].

Bulls with and without harems defend rutting areas [221]. Cohesion and size of harems is determined largely by the extent to which a male can defend a female group from other males [344]. Harem sizes decreased as bull:cow ratios increased in Michigan and Washington, presumably because bulls are less able to defend a harem in the presence of increasing numbers of competitor bulls due to the increased energetic demands of holding large harems [27]. Large, mixed age and gender rutting groups may form in open terrain where population densities and bull:cow ratios are high, such as in the northern Yellowstone elk herd [221]. Young bulls increase rutting activity at the end of the rut after waning of rutting activity by older bulls, at which time they may be allowed to join cow herds and breed cows that did not conceive during their earlier estrus cycles [91,230]. When bulls ≥5 years old are the primary breeders, the rut may occur earlier and last a shorter time than when yearling bulls are the primary breeders [221]. See Reproduction and development for more information.

Reproduction and development: Gestation ranges from 244 to 265 days [128,221,230,344]. Most calving occurs from late May to early June [128,230,296,344]. Male calves tend to be born earlier than female calves; this might be due to the slightly greater proportion of male calves born to first-time mothers [127].

Conception dates in late summer and fall and thus timing of parturition in late spring and early summer are related to cow nutritional condition, cow lactation status, and bull age [230]. In general, cows in good physical condition conceive earlier than those in poor condition [312]. Because lactating cows are generally in relatively poor condition, they often conceive later than nonlactating cows [208,312]. In Oregon, cows with the highest kidney fat indices (indicating good physical condition) conceived on average 19 days earlier than cows with the lowest kidney fat indices [312].

Conception dates tend to be later and less synchronous in herds where yearling males do most of the breeding [221,230]. In captive elk populations in southwestern Oregon, births of yearling-sired calves peaked in early July, whereas calves sired by 2.5- and 3.5-year-old bulls were born in late May and early June [120]. In an experimental, semi-confined population at the Starkey Experimental Forest and Range in northeastern Oregon, conception dates of elk cows bred by 4- and 5-year-old bulls were on average 16 days earlier than conception dates of cows bred by yearlings [208]. Bull age also alters the length of the rut [230]. When 5-year-old bulls were the primary breeders at the Starkey Experimental Forest and Range, the rut was 41 days, whereas the rut lasted 71 days when yearling bulls were the primary breeders [208]. Late conception dates resulting from a delayed or lengthened rutting season may reduce calf survival because late-born calves may not have enough time to grow adequately and build fat reserves before forage becomes limited and environmental conditions worsen in winter [221,230]. For more information, see Calf survival.

As parturition approaches, pregnant females may move away from the herd to calving areas. Cows with calves may not rejoin their herd for up to a month. Newborn calves hide and may be separated from their mothers for long periods. Calves are weaned in the fall when their mother breeds again [128]. Young remain with their mother until the following spring, when their mother drives them away several weeks before giving birth [91,96,230]. For more information, see Dispersal.

Growth: Elk calves weigh 33 to 49 pounds (15-22 kg) at birth; male calves are slightly heavier than females [127,128,221]. Average weight gain of captive elk for the first 4 to 5 months ranges from 1.5 to 2.0 pounds (0.7-0.9 kg)/day [58]. Calves weigh about 265 pounds (120 kg) when weaned. In spring, elk calves in good condition weigh about 310 to 350 pounds (140-160 kg). During the rut the following fall, females weigh approximately 485 pounds (220 kg) and males weigh approximately 550 pounds (250 kg) [128]. Females reach peak body size at 3 to 7 years old and males reach peak body size at 5 to 9 years old [221]. In general, antler size peaks at 12 years old [128].

Bulls in good condition shed their antlers earlier than bulls in poor condition. Thus, antlers may be shed earlier after mild winters than after severe winters [221]. Old bulls shed their antlers earlier than young bulls [128,221]. For large, old (≥5 years old) bulls in good condition ("prime" bulls), velvet is shed in late July or early August, and antlers are cast as early as mid-January to late February. For 2-year-old bulls, velvet is shed in late August, and antlers are cast from March to mid-April [128].

Pregnancy and twinning rates: Elk produce one calf annually; twinning is rare (<1% of pregnancies) [127,128,221,230,344]. Males and females can first breed as yearlings, but the majority of yearlings in the wild do not breed [58,128,221].

Pregnancy rates of yearlings range from 0 to 81% [221], while pregnancy rates of older cows are higher: for 2.5-year-olds, 33% to 92%, and for 3.5- to 7.5-year-olds (“prime” cows), 49% to 99%. Calf production typically declines in cows >7.5 years old. Prime cows are the major contributors to the productivity of elk populations [230]. The elk population increased 35% in the blast zone the first 3 years following the eruption of Mount St Helens. Both immigration and high pregnancy rates contributed to the high population growth. Pregnancy rates were 31% for yearlings, 33% to 50% for 2-year-olds, and 87% for older cows [200]. A newly established, increasing population in Theodore Roosevelt National Park, North Dakota, increased 11 times its size in 19 years; pregnancy rates during that time averaged 54% for 1.5- to 2.5-year-olds and 91% for prime cows [255].

According to a review, reproduction declines in cows more than 14 years old, although about 50% of 15- to 21-year-old cows may reproduce [230]. Reproduction had not declined in elk up to 16 years old in the upper Madison River drainage in western Yellowstone National Park [94], whereas >9-year-old elk exhibited reproductive declines in northeastern Oregon [290].

The age at which a cow elk first breeds is related to her body weight and physical condition [58,230,344]. According to a review, about half of cow elk come into estrus at 70% of mature weight [128]. Captive elk cows in Alberta weighing <420 pounds (190 kg) during the rut generally did not breed, and cows weighing <510 pounds (230 kg) had a reduced probability of breeding [127]. In the northern Yellowstone herd, no yearling elk weighing <335 pounds (152 kg) became pregnant, whereas 10% of yearlings weighing 335 to 359 pounds (152-163 kg) and 25% of yearlings weighing 359 to 373 pounds (163-169 kg) became pregnant (Greer 1968 cited in [230]). Most 2.5-year-old females are large enough to breed [344] although, in the Oregon Coast Range, many cows failed to breed until 3.5 or 4.5 years old apparently because of poor physical condition (Stussy 1993 cited in [344]).

Nutrition during the previous year may affect yearling breeding rates. In 2 populations in Utah, yearling cows were less likely to breed after a severe winter (0%) than after a mild winter (11-66%). Excessive winter weight loss apparently precluded yearlings from breeding the following fall because a greater proportion of nutrition in summer was allocated to recovery than to growth [105].

Reproductive success in cows is influenced largely by physical condition. During an 8-year study at Starkey Experimental Forest and Range, pregnancy rates of females were positively related to kidney fat index (P=0.04) [209]. In the northern Yellowstone elk herd, as body fat in mid-winter declined, the probability of pregnancy declined. Lactating cows, often in poorer physical condition than nonlactating cows [60], tend to have lower pregnancy rates than nonlactating cows, especially after severe winters or on poor quality rangelands [58,221,230]. Studies in Oregon found pregnancy rates of 48% to 82% for lactating cows and 75% to 100% for nonlactating cows ([312], Harper 1971 cited in [230]). At Starkey Experimental Forest and Range, lactating cows in poor physical condition (indicated by low rump fat) were less likely to become pregnant than lactating cows in good physical condition [290].

Females bred by yearling bulls tend to have lower pregnancy rates than females bred by prime bulls. At Starkey Experimental Forest and Range, pregnancy rates of elk cows ranged from 89% when yearling bulls were the primary breeders to 97% when 5-year-old bulls were the primary breeders, but the difference was not significant [208]. In captivity, pregnancy rates were 86% and 93% for cows bred by yearling bulls and 3.5-year-old bulls, respectively (Follis 1972 cited in [230]).

Population density may also influence pregnancy rates in elk. At Starkey Experimental Forest and Range, the proportion of pregnant females was negatively related to population density across 4 years (r_s= -0.687, P=0.030). Rump fat thickness of females was negatively correlated with population density (r_s= -0.855, P=0.003) but not to annual precipitation or temperature (degree/days), suggesting that pregnancy rates in elk were primarily density dependent. The authors concluded that increased population density may result in lower fat reserves and pregnancy rates and thus possibly lower survivorship of young [290].

Sex ratios: Sex ratios of elk at birth are generally close to parity or skewed towards males [221,230]. In captive elk, mothers in good physical condition produced more males than females (P<0.01), whereas mothers in poor condition produced equal numbers of each gender [144]. Similarly, throughout Oregon, cows in poor condition (low kidney fat index) were more likely to produce daughters than cows in good condition [152]. At the National Elk Refuge, Wyoming, elk were supplementally fed for about 3 months during winter for 4 years. In years when supplemental feeding began early, more male calves were born in spring (R^2= -0.70, P=0.02). Either survival of male fetuses was favored by nutritional supplementation early in gestation, or survival of female fetuses was reduced by winter stress on gravid females [280]. In contrast, when the northern Yellowstone elk herd in southwestern Montana was at low density, beneficial late-spring growing conditions improved maternal physical condition and correlated with production of more female calves [71].

Adult sex ratios may be highly skewed towards females, particularly in hunted populations. According to Peek [221], adult sex ratios in elk populations may vary from as low as 4 bulls:100 cows in heavily hunted populations to >40 bulls:100 cows in "relatively unexploited" populations with quality forage. Bull:cow ratios may decline as population density increases. In Yellowstone National Park, the bull:cow ratio declined from 62:100 when the population consisted of 5,000 elk to 47:100 4 years later when the population had increased to 12,000 elk. Higher dispersal rates among males than females may have contributed to high male mortality (Houston 1982 cited in [230]). See Hunting for more information on this topic.

Pregnancy rates may be lower in elk herds with few prime bulls (<10 prime bulls:100 cows) [230]. However, based on elk population data from 20 years in Colorado, White and others [338] concluded that increasing adult bull:cow ratios would have little impact on population productivity.

Social behavior: Elk are gregarious and occur in groups (herds) throughout the year [221]. Aggregations are not consistently composed of the same individuals (e.g., [29,151,186]). Cow groups are more stable and cohesive than bull groups [91]. In both cow and bull groups, the oldest animals tend to be dominant [91].

Habitat, presence of predators and hunters, availability of forage, population density, breeding activities, and weather, particularly snow conditions, influence elk aggregation patterns [29,221].

Groups vary in size and composition throughout the year [221]. The largest groups often form in winter or early spring, when large herds composed of cows, calves, and bulls congregate on winter rangelands [29,75,221]. In spring, migratory elk populations move en masse at first, but as they reach intermediate elevations, they tend to disperse in small groups over large areas [131]. Migrating elk groups with pregnant cows halt temporarily for calving in late May and early June [131,221]. Pregnant females leave the herd a few hours or days before giving birth. This is followed by a hiding period, in which calves are secluded up to 3 weeks with their mothers in calving areas [91,221,344]. After seclusion, cows with calves join "nursery herds", composed of cows with calves, as well as some yearlings and 2-year-old males, and remain in these groups during summer [91,221,344]. Size of migratory and nonmigratory nursery herds on summer range varies from a few individuals up to 100 individuals [344]. As calves grow and become better able to escape predators during summer, nursery herd size decreases [96]. Nonpregnant, yearling, and 2-year-old females separate from pregnant cows and cows with calves during calving, and some remain segregated throughout the summer [131]. Two-year-old males and often yearling males may leave cow groups during calving and join bull groups of up to 20 individuals in spring and early summer (see Dispersal). Some young males may return to cow groups during mid-summer when cows with calves join nursery herds [91].

Prior to the rut in fall, individual herds may aggregate into large herds, which subsequently break into smaller groups as males seek out cow groups and form harems [75]. During the rut, typically small 2.5-year-old and often yearling males are expelled from the harem by large, dominant bulls [91], and groups of small, young, nonbreeding bulls may form [221]. After the rut, large bulls often band together, and harem subgroups reunite into a single cow herd [91]. Small bulls may occur in cow herds after the rut [96] and may attempt to breed, although few copulations apparently occur [91]. Migratory herds form after the rut [344] and may be composed of >5,000 individuals [131].

Elk often form larger groups in open habitats than in closed-canopy forests, possibly as a strategy to avoid predators [96]. In the Bob Marshall Wilderness, Montana, groups of elk in the Sun River elk herd averaged 7.2 individuals in openings and 2.5 in forests [226]. However, in Pigeon River Country State Forest, Michigan, elk group sizes did not vary with cover, perhaps because of abundant hiding cover and/or lack of predators [28]. In Gallatin Canyon in the western Greater Yellowstone Area, elk group sizes increased as distance to protective cover increased. However, the increase in herd size may not be related to predatory avoidance. Herd size increased only on days when gray wolves (*Canis lupus*), a major elk predator, were absent. When gray wolves were present, elk herd size remained small at all distances from cover. This suggested that large groups were gathering in open habitats because of foraging opportunities, not because of predator avoidance [67]. Limited information suggested that dense elk populations have larger groups than sparse populations [115].

Home range and movements: Elk may inhabit the same range throughout the year or migrate to separate summer and winter ranges. Migratory elk herds are generally found in mountainous regions where they move up and down elevation or river drainages, apparently in response to weather and seasonal changes in vegetation. Transitional ranges are used in spring and fall as elk move between summer and winter ranges. Individuals generally retain the same ranges from year to year and travel the same routes between ranges [131,221].

- Daily activity
- Seasonal movements and migration
- Dispersal
- Home range

Daily activity: Elk are active throughout the day and night, but activity peaks at dawn and dusk (e.g., [1,186,194,259,332,347]).

Seasonal movements and migration: Elk may inhabit the same range throughout the year (nonmigratory) or migrate annually in spring and fall to separate summer and winter ranges (migratory) [221]. For example, in the Greater Yellowstone Area, the Gallatin Canyon, northern Yellowstone, Sunlight Basin-Crandall Creek, North

Fork of the Shoshone, and Jackson elk herds are migratory, whereas the Madison River elk herd is nonmigratory but exhibits local shifts in habitat use among seasons [64].

Spring migrations generally occur during May but may occur from April to June. Fall migrations occur from September to December. Migration distances range from <2 miles (3 km) to >90 miles (150 km) [131]. One of the longest elk migrations occurs in Wyoming, where elk in the mountains travel up to 200 miles (322 km) to reach winter rangelands in the Little Colorado and Red deserts (Sura 1967 cited in [210]). Elk migration may take from several days to up to 2 months to complete [131].

The timing of elk migrations is associated with greening and curing of vegetation and with snow accumulation [131,131,186,275,296]. The timing and amount of rainfall influence the volume and nutritional value of forage on summer rangelands, which can influence the amount of time elk spend on summer ranges [131]. In Yellowstone National Park, elk migrated earlier than usual during severe drought [321]. Deep snow may cause elk to move to winter range or to areas within their range where snow is less abundant (e.g., [35,172,259,296]), although in Yellowstone National Park, fall migration occurred prior to snow accumulation [321]. In northern Yellowstone, spring migrations occurred earlier in years with shallow snow pack and early spring green-up [340]. The migratory period for the majority of elk in the western Sierra Madre area of Wyoming coincided with spring green-up each year (Compton 1975 cited in [131]).

The timing and extent of migrations vary by the age and gender of individual elk. Mature bull elk are often the first to migrate in spring [131,296]. "Old" bulls of Colorado's White River plateau herd reached summer range several weeks ahead of cows [39]. In south-central Washington, ≥5-year-old males consistently migrated from summer range to winter range before other elk, and most of these males were on winter range by late November, even prior to heavy snowfall. The author speculated that rut-depleted bulls may reduce the energetic costs of migrating by moving before heavy snows [193]. Conversely, old bulls may not migrate at all, tending to spend winter at higher elevations—and in deeper snow—than do other elk [131]. In Rocky Mountain National Park, "old" nonbreeding bulls wintered on high, open alpine meadows that were generally avoided by other elk [213].

Elk usually return to ranges used the previous year and have a strong tendency to follow the same migration routes each year, often using the same routes for both spring and fall migrations [131]. In Jackson Hole, Wyoming, 98% of elk ≥3 years old used the same summer ranges each year (Smith and Robbins 1994 cited in [230]). In the northern Yellowstone herd, elk showed greater fidelity to summer range (96% fidelity) than winter range (61%) [340]. According to a review, habitual use of the same travel routes probably is due largely to topography, which shapes natural travel corridors [131]. However, severe weather, fire, and human disturbance may cause elk to change their migration routes. Elk in the Jackson herd tended to cross ridges and mountain slopes while migrating during normal fall weather, but used more direct routes along drainages during severe weather [35]. After the 1988 fires, 3,000 to 4,500 elk consistently spent winters at the northernmost extremity of the northern Yellowstone elk winter range, where only 700 elk wintered prior to the fires [266]. In Wyoming [35], Montana [226], and Utah [147], hunting changed elk migration routes and led to changes in the proportion of elk migrating in a population.

Dispersal: Males are more likely than females to disperse [230,279]. Yearlings may be dispersed by their mothers just prior to parturition [91,96,230]. Harem bulls often aggressively drive yearling bull offspring from their mothers' range during the rut [91,96,230]. However, young males may not be forced to disperse until they are 2.5 years old [96,230,279]. Female offspring tend to establish ranges in or adjacent to their mother's group, whereas males only rarely make contact with their mothers after dispersal [230].

Limited evidence suggests that dispersal may be density dependent [230]. Dispersal in south-central Montana was attributed to increasing elk populations on restricted ranges [323]. However, Smith and Anderson [279] considered dispersal of Jackson elk as independent of density in part because many elk dispersed to areas with higher elk densities.

Dispersal movements vary greatly but are typically short. Mean dispersal distance in northwestern Montana was 15.3 miles (24.6 km) for 2.5-year-old bulls and 2.2 miles (3.6 km) for cows (Hurley and Sargeant 1991 cited in [230]). The longest dispersal distance reported as of this writing (2011) was for a yearling bull that traveled at least 1,740 miles (2,800 km) from Sweetgrass Hills, Montana, to Independence, Missouri (Olson 1991 cited in [210]).

Home range: A review reported that elk home range sizes range from 1 to 95 miles² (3-245 km²) [221]. Some of the largest reported elk home ranges as of this writing (2011) were an average of 247 miles² (639 km²) for males and 149 miles² (386 km²) for females in the White Mountains of Arizona [332]. Adult bulls often have larger home ranges than cows in summer and appear to have less home range fidelity than cows [96].

In a review of 14 studies of summer home range sizes of elk in North America and Europe, Strohmeyer and Peek [293] stated that precipitation, forage availability, juxtaposition of resources, cover quality, ambient temperature, difficulty of travel, population density, plant phenology, abundance of insects, social behavior, and human disturbance influenced elk home range sizes [349]. In mesic California redwood forest, 2 nonmigratory cow groups occupied areas approximately 1 mile² (3 km²) year-round [91]. In western redcedar-western hemlock forests in northern Idaho, home ranges of nonmigratory male and female elk averaged 4.9 miles² (12.6 km²) in summer and 0.8 miles² (2.1 km²) in winter [132]. In contrast, mean annual home range of nonmigratory male and female elk in xeric sagebrush steppe in southeastern Idaho was much larger, 213 miles² (551 km²) [293]. In south-central Washington big sagebrush steppe, annual home ranges of nonmigratory elk averaged 62 miles² (161 km²) for females and 63 miles² (163 km²) for males. The authors found that annual precipitation was inversely correlated with annual home range size ($r^2=0.97$; $P<0.001$) [195]. The large mean annual home ranges of male (133 miles² (345 km²)) and female (55 miles² (145 km²)) elk in the arid Trans-Pecos region of western Texas were attributed to high population density, low forage production, and lack of water [349].

According to a review, males and females tend to occupy separate areas within ranges. For example, adult bulls on winter range in the Gallatin Canyon, Montana, tended to concentrate on the fringes of the winter range, whereas cows, calves, and young bulls most frequently occupied the central portions [221]. In contrast, in Prairie Creek Redwoods State Park, California, bull and cow groups often overlapped ranges throughout the year [91].

Home ranges are generally smaller where forage is abundant. In Alberta and Wisconsin, where nonmigratory elk tend to congregate in small groups in forests, summer and winter home range sizes were inversely related with mean forage biomass; in winter, when forage resources were scarce, elk home range sizes increased. In Yellowstone National Park, where migratory elk concentrate in large groups in open areas, home range sizes were positively related to mean forage biomass. Migratory behavior and the relatively high population density of elk in Yellowstone National Park may have caused elk to range over larger distances than elk in the Wisconsin and Alberta populations [7].

Winter ranges are often smaller than summer ranges [131]. Winter range of the Big Prairie herd on the Flathead National Forest, Montana, was only 17% of the size of summer range [93]. In the Columbia Mountains of southeastern British Columbia, mean late-winter ranges (4 miles² (11 km²)) were only 4% of mean annual ranges (95 miles² (247 km²)) [215]. Deep and/or crusted snow hinders elk movements. One review stated that snow >16 inches (40 cm) deep often cause elk to reduce movements and restrict activities to small areas. Hard, crusted snow can also hinder movements [296]. Travel through deep and/or crusted snow is high in energy cost [58,296]. Deep and/or crusted snow also reduces the availability of food growing near the ground. If snow becomes too deep or encrusted, elk can only forage on plants that are emergent from the snow and within their reach [296]. When snow is deep and/or encrusted, elk frequently move to and remain in places with high canopy cover, or other habitats where snow may be shallower and/or softer, to conserve energy (see Preferred habitat) [131,215,296].

Because of their shorter legs, calves may be more restricted by deep snow than adults. Similarly, because of their large body size, adult males may be least affected by deep snow [58,131]. According to Trottier and others [314], elk calves are hindered by snow depths >1.7 feet (0.5 m), whereas adults are hindered by depths >1.9 feet (0.6 m). On the Flathead National Forest, Montana, loose snow >3.3 feet (1.0 m) restricted adult elk movements, and snow >2.5 feet (0.8 m) restricted calf movements. Where the snow was packed or crusted, snow >2.5 feet deep also restricted adult elk movements [93]. Body size differences may help explain differential movements of age and gender groups during winter in some areas. For example, on the Olympic Peninsula in Washington, groups of bull elk were found in areas where snow was up to 6 feet (1.8 m) deep. These areas were not used by other age and gender groups [259]. The physical condition of the animal likely affects the influence of a given snow depth. Animals in late winter may be less able to withstand stress due to weather because of their poor physical condition [296].

Life span and survival: According to a review, the oldest bull in an unhunted elk population was 14 years old and the oldest cow was 21 [230]. However, bulls typically live <10 years in unhunted populations and <5 years in hunted populations [344]. In a hunted population on Colorado's White River plateau, maximum longevity was <7 years for bulls and <10 years for cows [39]. Greater harvest of males may skew sex ratios in favor of females [279]. In areas not hunted, mortality of males is higher than that of females, related in part to rutting activities [221,230]. See Sex ratios for more information on this topic.

Primary sources of elk mortality are hunting and predation. Severe winter weather can result in high elk mortality, especially in calves. Other sources of mortality are diseases, parasites, and the cumulative and interacting effects of malnutrition, late parturition, and low birth mass on calves [230,344]. Fire may directly kill elk (see Direct Fire Effects).

- Hunting
- Predators
- Diseases and parasites
- Malnutrition and weather
- Calf survival

Hunting: According to reviews, hunting is the major source of adult elk mortality in most populations [221,230,344]. In a north-central Idaho population, annual survival rates of hunted bulls averaged 60% during 5 years, whereas survival rates of cows subjected to limited hunting averaged 89% [320]. A hunted elk population segment in New Mexico had 55% survival, whereas an unhunted population segment had 91% survival (White 1985 cited in [230]).

High hunting pressure coupled with high exposure in areas with dense roads may reduce elk survival [230]. Annual survival rate was 41% for >2-year-old bulls and 44% for yearling bulls in a roaded area and 78% for >2-year-old bulls and 79% for yearling bulls in an unroaded area in north-central Idaho (Unsworth and Kuck 1991 cited in [230]). In northeastern Oregon, increased road access and loss of cover apparently led to a posthunting bull:cow ratio decline from >15:100 to <5:100 (Leckenby and others 1991 cited in [230]). For more information on this topic, see Human disturbance.

Migrating and nonmigrating elk may have differing susceptibilities to hunting mortality. In northwestern Colorado, survival of migrating 1.5- to 3-year-old males was 25% during 2 years, whereas survival of resident males was 89% during the 2 years [223]. Dispersing elk, which are largely young males (see Dispersal), may be most vulnerable to hunting. In the Jackson, Wyoming, area, 1- to 2-year-old males had higher mortality than females [279]. In northwestern Montana (Hurley and Sargeant 1991 cited in [230]) and western South Dakota (Millspaugh 1999 cited in [230]), mortality rates were highest for dispersing bulls.

Hunting may also change elk habitat use and behavior. For more information on this topic, see Predation risk.

Predators: Primary elk predators include gray wolves, coyotes (*Canis latrans*), American black bears (*Ursus americanus*), grizzly bears (*Ursus arctos horribilis*), and mountain lions (*Puma concolor*) [230,358]. Predators are a particularly important source of calf mortality in summer [221,344]. According to a 2006 review, annual elk calf mortality from Washington, Wyoming, and Idaho ranged from 44% to 98%, and highest annual mortality was caused by bears (*Ursus* spp.), mountain lions, and coyotes [358]. In the northern Yellowstone elk herd, predation was the greatest source of calf mortality (44%) during 4 years. All but one instance of predation occurred during summer. Winter malnutrition (23%) was the second leading cause of elk calf mortality [267]. See Calf survival for more information.

Predators also kill older individuals. Along the North Fork of the Flathead Valley in northwestern Montana and southeastern British Columbia, gray wolf-caused mortality rates were not different among age classes [159]. In

Banff National Park, Alberta, gray wolves killed a higher proportion of adult males and calves than occurred in the population. Adult elk killed by gray wolves were older and in poorer condition than those killed on the road or railway [130]. Conversely, in the Greater Yellowstone Area, gray wolves tended to select elk calves and adult females; 43% of elk killed were calves, 28% were adult females, and 21% were adult males [281]. In the Gallatin Canyon, Montana, gray wolves tended to select elk calves and adult males; adult females were killed by gray wolves 33% less often than expected by chance, adult males were killed 2.2 times more often, and calves were killed 2.5 times more often [67]. In Riding Mountain National Park, Manitoba, gray wolves killed more elk >11.5 years old (47%) than younger animals (26-27%), and elk killed were in good physical condition [45]. Other studies in Glacier National Park area [38] and the northern Greater Yellowstone Area [86] reported that gray wolves killed old adults more frequently than young adults. Along the North Fork of the Flathead Valley, young (≤2 years old) and old (≥8 years old) elk were most vulnerable to mountain lion mortality [159].

Winter severity may influence gray wolf predation on elk. In Banff National Park, calf movements were hindered by shallower snow depths than adult movements, which made them more vulnerable to gray wolf predation. Calves and adult elk occurred in approximately equal numbers in gray wolf diets when snow was 0 to 20 inches (0-50 cm) deep, and calves predominated in the diet when snow was 20 to 24 inches (50-60 cm) deep; only adults were killed in snow >24 inches deep. Although calves occurred in snow >24 inches deep, they may have been less abundant than in shallow snow [129]. In Yellowstone National Park, gray wolf kill rate was higher and mean marrow fat content—an index of physical condition—of killed elk was lower during a severe winter than during a mild winter. More calves were killed during the mild winter, and more male than female elk were killed during the severe winter [197]. Conversely, along the North Fork of the Flathead Valley, annual elk survival rates were not correlated with the number of days/winter with >12 inches (30 cm) of snow [159].

Predators may indirectly affect elk survival by modifying elk behavior, which can affect their physical condition. In the Upper Gallatin elk herd, elk were nutritionally stressed and relied on their own stored fat and muscle to meet energy requirements in winter. The presence of gray wolves increased the nutritional deficit, primarily through declines in intake, which was considered sufficient to reduce overwinter survival and reproduction [50]. See Predation risk for more information.

Migrating and nonmigrating elk may have differing susceptibilities to predation mortality. Resident elk of the Ya Ha Tinda herd in southwestern Alberta were exposed to higher night-time predation risk by gray wolves in winter than migratory elk. Because gray wolves avoided human activity and remained close to forest-grassland ecotones during the day, a predation refuge existed in the center of grasslands. At night, however, elk were unable to avoid exposure to predation because gray wolves moved into the grasslands far from forest. Because resident elk remained further from forest than migrants at night, they were exposed to greater predation risk at night than migrants [246].

Diseases and parasites: Numerous parasites infest elk. Although parasites such as meningeal worm (*Parelaphostrongylus tenuis*), psoroptic mites (*Psoroptic* spp.), and giant liver flukes (*Fascioloides magna*) cause elk mortality, evidence for impacts on elk populations is limited [302].

The two most important diseases causing mortality in elk, according to a review, are brucellosis (*Brucella abortus*), which causes infected cow elk to lose their first calf after infection, and bovine tuberculosis (*Mycobacterium bovis*), which may be debilitating or cause death [230]. Fire may indirectly affect the prevalence of diseases and parasites in elk (see Indirect fire effects). For a comprehensive review of diseases and parasites that infest elk, see Thorne and others [302].

Malnutrition and weather: According to a review, nutrition can affect productivity of elk by influencing the timing of estrus and birth date, probability of conception, fetal growth and survival, birth weight, resistance to disease and parasites, juvenile growth and survival, age at first reproduction, and adult survival [58]. Deep snow in winter can reduce elk nutrition by reducing access to food. Because of their small body size and low fat reserves, malnourished calves may have high winter mortality. Because they have lower fat reserves in fall due to rutting activities, adult males may have higher winter mortality rates due to malnutrition than adult females. Although severe winters may cause substantial elk mortality, winters with high snow accumulation and consequent delayed plant growth in spring may provide a higher quality diet for elk for a longer period in late summer and fall than years with average phenological development [221,230].

Deep snow in winter can bury and reduce access to forage even in high-quality habitats, which can lead to malnutrition, starvation, and ultimately death [221]. During 23 years on the northern Yellowstone winter range, bull and cow mortality rates were positively correlated and per capita rate of increase was negatively correlated with spring precipitation in the prior year. Winter calf mortality was positively correlated with spring precipitation in the current year. Abundant, early-spring precipitation the prior year may restrict access to summer forage and increase thermoregulatory costs, causing elk to enter winter in poor condition [62]. Survival of prime-aged females (<10 years old) in an unhunted elk population in the upper Madison River drainage in western Yellowstone National Park was little affected by snow conditions (measured using snow water equivalent, a measure that integrates snow depth and density [316]), except during the most severe winter. Survival of females ≥10 years old progressively decreased as snow conditions worsened. Snow water equivalent was negatively correlated with elk recruitment (r^2=0.91), with the most severe winter resulting in the "virtual elimination" of a juvenile cohort [94].

The simulation models of Turner and others [316] and Wu and others [354] evaluated the relative contributions of fire pattern, winter weather, and initial elk numbers in determining elk winter survival in northern Yellowstone the winter after the 1988 wildfires (see Case study). Both models predicted that snow conditions (based upon snow water equivalent) would be the primary controlling variable in elk mortality following the fires. The models predicted that the fires would have little effect on elk survival if snow conditions were equivalent to the most mild recorded during the 1900s, but that mortality would be high, regardless of the occurrence or pattern of burning, if snow conditions were equivalent to the most severe winter recorded. The model predicted that, under the most severe snow conditions, 100% of calves, 85% of cows, and 80% of bulls would die. Under the most mild snow conditions, no elk mortality was predicted even though the simulated fires removed 22% of the winter range. Based on these models, Wu and others [354] concluded that many elk would have died in the first postfire winter even if the northern range had not burned, due to the moderately severe snow conditions.

Due to greater home range fidelity, greater use of marginal habitats, and lower fat reserves in fall due to rutting activities, adult males may have higher mortality rates during severe winter weather than other age and gender groups [264,268,321]. Bull mortality was high the first winter after the 1988 Yellowstone fires when severe snow was coupled with reduced forage caused by the fires and drought. Because bull elk were less likely to migrate out of burned winter ranges, bulls died at higher rates than cows. By late winter, bull:cow ratios in the northern Yellowstone elk herd were only 18:100 compared to a typical ratio of 30:100 [264,268]. In Yellowstone National Park in winter, the probability of an elk dying was related to animal age and the proportion of winter home range burned in the 1988 fires. Adult bulls had the highest mortality rates, followed by cows and subadult bulls [321].

Calves of the year may have high mortality during severe winter weather due to their growth requirements and lack of fat reserves (see Calf survival). In the northern Yellowstone elk herd, calves born following mild winters were heavier than calves born following average or severe winters (P=0.029), and birth weight was positively correlated with annual survival (P=0.006) [267]. The spring following the 1988 Yellowstone fires, calf weights were reduced 17% relative to previous years, and calf mortality during the first 6 weeks of life was twice that of previous years [268]. In the Jackson Hole and Grand Teton National Park areas, annual calf survival was inversely correlated with winter (December and January) precipitation (r= -0.99, P=0.03), and higher calf:cow ratios in August were positively correlated with mean temperature during April (r=0.93, P=0.01) [278].

Calf survival: Calf survival is variable among years and populations. According to a review, winter cow:calf ratios, which reflect changes in calf production and survival, range from <10 calves:100 cows to >70 calves:100 cows [221]. Because elk calves depend on energy stored in fat and muscle during summer and fall to survive winter, birth weight, birth date, gender, and body condition of a calf influence its survival. These variables are influenced by a variety of factors, including the age of the calf's mother and her nutritional condition, the age of the calf's father, population density, weather, predation, or a combination of these factors [58,221,230].

Summer survival of elk calves is positively related to their weight at birth [58,221,267,301]. In captivity, calves that were small (<25.1 pounds (11.4 kg)) at birth had a lower probability of surviving 4 weeks (<50% survival) than larger calves (>35.3 pounds (16.0 kg)) (>90% survival) [301]. In Yellowstone National Park, summer calf survival was positively correlated with birth weight (*P*=0.001). Predation on calves in summer was the greatest source of mortality (44% of all mortalities) and predated calves weighed less at birth than those that survived, possibly because small calves may be slower and easier for predators to catch than large calves [267]. Neonatal mortality resulting from predation was greater on early-born calves than late-born calves of the Jackson elk herd (*P*=0.055). Predators may have hunted calves more actively early in the parturition period either because other protein sources were less abundant, or because the proportion of very young and thus very vulnerable calves, relative to all calves, was higher [277].

Late-born calves often have high mortality in winter. In Yellowstone National Park, malnutrition was the leading cause of winter calf mortality, and winter mortality of late-born calves was higher than that of early-born calves [267]. Late-born calves may enter winter smaller than early-born calves, and small calves may have greater rates of decline in body condition in winter due to large surface-to-volume ratios that may predispose them to larger energy losses than large calves. Small calves also have more difficulty traveling and foraging in deep snow than large calves because of their relatively lower chest height and smaller hoof-surface area (see Home range) [230]. Thorne and others [301] reported that small elk calves grew more slowly than calves of normal birth weight on an absolute basis (pounds/day). They grew equivalently on an incremental basis (%/day), so weight differences at birth are likely to increase as calves grow. This may result in lifelong disadvantages.

Male calves may have higher mortality than female calves. In the Jackson elk herd, neonatal survival (birth to July 15) was higher among females (90%) than males (74%), and annual calf survival was higher among females (66%) than males (50%). The researchers suggested that male calves may be more active than females and thus fall prey to predators more often [277].

Calves of yearling cows, older cows, and cows in poor body condition during pregnancy experience substantially higher mortality than do calves of healthy, prime cows. Prime cows produce the heaviest, earliest born calves, which, in turn, have comparatively high survival rates [230], even though they may be subject to higher neonatal predation [277]. Calf mortality in Banff National Park between 3 months after conception and 6 months after parturition was 38% for yearling cows, 27% for 2- to 13-year-old cows, and 44% in ≥14-year-old cows (Flook 1970b cited in [230]). Calf survival may also be reduced when yearling bulls are the primary breeders because of late conception dates resulting from a delayed or lengthened rutting season [221,230]. For more information on this topic, see Reproduction and development.

Recruitment and calf survival may depend on population density and relative forage availability. Over 23 years on the northern Yellowstone winter range, when the elk population numbered about 5,000 individuals, summer calf recruitment rate was 56 calves/100 cows. When the population increased to 15,000 individuals, summer calf recruitment was about 30 calves/100 cows. Winter calf mortality was <1% when the population was at 5,000 individuals but increased to over 50% when the population was at 15,000 individuals. The authors suggested that food became limiting at high population densities [62]. In Grand Teton National Park, calf:cow ratios averaged 45:100 when the population of cows, calves, and yearling males was 500 individuals. The calf:cow ratio declined to approximately 25:100 when the population was 1,300 individuals (Boyce 1989 cited in [221]). In Yellowstone National Park, winter calf survival was negatively correlated with population size during 4 winters (*P*=0.0002) [267].

Diet: Along the continuum from grazers to browsers, elk are classified as intermediate or mixed feeders and can switch from a diet composed primarily of grasses to one of browse [58,221]. Elk consume the flowers, stalks, seeds, and pods of grasses and forbs. They eat the stems, leaves, and bark of trees and shrubs. They also eat lichens, mosses, and ferns and dig up belowground plant structures such as the roots of perennials [58,109,221,259]. Forage preferences vary among ranges, seasons, and years, and appear strongly related to forage availability and phenology [58,221]. According to a 1985 review, elk prefer grasses, then forbs. As curing or loss of herbaceous material occurs, they use deciduous browse first and conifer browse last [76].

Food habits of elk vary because the species occurs in many different habitats throughout its range. A 1973 review reported 159 forbs, 59 grasses, and 95 shrubs in annual diets of elk in the Intermountain West and Manitoba [156]. Species or genera identified as the "best documented" highly valuable forage species in at least one season included pale agoseris (*Agoseris glauca*), wheatgrass (*Agropyron* spp.), Saskatoon serviceberry (*Amelanchier alnifolia*), sedge, ceanothus (*Ceanothus* spp.), fescue (*Festuca* spp.), geranium (*Geranium* spp.), lupine (*Lupinus* spp.), bluegrass, aspen and cottonwood (*Populus* spp.), cherry (*Prunus* spp.), antelope bitterbrush (*Purshia tridentata*), Gambel oak (*Quercus gambelii*), and willow [156]. According to a 2002 review of elk diets in the Pacific Northwest, bentgrass (*Agrostis* spp.), sweet vernalgrass (*Anthoxanthum odoratum*), woodrush sedge (*Carex luzulina*), orchardgrass (*Dactylis glomerata*), California oatgrass (*California danthonia*), wildrye (*Elymus* spp.), and red fescue (*Festuca rubra*) were the most valuable graminoids; and fireweed, horsetail (*Equisetum* spp.), hairy cat's ear (*Hypochaeris radicata*), and twinflower (*Linnaea borealis*) were the most valuable forbs in the diet in at least one season. The most valuable browse species were vine maple (*Acer circinatum*), red alder, dwarf Oregon-grape (*Berberis nervosa*), salal (*Gaultheria shallon*), gooseberry currant (*Ribes montigenum*), Himalayan blackberry (*Rubus armeniacus*), salmonberry, trailing blackberry (*Rubus ursinus*), Pacific dewberry (*Rubus vitifolius*), red elderberry (*Sambucus racemosa*), Pacific yew (*Taxus brevifolia*), western redcedar, western hemlock, and blueberry (*Vaccinium* spp.) [58]. In California, important grasses included desert needlegrass (*Achnatherum speciosum*), Indian ricegrass (*Achnatherum hymenoides*), bottlebrush squirreltail (*Elymus elymoides*), James' galleta (*Hilaria jamesi*), foxtail barely (*Hordeum jubatum*), knotgrass (*Paspalum distichum*), and Sandberg bluegrass (*Poa secunda*). The most important forbs included scalebud (*Anisocoma acaulis*), fivehorn smotherweed (*Bassia hyssopifolia*), cryptantha (*Cryptantha* spp.), eriogonum (*Eriogonum* spp.), stork's bill (*Erodium* spp.), gilia (*Gilia* spp.), American licorice (*Glycyrrhiza lepidota*), common sunflower (*Helianthus annuus*), tidytips (*Layia* spp.), alkali mallow (*Malvella leprosa*), yellow sweetclover (*Melilotus officinalis*), and blazingstar (*Mentzelia* spp.). Important browse included big sagebrush, big saltbrush (*Atriplex lentiformis*), Eastern Mojave buckwheat (*Eriogonum fasciculatum*), winterfat (*Krascheninnikovia lanata*), antelope bitterbrush, willow, and black greasewood (*Sarcobatus vermiculatus*) (McCullough 1969 cited in [58]).

In early spring, elk typically eat plants that begin growth early, usually grasses [58]. In late spring and summer, use of forbs and shrubs increases, but use of grasses generally remains high. In fall, grasses remain important in elk diets, forb use decreases, and shrub use generally increases [58,156,221]. Five years after the eruption of Mount St Helens, elk in the blast zone primarily consumed forbs in summer, including horsetail, hairy cat's ear, western pearly everlasting, and fireweed. In fall, they switched to grasses such as red fescue and tall fescue (*Schedonorus phoenix*), which were seeded after the eruption. Shrubs, including willow, red elderberry, salmonberry, and maple (*Acer* spp.), were common in elk diets during all months [200]. In winter, elk consume mostly grasses or browse depending on availability [156,221]. A 2007 review of 72 studies of elk winter diets conducted in western North America between 1938 and 2002, stated that graminoids dominated elk diets and consistently occurred at a higher proportion in the diet than in elk foraging habitats. Forbs accounted for <10% of the winter diet in 84% of cases and appeared to be consumed incidental to grazing for graminoids. Browse was consumed more frequently than forbs but in proportion to its availability, implying that the amount of browse in the winter diet was primarily determined by habitat use rather than selection [49]. A review of elk wintering on Montana grasslands reported that "climax" grasses, particularly bluebunch wheatgrass, Idaho fescue, western wheatgrass, and alpine rough fescue, constituted 65% to 100% of elk winter diets (Rognrud and Janson 1971 cited in [221]). In some regions, such as in north-central Idaho, elk consume mostly browse in winter. In the Lochsa River area of Idaho, elk consumed 92% browse in winter, preferring redstem ceanothus, snowbrush ceanothus (*Ceanothus velutinus*), Rocky mountain maple, scouler willow, and serviceberry (Hash 1974 cited in [221]).

In winter, forage availability and elk diet change with snow depth and hardness. When snow is shallow, elk paw through it to reach understory vegetation but also browse shrubs, conifers, and lichens that protrude from the snow. Deep snow can limit elk use of forage to that which protrudes from the snow, or cause elk to move to areas with shallow snow. Typically, elk eat fewer low-growing herbs and shrubs and eat more tall shrubs, conifers, and arboreal lichens as snow depth increases [49,58]. In the Blue Mountains, Oregon, browse comprised 74% of the diet after a winter storm deposited 12 inches (31 cm) of snow, though browse formed only 27% of the diet in periods with less snow accumulation (Skovlin and Vavra 1979 cited in [49]). In the San Juan

Mountains, Colorado, snow depths of 16 to 28 inches (40-70 cm) caused elk to change from a diet of herbaceous forage to a diet of browse; elk avoided areas with deeper snow [296]. The Big Prairie elk herd on the Flathead National Forest switched from grazing to browsing when snow depths exceeded about 2.5 feet (0.8 m). When the snow was hard-packed or crusted, elk switched to browsing at shallower snow depths [93]. In Glacier National Park, elk consumed more browse during a winter when snow averaged 28 inches (70 cm) deep than during a year when snow averaged 20 inches (50 cm) deep (P=0.07) [138].

Yearly differences in precipitation and plant growth alter elk food habits. In the Missouri River Breaks, Montana, yearly differences in elk habitat use and food habits were largely related to the influences of annual variations of precipitation on forage supplies [186]. Yearly differences in habitat use by Montana's Sun River elk herd was attributed to variation in succulence of forbs related to July weather [226].

Nutrition: Nutritive value of elk forage varies among different types of forage, which provide different levels of critical nutrients at different times of year. Protein in herbaceous plants is typically less than or equal to that in shrubs during the growing season, but it decreases more rapidly and typically reaches concentrations below shrubs by the end of the growing season. Digestible energy tends to be greater in herbaceous plants than shrubs across all stages of growth. Beginning in fall, both protein and digestible energy of all forage on elk winter ranges decreases rapidly with the cessation of growth and senescence. Herbaceous plant quality continues to decline throughout winter, whereas shrubs typically retain higher quality [25,57].

Elk appear to select mixed diets to meet nutritional requirements [25]. Near Estes Park, Colorado, elk maintained a relatively stable winter diet quality over time and space, despite year-to-year variation in forage quality, by shifting between forage classes (graminoids and browse) during winter [121]. Elk also tend to select habitats that offer the most nutritious foods. In the Burwash-French River area of Ontario, reintroduced elk always selected high-quality plants (based on dry matter digestibility) irrespective of the quality of the surrounding habitat, whereas low-quality plants were only included in the diet when better alternatives were rare. Elk broadened their diet in low-quality habitats containing fewer high-quality plants and narrowed their diet in high-quality habitats containing abundant high-quality plants [110]. For these reasons, researchers suggested that managers maintain plant communities with a diversity of forbs, grasses, and browse to provide for elk nutritional needs [25,122].

According to a review, forage conditions on winter rangelands are often considered most limiting to elk populations, whereas forage on spring and summer range is generally assumed to be adequate for most elk populations [275]. However, Lyon and Christensen [184] stated that the significance of summer range as a factor in preparing elk for overwinter survival was frequently underestimated and that high-quality forage during summer is essential to overwinter survival of most herds. This is supported by a study in which cow elk from high- and low-density populations were given the same winter diet. Elk from the high-density population, which had been on summer range with poorer nutrition availability, had poorer body condition and lower reproduction than elk in the low-density population. The authors concluded that summer range quality determines accumulation of energy stores in elk, while winter range quality and length of winter determine depletion of energy stores. Thus, animals that are nutritionally stressed during summer are probably more affected by winter forage conditions than animals with good nutrition during summer [290].

Successional changes in elk forage: The quantity and nutritional quality of preferred forage species may fluctuate due to disturbance history and the stage of forest succession. Quantity and nutritional quality of elk forage species may increase or decrease after fire, logging, and other disturbances and change as forests mature. Ultimately, successional dynamics are unique for each forage species. For information on effects of fire on elk forage species, see Postfire vegetation changes and succession. For information on logging effects on elk forage species, see Postlogging vegetation changes and succession. See also FEIS reviews of plant species of interest.

Elk foraging effects: Intensive foraging pressure by elk populations at high density may alter vegetation composition and affect the successional trajectory and rate of succession of habitats they occupy, particularly in the absence of gray wolves [221]. Elk can influence plant species composition and diversity by consuming palatable species and allowing unpalatable species to gain dominance [61,203,221]. For example, in the Jemez

Mountains, New Mexico, elk reduced preferred forage species; slowed or altered succession in grasslands; contributed to or exacerbated soil erosion; and degraded high-elevation water sources by overutilizing the grasslands that established after the La Mesa fire [5,351]. On the Flathead National Forest, elk overbrowsing of quaking aspen, willow, black cottonwood, and lodgepole pine hastened succession to Engelmann spruce on moist sites [93]. Elk may also influence rates of nutrient cycling by altering litter quantity and quality and via urination and defecation [274]. Their foraging habits can alter patch dynamics in old-growth forests [257], although some studies suggest that elk have little effect on plant species composition and that other factors, such as drought and changes in fire regimes, may be more important (e.g., [271]). For more information on elk foraging effects, particularly on quaking aspen, see Elk interactions with fuels and fire effects.

PREFERRED HABITAT:

- **Topography**
- **Cover**
- **Forage**
- **Successional status of elk habitats**
- **Edge habitats**
- **Age and gender**
- **Predation risk**
- **Other factors**
- **Cover requirements**

Elk are probably the most adaptable of North American ungulates [88] and inhabit a wide variety of habitats [85,184]. Across the elk's range in North America, important elk habitats include open grasslands, shrublands, and open- and closed-canopy conifer, hardwood, and mixed hardwood-conifer forests from valley bottoms up mountain slopes to alpine areas (see Plant Communities) [184]. In addition, elk are "highly adaptable" to a wide range of ecological disturbances, including fire, and occur in early-successional habitats such as logged areas, burns, and subalpine shrublands [184,306]. On the landscape scale, elk are generally associated with a mosaic of open areas used for foraging and forested area used for cover. Habitat use depends upon season, weather (e.g., snow conditions; see Cover); calving; presence of lick sites and water; presence of predators and human disturbance; individual age and gender; and juxtaposition of habitats (see Edge habitats) [275].

Topography: Elk commonly use high elevations as the summer progresses and low elevations in winter, although lower and upper slopes are used throughout the year. Valley drainage bottoms may also be used during summer, because associated riparian habitats provide a source of late-summer food and water [275]. In winter and spring, elk prefer upper south- to west-facing slopes that, because of wind, solar radiation, or shade pattern are the first to become bare of snow, making forage more available (e.g., [72,93,172,189,212,262,275,296]). In summer and fall, elk typically use northern aspects on upper landscape positions. Forest cover on upper north-facing slopes usually provides the coolest habitat during summer and the most-succulent, high-quality forage in fall [214,275].

Elk generally prefer gentle to moderate slopes (<40%); slopes >60% are used less often [85,186,275]. In areas with high gray wolf density in Yellowstone National Park, elk used steeper slopes than they did prior to gray wolf reintroduction, presumably to avoid predation (see Predation risk) [188]. Elk in east-central Idaho shifted to steeper, upper slopes when ranges were shared with livestock than when livestock were absent (see Livestock grazing) [356].

Cover: Elk often use forests for cover, although they also occur where forest cover is unavailable [221,222]. Although forest cover is not required for elk, when it is available, elk often select closed-canopy, mature, and old-growth forests for cover and typically remain within 1,200 feet (400 m) of cover when using openings (see Edge habitats) [221,222]. Although elk often select dense stands [344], a review suggested that more open forests on relatively moist areas are preferred [222]. Marcum [189] found that the most frequently used bedding sites occurred in areas with high canopy cover (75%-100%), whereas feeding occurred most often in areas with low canopy cover (0%-25%).

In areas with abundant forest habitat, elk may select openings, whereas in areas with abundant openings, elk may select cover [214]. In the southeast Bighorn Mountains, Wyoming, female elk in an area with <8% forest cover selected forest patches that averaged 117 acres (47 ha), which was 9 times the size of the average available forest patch (14 acres (6 ha); $P<0.001$) [214].

Forest vegetation and topographic features can provide important hiding cover from predators and human disturbances such as hunting and logging [188,275]. In forested areas, elk avoid areas near roads open to motorized vehicles [344]. Elk increase use of forest cover during the rut in fall, especially during hunting season [165,189,275]. In the Clearwater National Forest, elk in nonroaded areas increased use of open-canopy forests in spring, probably due to large quantities of succulent early-growing vegetation; whereas in roaded areas, elk increased use of closed-canopy forests in spring, probably because of increased recreation and logging activity [319]. In western Montana, the distance that elk moved during logging disturbance was reduced where topographical barriers existed between elk and the disturbance [181]. In the absence of forest cover, elk in the high-desert region of southwestern Wyoming seemed to rely on a combination of shrubs, topography, and low human disturbance to meet their cover requirements [256]. Elk apparently cannot persist in areas lacking forest cover unless human disturbance is minimized [182,221,222]. See Human disturbance for more information.

Forests may provide elk with thermal cover via shade from solar radiation during summer or mild winter weather. In the Garnet Mountains, Montana, elk selected closed forest communities during warm summers and used moist habitats more heavily than dry sites during dry summers. They also moved to mesic sites earlier and in greater numbers in dry years than in wet years [190]. During an 8 year study, western Montana elk herds increased summer use of cool, mesic areas during hot, dry years [181]. According to a review, elk prefer dense forests the entire summer in some areas while in other areas, they move into dense forests in early August as the rut approaches [34].

Peak use of clearcuts occurs when herbs and shrubs providing forage have built up and scattered trees provide cover. In Alberta, habitat quality for elk in white spruce forest declined during 5 years after clearcutting due to a decrease of browse and cover. Seventeen years after clearcutting, the clearcuts provided both cover and forage for elk [285]. Mechanical treatments on 5,800 acres (2,300 ha) of pinyon-juniper woodland on the Fort Bayard Watershed in southwestern New Mexico showed that clearing large areas decreased elk use. Elk use increased, however, on areas where islands of living trees were left on north aspects and steep slopes [262]. A 1 mile^2 (2.6 km^2) clearcut in mature white spruce forest in western Alberta had greater cover of grasses and forbs and lower browse cover 5 years after logging compared to uncut controls. During the first 3 summers after logging, elk restricted use of the clearcut to the periphery. During postclearcut summers 4 and 5, however, elk used the clearcut more broadly [286], presumably because of increased tall grass cover. Using a model, Lyon [180] demonstrated that elk presence in small clearcuts increased with vegetation height, reaching a maximum when vegetation reached about 4 feet (1.2 m) tall [180].

Elk may use forests in winter because they have less snow than openings. In Glacier National Park, elk used postfire successional shrub fields when snow was <24 inches (60 cm) deep. Deeper snow caused elk to use nearby conifer stands where presumably forage was available under tree canopies that intercepted the snow [191]. Near Augusta, Montana, Sun River elk typically used grasslands during winter, but deep (12 inches (30 cm)) and crusted snow caused them to move to adjacent limber pine (*Pinus flexilis*) savanna where the snow was not crusted [151]. In northern Idaho, elk moved to conifer forest at low elevation when snow depths approached 24 inches but used postfire successional shrub fields when snow was shallow [172]. In Glacier National Park in winter, elk preferred fire-maintained lodgepole pine savanna (26% of observations) and Engelmann spruce forest (23% of observations), where snow cover was less than in grasslands; in grasslands use was similar to availability (10% of observations). In spring and fall, elk preferred grasslands (62-76% of observations) over lodgepole pine savanna (10% to 15% of observations), and no elk were observed in Engelmann spruce forest [265]. Shrublands at low elevation may also be used when snow depth increases. In southwestern Wyoming, elk generally used alpine grass/moss habitats in winter but moved to low-elevation shrublands when snow depth increased [212].

Forage: Elk forage-site selection is based in part on forage quantity and nutritional quality, which is influenced by plant species composition, plant phenology and related changes in nutrition, site characteristics (soils, shade, and topography), successional stage, grazing and browsing pressure, and weather. Elk forage-site selection is also affected by predation risk and proximity of the foraging sites to habitats providing cover.

Elk forage in grasslands, shrublands, and forests, although many researchers found that they prefer grasslands (e.g., [135,142]), and that they prefer grasses when snow depths do not impede foraging (see Diet) (e.g., [138,151,206]). In the North Fork of the Flathead Basin, northwestern Montana, elk preferred mature forest communities during a severe winter and grasslands and logged spruce communities during a mild winter; lodgepole pine savanna was preferred during both winters [135]. In Riding Mountain National Park, grassland was used more than any other habitat during 8 winters. Elk selected 8- to 17-year-old burns, grassland, and shrubland and avoided quaking aspen-white spruce, white spruce, and jack pine forests and bogs [251]. In Banff National Park, 4 to 18 times more elk pellet groups were found in shrub communities including willow-bog birch (*Betula pumila*), shrubby cinquefoil-wildrye, and open lodgepole pine/kinnikinnick (*Arctostaphylos uva-ursi*) forests than in mature conifer forests with Engelmann spruce and lodgepole pine [254].

Forests may serve as high-quality elk habitat where they provide forage as well as cover (e.g., [93,124,137]). In the southern Coast Range of southwestern Oregon, where elk are nonmigratory and typically occupy the same drainage year-round, elk densities decreased curvilinearly as the proportion of old-growth Douglas-fir-western hemlock forest decreased in 18 drainages ($r^2=0.89$, $P<0.05$). The authors suggested that old-growth forest structure, including a mosaic of small (0.13 acre (0.05 ha)) openings and a multi-story canopy that was 70% to 90% closed, provided both forage and thermal cover for elk within one stand [282]. On elk winter range along the White River drainage in Washington, old-growth (>200 years old) Douglas-fir-western hemlock forests had more evergreen shrubs (e.g., Pacific yew) and conifer browse (e.g., western redcedar) than young forests (<35 years old). These species were important alternate forages for elk when herbaceous forages in young forests were unavailable after snowfall [137]. For more information on forage-site selection, see Diet.

Successional status of elk habitats: Because elk use several different kinds of habitat daily, seasonally, and annually, the distribution and interspersion of plant communities and successional stages is critical. Elk use habitats in all stages of succession and show considerable plasticity in their response to changes in habitat [200]. Neither recent disturbances (<1 year old) nor undisturbed continuous forests support the highest elk density [23,266,324]; early successional stages usually have the best forage, while middle and late successional stages provide the best shelter [247].

According to Swanson [295], the stage when herbaceous cover has built up but before trees and shrubs take over is "optimum" for elk. In areas where forest canopy openings are important elk foraging sites, the early-seral stage of vegetation is very short lived (10-20 years) and the period of optimum forage production may last only 5 to 10 years [306]. According to a 2002 review, postfire succession of herbs and shrubs in young forests provides excellent forage and cover for elk for 20 to 30 years, until forest canopy shade reduces the understory [275]. In the Tuchodi River area of northeastern British Columbia, elk preferred early-seral stages of postfire forest succession (<20 years old) substantially more than older seres during winter and early spring [219]. Sagebrush in grasslands on Yellowstone's northern range supply critical winter forage for elk. After fire, sagebrush may take up to 30 years to recover to prefire levels [24]. See Postfire vegetation changes and succession for more information. For additional information on postfire and postlogging succession of plant communities important to elk, see FEIS reviews for plant species of interest.

Elk readily adapt to new habitats following translocation and readily colonize early-seral habitats after disturbance. For example, they commonly use logged forests (see Logging) and burns (see Indirect fire effects). Elk reoccupied the Mount St Helens blast zone in Washington within 1 year after the eruption [200]. See Pregnancy and twinning rates for information on elk population growth rates after the eruption.

Elk are ecological generalists. To satisfy their high energy demands, herds and subherds move opportunistically among habitats to forage [96]. In addition to early-seral habitats, elk often use mid-successional, mature, and old-growth forests as well as "stable" grasslands [88]. Near Augusta, Montana, Sun River elk in summer, particularly in July and August, used extensive 50- to 60-year-old burns in open-canopy subalpine fir-Engelmann spruce forest [151]. Singer [272] analyzed elk use of plant communities in relation to disturbance regime in northwestern Glacier National Park. Most elk use (82%) was associated with habitats that were maintained by frequent disturbance. Preferred habitats included grasslands and lodgepole pine savannas maintained by frequent surface fire, and willow/sedge communities maintained by frequent flooding. Quaking aspen communities and lodgepole pine-subalpine fir communities were used less often. Elk used these communities mainly after fire, when sprouting of aspen and shrubs was abundant. Douglas-fir communities with a history of repeated surface fire and occasional crown fires were used when snow was shallow or during early winter prior to deep snow accumulation [272]. Old-growth forests in the Olympic Peninsula appeared to provide a constant resource base for elk because small, local disturbances due to flooding and windthrow of trees were common and seemed to produce continuous elk forage [124].

Martinka [191] concluded that the highest elk densities were found in a complex of multi-aged conifer stands, intermixed across the landscape with previously burned bunchgrass and seral-shrub communities. Because of a lack of cover, the frequency of occurrence of elk in large burns or in clearcuts is expected to increase with forest succession due to a trade-off between cover and forage availability (Lyon and Jensen 1980 cited in [87]). Gruell [100] suggested that increases in cover as a result of succession may have benefited elk in some areas, although long-term succession leading to continuous forest cover would displace elk.

In the Trans-Pecos region of Texas, elk appeared to select habitats with a mix of forest and grassland. They used Pinchot's juniper woodland near riparian Coulter's brickelbush-honey mesquite-littleleaf sumac woodland and Mexican pinyon-gray oak-Pinchot's juniper woodlands year-round [349]. In southwestern Montana, two-layered forest stands were used more frequently by elk than were single-layered stands (Lonner 1976 cited by [275]). On summer ranges on Gila National Forest, New Mexico, the number of elk pellet groups was higher where shrubs such as birchleaf mountain-mahogany (*Cercocarpus montanus* var. *glaber*), Wright silktassel (*Garrya wrightii*), skunkbush sumac (*Rhus trilobata*) and *Quercus* × *pauciloba*, were intermixed with Colorado pinyon-alligator juniper-Utah juniper (*Pinus edulis*-*Juniperus deppeana*-*Juniperus osteosperma*) stands than where shrubs were absent [235].

A variety of habitats and seral stages can benefit elk because they provide food and cover throughout the year, as weather conditions and plant phenology change. Elk in northern Idaho along the Coeur d'Alene River in spring preferred grasses and sedges in seral brushfields, forbs in clearcuts, and evergreen shrubs in mature forests; in summer, they preferred shrubs in seral brushfields and mature forests, and fed on forbs in clearcuts; in fall, elk fed on evergreen shrubs in mature forests; in winter, they preferred shrubs in seral brushfields [133]. Twelve to 14 years after the 1988 Yellowstone fires, elk on the northern range selected areas of high vegetation diversity at large spatial scales during summer, and during winter elk selected less diverse areas such as grassland with interspersed forest at low elevation with less snow [36].

Edge habitats: Ecotones between forests and nonforest openings are important elk habitat when they provide a higher diversity and greater quantity of forage plants used by elk than do either of the adjacent communities individually [275]. The center of a large opening such as a meadow or burn may be little used by elk if it is too distant from shelter or water, and large areas of mature forest may be little used if there is little forage available [247]. In mixed-mesophytic hardwood forest in southeastern Kentucky, reintroduced elk had the highest release-site fidelity 1 year after release in areas with the greatest forest-opening edge and the least amount of human disturbance. The absolute area of forest or openings did not appear to affect site fidelity [162]. Typically, elk use of openings decreases with increased distance from cover (e.g., [164,189,234,236,275]). In the Blue Mountains of Oregon, >80% of elk used summer forage areas within 1,200 feet (400 m) of habitats providing cover [164]. In north-central Idaho, elk preferred large (>200 acres (81 ha)) clearcuts, but the preference may have been based on clearcut age (large clearcuts being younger than small ones). Elk seldom traveled farther than 150 feet (50 m) from the edge of clearcuts unless scattered clumps of trees were present in the clearcuts [118]. On northern Utah summer range, elk did not graze further than 200 feet (60 m) from the edges of quaking aspen or lodgepole pine forests [55]. In the Black Hills of South Dakota, the number of elk was positively associated with the shape complexity of meadows, as well as elevation, proportion of roadless habitat, proportion of forest stands with ≤40% overstory canopy cover, and proportion of quaking aspen [294]. In 5- to 15-year-old logged ponderosa pine forest on the Apache National Forest, Arizona, elk use of natural openings in the forest declined at distances >400 feet (120 m) from the forest border [234]. Elk often calve in edge habitats. See Calving areas for more information.

Age and gender: Habitat use often differs by individual elk age and gender. In a review DeByle [96] hypothesized that because of their smaller body size, females may require less food than males and thus, females may tend to sacrifice food in favor of security, whereas males may be more likely to sacrifice security in favor of food [96]. However, support for this idea is not consistent in the literature. Bull elk selected more southerly aspects, steeper slopes, denser forest canopies, and habitats farther from ecotones than cow elk from June through November in the Sapphire Mountains, Montana [189]. In contrast, in Prairie Creek Redwoods State Park, bulls were seen more frequently in forests than cows [91]. In fir-Douglas-fir forest at Starkey Experimental Forest and Range, thinning and burning of late-successional stands may improve habitat for female elk but have little benefit for male elk [177]. In the Clearwater National Forest, Idaho, >1-year-old bulls used seral shrub habitats less and open forests more than cows during winter [319]. In south-central Washington, all elk avoided roads, but adult males selected summer-fall home ranges in higher, steeper areas with relatively more mature closed-canopy forest and lower road densities than females [193]. In Oregon, there were no consistent differences in habitat selection among yearling male, yearling female, and adult female elk (Pederson and others 1980 cited in [319]).

Differing habitat use among genders may result in gender-biased mortality. Elk generally avoided the Blacktail Plateau during the first postfire winter after the 1988 Greater Yellowstone Area fires when 25% of the available foraging area burned. However, because bulls remained in greater numbers in burned areas than cows, bulls died at higher rates than cows [264,268], presumably from malnutrition. For more information on gender-biased mortality, see Predation risk.

Predation risk: Presence of predators alters elk habitat use, movements, diet, and behavior. Following gray wolf reintroduction in Yellowstone National Park, elk altered their movements and foraging patterns, presumably to minimize their risk of predation [188,240,244]. They increased use of forests and decreased time spent in open areas, riparian areas, and quaking aspen stands [188,336,350]. In low wolf-use areas in the northern Yellowstone winter range, cows preferred quaking aspen stands, followed by open areas and then conifer forests. As the risks of gray wolf encounter increased, open areas were preferred over quaking aspen stands followed by conifer forests. In high wolf-use areas, elk preferred conifer forests over open areas and quaking aspen stands, suggesting a trade-off between the search for food and safety [90]. In Greater Yellowstone areas with gray wolves, there was a negative relationship between the number of elk and distance from forest edge ($r^2=0.65$, $P=0.001$), but there was no such relationship in areas without gray wolves. The shift in habitat use from "riskier" open meadows to "safer" forests resulted in lower quality elk diets ($P<0.001$) [117]. In the Gallatin Canyon population, elk were more likely to forage in open grasslands in the absence of gray wolves but moved into conifer forests in the presence of gray wolves, presumably for protective cover [68]. In contrast, reintroduced elk on Chequamegon National Forest, Wisconsin, used forested areas proportionately to their availability and attempted to avoid gray wolves, establishing home ranges in the periphery of gray wolf territories. Forests were abundant, covering >63% of the landscape [8].

The Upper Gallatin elk herd consumed more willows in the presence of gray wolves. The authors suggested that either dense willow stands offered protective cover in a manner similar to conifer forest, or elk simply moved to the nearest trees or shrubs when they detected wolves, even if the cover was "less than ideal". Bull groups increased willow consumption in response to gray wolf presence more than cow-calf groups [65]. Other studies in the Greater Yellowstone Ecosystem suggested that willow and *Populus* spp. have been released from herbivory by elk since gray wolves were reintroduced, largely as a result of changing elk movements and behavior but also via additive direct predation by gray wolves (e.g., [30,241,244]). However, Kimble and others [148] noted that, even though elk numbers on the northern Yellowstone elk winter range have declined since gray wolf reintroduction, quaking aspen recruitment had not increased at the landscape scale on the Gallatin National Forest north of Yellowstone National Park. For more information on this topic, see Elk interactions with fuels and fire effects.

Elk may use terrain features to reduce predation risk. Elk on the northern Yellowstone winter range avoided riparian narrowleaf cottonwood (*Populus angustifolia*) and black cottonwood communities in high-risk habitats that had low visibility and/or barriers to escape (i.e., terrain features that could impede elk escape from attack, such as high terraces, steep streambanks, and gullies). They remained in or increased use of low risk riparian sites that allowed early detection, avoidance, and/or successful escape from gray wolves. They selected for upland habitats, which also likely lowered their risk of predation by gray wolves due to lower predator density and better escape terrain. The authors hypothesized that the use of upland conifer forests by elk was a risk-sensitive foraging strategy to avoid, detect, escape, and/or evade gray wolves [240]. See Ripple and Beschta [242] for a review of elk and other ungulate use of uplands and hill slopes as a means to reduce encounters with gray wolves that often use valley bottoms as travel corridors, rendezvous sites, and denning sites. Other terrain features that may be relatively unfavorable to elk and ungulates in general include deeply incised channels, multiple channels, oxbows, cut banks, terraces, and woody debris accumulations, which may limit visibility or cause fleeing elk to lose speed and maneuverability during a chase [242]. However, elk in the northern Madison Range, southwestern Montana, were more vulnerable to gray wolf predation in open vegetation types such as grassland. Although less vulnerable to gray wolf predation in juniper savanna, they were more vulnerable to mountain lion predation [14].

Elk alter their behavior in the presence of gray wolves. Bulls respond to gray wolf predation risk less than cows [68], with correspondingly higher mortality from predation. Cow elk in Yellowstone National Park, where gray wolves were present, spent more time in vigilance and less time foraging than cows in Rocky Mountain National Park, where gray wolves were absent. Cows in Yellowstone National Park also retreated to forest cover during midday inactive periods, whereas cows in Rocky Mountain National Park remained in open habitats [350]. In the upper Gallatin River drainage, southwestern Montana, male and female elk moved into or closer to forests in response to gray wolf presence. Cows responded to increased predation risk by increasing vigilance and decreasing foraging, and large mixed herds (cow, calf, and young bull) decreased in size. Bulls were in substantially worse body condition than cows throughout the winter, and bulls did not increase vigilance and decrease foraging in response to increased predation risk. Based upon proportions in the population, gray wolves selected bulls as prey more than expected and cows less than expected. The authors concluded that because of their poorer condition, bulls were less able to pay the costs associated with antipredator behaviors (i.e., reduced foraging) and were thus more susceptible to predation [343].

Predation risk from human hunting is also associated with reduced use of grasslands and increased use of forests (e.g., [182,204,275]). Other elk behavioral responses to human predation risk include changes in grouping behaviors and movement rates as well as distribution shifts from areas that allow hunting to areas where hunting is prohibited (e.g., [43,228,229]). Similarly, human disturbances such as logging and road building may cause substantial behavioral and physiological responses by elk, including movement, displacement, changes in group size, habitat shifts, and increased stress (see Human disturbance) [49].

Other factors:

Time of day: Elk are active throughout the day and night (see Daily activity), and their habitat use differs by the time of day. On the Olympic Peninsula, Washington, wintering elk usually fed in the bottomlands in the morning and gradually moved upwards to benches and hillsides to bed during mid-day. In the late afternoon, they gradually returned to the bottomlands where they fed until after dark [259]. From April to November at the Starkey Experimental Forest and Range, female elk during the day used habitats with greater forest cover, greater herbaceous plant abundance, and greater distance to hiding cover and open roads than at night ($P<0.05$), transitioning between daytime and nighttime habitats at dusk and dawn. Because elk used areas closer to roads at night, the authors suggested that the assumption that roads and associated disturbances are primary agents driving elk distributions across landscapes might be an oversimplification [1]. See Human disturbance for more information.

Coarse woody debris: Elk often avoid areas with abundant coarse woody debris [262,328]. See Logging slash and Physical barriers for more information. However, a 2002 review stated that coarse woody debris may be important as cover in calving areas [275]. See Calving areas for more information.

Roads: Elk habitat use may be limited by the extent of roads open to motor vehicles [184]. See Human disturbance for more information.

Cover requirements:

- Water
- Calving areas
- Lick sites

Water: Elk often select riparian areas seasonally. Elk summering in the Blue Mountains of Oregon spent 40% of their time in riparian zones, which made up only 7% of the summer range. The authors suggested that these areas were attractive to elk because of the abundance of thermal cover and the microclimate produced by vegetation (Thomas and others 1979c cited in [262]). Similarly, in Utah, elk spent 44% of their grazing time and 50% of their time for resting and other activities in wet meadows, which made up only 3% of the total area. Wet meadows were described as seldom exceeding 49 feet (15 m) in width, restricted to areas immediately adjacent to stream courses, and often densely covered with live and fallen trees, beaver dams, high shrubs, and tall grasses (Collins 1977 cited in [262]). In Idaho, highest elk forage utilization occurred in moist habitats between streams or bogs and upland sites (Hayden-Wing 1979 cited in [262]).

Studies in Utah (Jeffrey 1963 cited in [78]), Montana [186,189], Idaho [132], Washington (Nelson and Burnell 1975 cited in [78]), Oregon [52,295], California (Grenier 1991 cited in [214]), and Arizona [78] found that elk generally prefer habitats <2,600 feet (800 m) from surface water.

Water availability may be particularly important during periods of forage desiccation, lactation, or heat stress (review by [34]). Elk in Oregon selected low-elevation forests near permanent water during calving [347]. In south-central Washington sagebrush steppe, elk movements and home ranges appeared to decrease in summer with the onset of summer drought and elk movements became increasingly centered around permanent water sources and riparian areas where succulent forage was still available. However, prior to calving in spring, female elk used areas near water very little, suggesting that water needs prior to calving were primarily met through forage consumption [194]. DelGiudice and Rodiek [78] suggested that the availability of more succulent, digestible forage at an earlier phenological stage of development probably influenced elk need for sites near water sources. In the southern Oregon Coast Range, the moistest habitat, the Aleutian maidenhair-common ladyfern (*Adiantum aleuticum-Athyrium filix-femina*) community, had the the most elk use; the driest habitat, the oceanspray (*Holodiscus discolor*)/salal community, had the least [295]. Water may be limiting to elk in many arid areas of western North America [344].

Elk resting and grazing near the Firehole River in Yellowstone National Park.
Photo courtesy of Katharine R. Stone, USDA Forest Service.

Calving areas: Pregnant cows leave the main herd in spring several days prior to parturition. After giving birth, the cow and calf remain in proximity of, but secluded from, the main herd for several days to several weeks (the "hiding period") [91,221,296,344]. Many cows return to the same areas each year to calve [165,231]. Calving usually occurs on transitional ranges, but may also occur on upper elevational limits of winter ranges, or less commonly on lower elevational limits of summer range [140,165,221,226,245,275,357]. According to reviews, calving habitat selection requires abundant succulent and nutritious vegetation, which is related to the receding snow line and plant phenology and thus elevation [275,296].

Throughout their range, elk calve in a variety of habitats including grasslands, shrublands, and forests (e.g., [72,109,226]). For example, in Boyes Prairie, northern California, 11% of calves were born along a Sitka spruce/salmonberry-meadow edge, 56% in grasslands, and 33% in riparian hardwood forests or shrublands [109]. Within open habitats, elk commonly select areas near ecotones providing cover for calving [221,275,296]. In the Gallatin Canyon, calving areas were located mostly in the ecotone between big sagebrush-lodgepole pine forest and big sagebrush-quaking aspen forest. Calving areas were an average of 220 feet (67 m) from forest if in sagebrush, and within 30 feet (9 m) from sagebrush if in forest [140]. At the Cimarron National Grassland in southwestern Kansas, reintroduced elk preferred to calve in riparian areas with plains cottonwood and nonnative saltcedar adjacent to sand sagebrush prairie remote from gravel roads and highways [31]. Newborn calves in Montana were often found close to edge habitats, a short distance into the forest community [233]. Within closed-canopy habitats, elk may select openings for calving [275]. For example, in Montana, elk used small openings in moderately dense forest as calving areas [189]. According to a 2002 review, coarse woody debris may be important to elk as cover in calving areas [275].

Topography appears important in calving area selection, with elk frequently selecting gentle slopes on southern aspects. In Oregon, cows selected calving areas that had a more open canopy and gentler slopes than paired random plots, and it appeared that cow elk were selecting calving areas with more forage than random sites, presumably to meet nutritional demands due to lactation [232]. In the San Juan Mountains, Colorado [296], and in the Madison River area, Montana [233], elk selected southern aspects for calving.

Lick sites: Mineral licks used by elk provide minerals (e.g., sodium, magnesium, and sulfur) and buffering compounds (carbonates and clays) important to elk nutrition and digestion [15]. Consumption of lick water and soils may improve rumen function and nutrient absorption during transition from low-quality, high-fiber winter diets to high-quality spring forage, or from high-quality spring forage to summer forage with higher concentrations of plant defense compounds; improve palatability and digestibility of forage by absorbing tannins and toxins; replace mineral reserves depleted during winter; and supplement elemental intake during molt, antler growth, and nutritional stress associated with pregnancy and lactation [16]. In the North Fork of the Clearwater River drainage, northern Idaho, mineral concentrations of 7 elk forages generally met estimated requirements for elk during May to November, with the exception of sodium [3]. In northeastern Nevada, sodium levels in 12 elk forages on summer range never exceeded about 10% of estimated requirements [25]. These studies suggested the importance of alternate sodium sources such as licks in elk diets [3].

Peak lick use occurs in spring after vegetation green-up and in early summer during calving (e.g., [16,73,357]). In northern British Columbia, high use of wet mineral licks in valley bottoms by male and female elk in late May followed vegetation greening at low elevations. Average attendance at licks by female elk was highest in late June coincident with high lactation demands [16]. Elk in Idaho used natural and manmade salt licks extensively in late April after they had been feeding on succulent forage for 2 to 3 weeks. Peak lick use occurred from late May to early June just prior to and during peak calving, which occurred the first week of June [73].

MANAGEMENT CONSIDERATIONS:

Federal legal status:

No special status

Other status: Information on state- and province-level protection status of animals in the United States and Canada is available at NatureServe, although recent changes in status may not be included.

Other management information:

- Status and threats
- Habitat management
- Population management

Status and threats: Historically, elk occurred throughout most of the United States [221]. Elk were extirpated from large parts of their range in the eastern and southwestern United States by the late 1800s and early 1900s [210,211]. Causes for historical range contraction included competition from livestock, overharvesting, agriculture and land development, and introduced diseases [211]. In 1890, only about 100,000 elk existed in the United States and most of these were confined to Yellowstone National Park [184]. However, by 1999, about 780,000 elk existed in the United States [221]. Much of the increase in elk numbers during the 1900s was due to a combination of human translocations of elk, natural range expansion, and extensive wildfire and logging that resulted in abundant foraging habitats [221,306].

Threats to elk populations include overharvesting; increased human disturbance, especially road building; reduction in forage quantity and quality because of successional changes in habitats; nonnative invasive plants; and possibly climate change.

Human disturbance: Elk are sensitive to human disturbance, although they can be conditioned to the presence of humans such as in national parks [221]. In general, elk avoid roads with human activity and avoid disturbances created by active logging operations [275].

Repeated human disturbance may reduce elk reproduction and calf survival. In an experimental study in central Colorado, repeated human displacement of female elk for 3 to 4 weeks during calving reduced calf:cow ratios on alpine summer ranges. Average calf production was 0.225 calves per cow lower for disturbed elk than for undisturbed elk [224]. A subsequent study showed that elk productivity rebounded following release from disturbance and full recovery occurred by the second year after disturbance ceased [263].

Roads: Elk avoid areas near roads open to motorized vehicles across a variety of seasons, landscape conditions, and geographic regions. Elk generally avoid habitat adjacent to roads, particularly during calving and hunting seasons and during the rut. In the Oregon Coast Range, elk avoided areas within 820 feet (250 m) of roads with human activity year-round, but the greatest degree of avoidance occurred during calving and the rut [348].

Elk avoidance of roads may be stronger during the hunting season [132,344], but in areas where elk are hunted, elk may be distributed away from roads even during the nonhunting season (Rowland and others 2000 cited in [221]). In the Lochsa River area of Idaho, elk winter counts decreased as the percent of summer range logged increased. Apparently logging and associated road building increased elk vulnerability to hunting mortality. The disturbance also caused elk to shift to a winter range where disturbance was less [169]. In the southern Oregon Coast Range, Cole and others [51] found that restricting vehicle access increased elk survival due to reduced poaching (P=0.03) and reduced their movements due to reduced disturbance (P<0.0001). See Wisdom and Cook [344] and Leege [165] for reviews of road effects on elk hunting success.

The width of the area adjacent to roads avoided by elk has been reported as 0.25 to 1.8 miles (0.4-2.9 km), depending on the amount and kind of traffic, quality of the road, and density of cover adjacent to the road [184]. Roads in grasslands and openings are most avoided. In northern Idaho, elk preferred unroaded shrub fields despite greater abundance of forage in roaded clearcuts [172]. In the southern Oregon Coast Range, elk increased use of open, foraging habitats such as grass-forb and shrub communities, after vehicle access was reduced, but they used areas close to roads less than expected regardless of vehicle access [52]. Reintroduced elk on Chequamegon National Forest, Wisconsin, avoided areas near roads when establishing a home range but selected areas near roads within the established home range. At the broad scale, roads may have been avoided because they presented a mortality risk due to cars and hunters. At a smaller scale, roads may have been selected within home ranges because they provided both openings and edges in the predominantly forested landscape (see Preferred habitat) [8].

Elk may use areas near roads as refuge from nonhuman predators. In Banff National Park, in high-predation risk sites with low human use, valley bottom trails were frequented by gray wolves and avoided by elk. The opposite effect occurred in low-predation risk areas, such as near highways, where elk were attracted to valley-bottom travel routes heavily used by humans but avoided by gray wolves [335].

Logging disturbance: Elk may move from actively logged areas to areas without such disturbance. Logging and associated road building may cause elk on summer range to move >4 miles (6.4 km) from the source of the disturbance [183,184]. However, in general, the distance elk moved in response to logging disturbance appeared to be the minimum necessary to avoid contact with people and equipment, and displacement was often <1 mile (2 km) [184]. Typically, displacement was temporary and elk returned to logged areas within a few days to weeks after the disturbance ended. However, the time elk required to return to disturbed sites varied; some animals return when logging activity ceased on nights and weekends; others returned within a few days to weeks after disturbance ended; and others became habituated to logging activity [183,184]. Elk that are forced to move great distances to find security may be less likely to return immediately [189]. Continual logging for 5 years within an individual watershed in western Montana imposed learned behavior that delayed elk return to previously used habitats [181]. Although displacement of elk during logging activity and road building is typically temporary, a review of logging activity effects on elk in western Montana suggested that even temporary displacement may reduce usable habitat and increase stress, which could be detrimental to elk [182].

Where cover is present, elk may not be disturbed by logging activity. In the Garnet Mountains, Montana, home ranges of individual cow elk were not altered because of logging activities when areas of extensive cover remained available within their home range. The authors concluded that logging activities that are restricted in time and space or conducted on seasonal ranges during periods when elk are not present will be least disruptive to elk movements and behavior [84]. Skovlin and others [275] stated that although logging and associated road building may diminish elk use in the short term, in the long term, logging can be designed to enhance diversity of elk forage and cover. See Logging for more information on this topic.

Succession: Elk use habitats in all stages of succession and show considerable plasticity in their response to changes in habitat (see Successional status of elk habitats). In areas with continuous forest cover, lack of early-successional habitats may limit elk densities [100]. Elk populations declined in much of the Rocky Mountain region during the 20th century due to fire exclusion [260,288]. In southwestern Manitoba, small elk populations in Spruce Woods Provincial Park were attributed in part to fire exclusion that allowed forests to become closed [123]. Elk herds expanded in north-central Idaho after large wildfires during 1910, 1919, and 1934, when burned forests succeeded to shrub fields with more abundant browse. As forests regenerated, elk numbers decreased because the later stages of succession, such as grand fir and western redcedar forests, were less desirable to elk, especially on winter range [166,333]. However, Lehmkuhl and others [174] concluded that population declines in the Lochsa River elk population in north-central Idaho were driven more by hunting and severe winter weather than by broad habitat changes during postfire succession. Yeo and Peek [355] commented that the fact that "high (elk) populations have been sustained in the Clearwater, St. Joe, and Coeur d'Alene River drainages even as many of the shrub fields have deteriorated and been replaced by sapling and pole stands of conifer illustrates an ability to adapt to what initially appeared to be an adverse change in habitat". For more information on this topic, see Fire Regimes.

Nonnative invasive plants: Spread of nonnative invasive forbs on elk ranges may reduce elk forage and thus elk use of infested sites. For example, graminoids comprise a major component of elk diets on many rangelands and, according to a review by Rice and others [238], decreases in graminoid production of 60% to 90% are common on spotted knapweed (*Centaurea maculosa*)-infested rangelands. Thus, spotted knapweed spread may lower the carrying capacity of elk winter ranges where grasses could provide late winter and early spring forage [238]. In southwestern Montana, the number of elk pellet groups/acre was 45 times higher on bunchgrass wheatgrass-dominated sites than spotted knapweed-dominated sites [102]. However, the effect of nonnative invasive plants on elk habitats varies. When spotted knapweed was removed with herbicides from an historic elk winter range in western Montana, elk use of the area increased dramatically, especially in the winter immediately following the herbicide treatment because of the rapid flush of high-quality perennial grasses. However, in subsequent winters, the accumulation of dead grass reduced the attractiveness of these grasses to elk [300]. In Theodore Roosevelt National Park, North Dakota, elk used areas with leafy spurge (*Euphorbia esula*) less than similar areas without leafy spurge, apparently because elk forage species were less productive in areas with leafy spurge. Elk use of needle-and-thread grass-threadleaf sedge (*Hesperostipa comata-Carex filifolia*) sites with leafy spurge was 81% less than sites without leafy spurge during 2 years ($P<0.07$). Elk use of chokecherry (*Prunus virginiana*) browse in green ash (*Fraxinus pennsylvanica*)-chokecherry woodland during summer and winter was reduced an average of 32% in areas with leafy spurge in part due to reduced density of chokecherry.

Several studies reported that elk consume nonnative invasive plants, such as spotted knapweed [163,201,352], or that elk use habitats with nonnative invasive plants more than adjacent, uninvaded habitats [192,352]. However, elk use of brome (smooth broom (*Bromus inermis*), Japanese brome (*Bromus japonicas*), and cheatgrass (*Bromus tectorum*))-infested western wheatgrass-threadleaf sedge sites was similar to that for areas without brome during 2 years [313]. In Idaho, elk used spotted knapweed habitats as much or more often than nearby bunchgrass-sedge habitats during winter. Elk commonly fed on spotted knapweed rosette leaves on open, south-facing slopes soon after snowmelt, and spotted knapweed was one of the few herbaceous plants readily available to elk in open areas when snow was >12 inches (30 cm) deep [352]. In southwestern Montana, elk generally avoided spotted knapweed-dominated sites [102], but where spotted knapweed was abundant, it was frequently consumed [163]. Differences among studies may be attributed to differences in elk densities, snow cover [352], and forage availability and phenology. In south-central Washington sagebrush steppe, elk preferred to forage in Sandberg bluegrass habitats that were burned by periodic wildfires over the past 35 years. Foraging was greatest in February and March when snow had melted and new growth was abundant. Cheatgrass habitats that were burned in periodic wildfires were heavily used during December and January while snow remained on the ground. Elk primarily foraged on tall forbs and grasses emergent from the snow in cheatgrass communities [192].

Fire can increase abundance of nonnative invasive plants, which may be detrimental to elk by reducing forage. In an attempt to improve elk rangeland by reducing encroaching limber pine, Rocky Mountain juniper (*Juniperus scopulorum*), Douglas-fir, big sagebrush, and rubber rabbitbrush (*Chrysothamnus nauseosus*), a spring prescribed fire was applied in a big sagebrush/bluebunch wheatgrass-Sandberg bluegrass-Dalmatian toadflax (*Linaria dalmatica*) community in the Elkhorn Mountains, southwestern Montana. In burned areas, Dalmatian toadflax biomass increased 2.5 times and its seed production increased 16 times compared to areas that were not burned. The authors concluded that fire on rangelands with Dalmatian toadflax may increase its dominance [134]. For more information on fire effects on nonnative invasive plants, see FEIS reviews of individual species and the synthesis: *Wildland Fire and Ecosystems: Fire and Nonnative Invasive Plants* [359].

Overgrazing by historically high levels of wintering elk was hypothesized to be a factor in spotted knapweed population expansion at the expense of native plant populations in Idaho fescue and alpine rough fescue grasslands of Glacier National Park [318] and bunchgrass and shrub habitats in southwestern Montana [163]. Thompson [300] suggested that when planning nonnative invasive plant removal to benefit elk, resource managers should consider elk density and distribution, as well as preexisting range condition, nonnative invasive plant density, occurrence of preferred forage species, and the probability of adequate soil moisture for subsequent grass growth in the first growing season after treatment.

Climate patterns and climate change: Because elk survival may be influenced by deep snow accumulations (see Malnutrition and weather), it is potentially affected by large-scale climatic fluctuations, which influence local temperature and precipitation patterns. In the Rocky Mountains, positive North Pacific Oscillation (NPO) index values are related to cooler winter temperatures, increased snowfall, and increased frequency of winter storms. Researchers examined the influences of the NPO on elk population dynamics in Banff National Park during 15 years for 3 elk populations exposed to different levels of predation by gray wolves. High NPO, which reflected increased winter severity, was related to reduced elk population growth rate, and the reduction was greater in areas with gray wolf predation [112]. At Tomales Point at Point Reyes National Seashore, California, elk population growth rate was positively associated with precipitation, likely due to increased plant productivity. The researchers concluded that elk populations may increase during strong El Niño Southern Oscillation years, when precipitation is high in California, with declining growth rates during dry inter-El Niño periods [126]. In Montana, dispersing elk expanded their movements outside of traditional habitats during wet years but under drier conditions rejoined source populations [323], suggesting that during inter-El Niño periods, when precipitation is high in Montana, elk may be more likely to disperse into new habitats and expand their ranges.

Because weather affects elk population dynamics, global climate change may potentially affect elk populations. Estimated effects of climate change on elk will depend on the direction and scope of changes that occur. Because local losses of elk are not predicted to be compensated by elk range expansion into new geographic locations, climate change models comparing current and predicted geographical distributions under doubled carbon dioxide levels predicted that elk's geographic distribution will shrink [141]. However, based on global and regional climate change models predicting reduced snow accumulation locally in Montana, elk populations were predicted to increase in this area [66,248]. See Millspaugh and others [202] and Wallace and others [330] for reviews of potential responses of fire regimes, vegetation, and elk to climate change in the Greater Yellowstone Area.

Habitat management: Disturbance can produce habitat for elk by favoring forage growth and by creating ecotones between areas of dense cover and more open feeding areas. Conversely, loss of cover over large areas can be detrimental for elk. Several researchers suggested that resource managers may need to consider proximity of food, cover, water, and mineral licks, and the effects of hunting and other human disturbances [193,344]. Timmerman [304] suggested that forest disturbance should be managed for elk and other ungulates to maintain a diversity of vegetation types and age classes.

- Prescribed fire
- Logging
- Livestock grazing

Prescribed fire: For information on the use of prescribed fire in elk habitats, see Fire management considerations.

Logging: Logging may alter the amount and distribution of cover and forage areas and change elk movements, distribution, and habitat use [165]. Logging may benefit elk because many elk forage species are well-adapted to disturbance, and early-seral habitats often contain a greater variety, quantity, and quality of elk forage than mature forests. However, increased forage quantity and quality in logged areas may not be immediate and may be short-lived [221,297,344,345]. Elk commonly use clearcuts and other logged areas for foraging, often selecting them over other available habitats (e.g., [215,347])(see Postlogging vegetation changes and succession). However, elk use of clearcuts is modified by opening size, proximity of cover, presence of roads and human disturbance, logging slash, predation risk, predisturbance movement patterns, and weather, particularly snow depth [58,183,184,221,262,345]. Although logging may offer some benefits to elk, a review by Lyon and Christensen [184] noted that few studies have reported increases in elk populations due to logging. Leege [165] suggested that beneficial forage can result after logging in elk home ranges that have a dense canopy and a limited understory of shrubs, grasses, and forbs, whereas logging in forests with many natural openings may not provide forage benefits.

Postlogging vegetation changes and succession: According to a review, logging is likely to cause an immediate but short-term (0-3 years) decline in elk forage availability followed by large increase in forage that may last 10 years or longer [345]. Using a model of forest succession in western Alberta, elk forage (herbaceous plants and browse) was predicted to peak 9 years following logging of lodgepole pine forest. Browse composition was predicted to shift from palatable species to unpalatable species after about 30 years. Forty years after logging, herbaceous forage biomass was predicted to be 50% higher than that in mature forest stands, whereas palatable browse biomass was predicted to be 25% less than the palatable browse biomass found in mature conifer stands [327]. Elk on the western Olympic Peninsula selected 6- to 15-year-old clearcuts and >150-year-old Sitka spruce bottomland forests during winter possibly due to abundant forage, snow interception, and juxtaposition of these habitats. They tended to select >10-year-old red alder-black cottonwood-bigleaf maple forests in valleys during spring, summer, and fall, which had >95% ground cover of elk forages. The youngest (1- to 5-year-old) clearcuts and even-aged 16- to 150-year-old conifer stands with >94% cover were generally avoided during all seasons, presumably due to lack of forage [258].

Understory vegetation production generally decreases as overstory cover increases, and potential benefits of timber harvest on elk populations largely emanate from this relationship [58]. In mixed-conifer forest in eastern Oregon, elk use based on pellet counts was highest in clearcuts, intermediate in uncut stands, and lowest in partial-cut stands, during the 5 years following harvest. The author attributed these patterns to forage production in clearcuts and the hiding cover provided by uncut stands. Partial-cut stands apparently lacked adequate amounts of either (Edgerton 1972 cited in [262]). There was an inverse relationship between ground cover and tree density in Colorado pinyon-juniper woodlands in the Zuni Indian Reservation in western New Mexico that were thinned to 3 levels: heavily thinned (30 ft^2/acre), moderately thinned (57 ft^2/acre), and lightly thinned (83 ft^2/acre). Burning was not conducted because surface fuels were too sparse due to livestock grazing. Understory vegetation density increased most in the heavily thinned plot during posttreatment years 1 to 5 and then declined, but was still 17 times that of control plots in year 8, when the study ended. The number of elk and deer (*Odocoileus* spp.) pellets in the heavily thinned plots ranged from 4 to 29 times the number in control plots during posttreatment years 1 to 8 [2].

Logging effects, and thus elk use of clearcuts, depend on many factors, including site characteristics and plant community composition. On elk winter range along the White River drainage in Washington, deciduous shrubs, forbs, and graminoids used as elk forage increased following clearcutting of western hemlock forest on xeric alluvial terraces and uplands. This seral community persisted for approximately 20 years but then became shaded by a dense mid-successional Douglas-fir overstory. In mesic floodplain western hemlock forest, however, a community of forbs and graminoids established after clearcutting and persisted at least 35 years, because high water tables and heavy elk browsing impeded forest overstory development [139]. In the Fraser Experimental Forest in central Colorado, 12 evenly spaced 3-acre (1 ha) clearcut blocks were placed in a 667-acre (270 ha) Engelmann spruce-subalpine fir-lodgepople pine forest. On average moisture sites, elk pellet groups were similarly low before and after logging on both uncut and clearcut blocks, although numbers increased gradually on the clearcuts during 5 years. However, on moist clearcut blocks, elk were 4 times more abundant 5 years after clearcutting than before clearcutting ($P \leq 0.05$) [70].

Elk forage quality may differ between logged and unlogged forests. In western Washington and Vancouver Island, nutrient content of trailing blackberry, an important elk forage species, dropped immediately after logging but recovered by postlogging year 9. Thereafter, crude protein content dropped steadily through postlogging year 25. Crude fiber content was high in mature forest, higher immediately after logging, and then favorably low through postlogging year 25 [297]. A 2002 review concluded that relationships between elk forage nutritive value and forest cover likely vary across regions and plant communities occupied by elk and depend in part on whether plants contain tannins [58]. In very wet, coastal regions in western North America, high solar radiation in clearcuts apparently increased elk forage nutritional value but also increased concentrations of tannins, which inhibit digestibility of forage [58]. For example, on the Olympic Peninsula, elk used old-growth and clearcut Sitka spruce-western hemlock forests where salmonberry, red huckleberry (*Vaccinium parvifolium*), vine maple (*Acer circinatum*), and western swordfern (*Polystichum munitum*) together comprised 18% of the elk summer diet, 7% of the fall diet, 32% of the winter diet, and 45% of the spring diet. These species were present in both old-growth (>200 years old) forests and in clearcuts (5-15 years old). However, these species generally had a greater proportion of leaves, were more succulent, had higher percent crude protein, and less tannin in old-growth forests than in clearcuts [107], suggesting that less understory forage biomass in old-growth forests compared to clearcuts may be offset by the higher digestibility of forage in old-growth forests [221].

Postlogging site preparation: Postlogging site preparation practices employed in elk habitats often include prescribed fire, and such practices may benefit elk in the short-term by increasing forage. On the western Olympic Peninsula, elk used 2 clearcuts in western hemlock forest that were burned in a "patchy" prescribed fire in late May. Some plots were also fertilized, seeded with grasses and forbs, and planted with western hemlock, western redcedar, and Douglas-fir seedlings. It took 2 years for the treatments to be completed. During postfire year 2, elk and mule deer (*Odocoileus hemionus*) pellet group densities were higher on unburned plots than burned plots. During postfire years 3 and 4, pellet group densities were higher on burned than unburned plots, coincident with peak forage grass production in burned areas. During postfire year 5, when grass production declined markedly, pellet group densities were higher on unburned than burned plots [173]. In a southwestern Alberta quaking aspen forest, elk browse production the second year after clearcutting and prescribed burning was 55% greater than in uncut stands. During posttreatment year 7, browse production declined compared to posttreatment year 2 but was still 52% greater than in uncut stands. Grass production was greater in treated stands than in uncut stands 2 years after treatment, but was similar to production on controls 7 years after treatment. Forb production was not affected by clearcutting and burning [299]. Elk on the Millicoma tree farm in coastal forests in southwestern Oregon increased foraging on logged and burned sites. Elk numbers peaked within 5 years of treatment and by postfire year 12 had declined to those observed the year following the treatment [108]. Elk appeared to be attracted to burned clearcuts due to the presence of grasses, forbs, blackberries (*Rubus* spp.), and early- and mid-seral trees [295]. Elk forage, particularly willow and quaking aspen sprouts, increased after a spring (March-April), low-severity prescribed fire in a ponderosa pine/Douglas-fir stand in Montana. The stand had been thinned from below, selectively cut, and slash-piles burned prior to the prescribed fire [11]. According to a review, prescribed burning may improve elk forage production on clearcut sites and extend the length of time preferred forages are available [196]. For more information on the effects of fire in elk habitats, see Indirect fire effects.

Opening size: Elk use of clearcuts may in part depend upon opening size [183]. According to a review, large openings are more likely to be used in unhunted and/or undisturbed populations. In areas where tree cover is nearly continuous, elk may use large openings but appear to prefer small openings. Apparently, elk are more likely to use large clearcuts in regions where large natural openings occur [184]. Because elk use of large openings typically decreases with distance from the forest-opening edge (see Edge habitats), elk may increase use of large openings with irregularly shaped edges; patches of cover within openings; and/or patches of cover connected to edges by stringers of trees [289]. For more information, see Burn size and shape.

Logging slash: A 1980 review stated that logging slash generally impedes elk movements and may act as a barrier to elk use of clearcut openings and selectively logged areas [183]. Lyon [180] used a model to demonstrate that elk use of clearcuts was reduced when logging slash and other coarse woody debris inside the clearcut was >1.5 feet (0.5 m) deep. Conversely, some logging slash may benefit elk by providing cover [184]. In the southern Oregon Coast Range, high elk use occurred where slash lay in patches or windrows that provided some hiding cover, whereas elk use was lower where slash was uniformly distributed [295]. In north-central Idaho, elk use of clearcuts treated for slash removal and those not treated was similar. However, the authors noted that slash buildup was not so tangled that it hindered elk movements or precluded use of forage beneath. The authors further noted that slash provided elk some escape cover without severely impairing their field of view [118].

Some investigators recommended prescribed fire to reduce logging slash for elk (e.g., [183,328]). In ponderosa pine forest in north-central Arizona, when small (0.5-3.5 ha) forest openings were created to increase forage in ponderosa pine forest, elk used openings that had been cut and windrows burned to remove slash more than openings that had been cut but not burned. Elk, mostly adult cows and calves, grazed primarily along burned windrows, where forage was green and succulent. Residual slash, when present, did not appear to provide a barrier to movement [88]. For information on use of prescribed fire in logged areas used by elk, see Fire management considerations.

Livestock grazing: Influences of livestock grazing on elk can be detrimental, neutral, or beneficial [326]. Grazing, as well as the physical presence of cattle (*Bos primigenius*), domestic sheep (*Ovis aries*), and other livestock, can have negative impacts on elk not only by reducing forage, but by causing behavioral changes and altering activity budgets that make foraging less productive [46]. Alternatively, removal of forage by livestock may improve forage quality for elk through effects on plant growth patterns, by enhancing regrowth, and by changing ratios of live to dead plant material [58].

Some studies reported that elk avoided areas grazed by livestock [46,186], whereas others studies reported that elk avoided areas only while livestock were physically present [165,184,186,274,275], and others indicated few behavioral changes in elk as a result of livestock grazing [46,48]. In Utah, elk preferred ungrazed areas during rest-rotation grazing (Clegg 1994 cited in [46]). Elk used higher elevations and steeper slopes due to cattle grazing in east-central Idaho [356]. At the Starkey Experimental Forest and Range, elk used low elevations when cattle were absent but moved to high elevations when cattle were present [291]. Because elk and livestock diets overlap, removal of forage by livestock increases the potential for competition and may result in reduced nutrient intake by elk [46,58,221]. Elk and livestock diet overlap increases when forage becomes less available [46], therefore the potential for competition appears highest on winter and transitional ranges that include low-elevation bottomlands and adjacent foothills, where forage and habitat use are most limited. Competition for forage during late summer and fall may also be high following periods of prolonged seasonal drought [221]. According to a review, elk appear to avoid areas where cattle are present if other options exist, but where no other options exist, elk will tolerate some cattle presence [48]. Elk choice of grazing areas in central Arizona was more dependent on tree growth patterns and terrain features than on the presence or absence of cattle grazing in the area (Halstead and others 2002 cited in [46]).

Livestock grazing of bunchgrasses can reduce accumulation of old, standing dead plant material, thereby increasing the availability of young, nutritious growth, which may increase the quality of elk diets [58,143]. On Oregon's coast range, summer grazing by domestic sheep did not reduce graminoid quantity and improved crude protein content and dry matter digestibility of graminoids the following October by stimulating regrowth of plants. The following spring, forage quality was similar, but forage quantity increased by 70%, apparently due to earlier green-up in grazed than ungrazed areas [237]. Anderson and Scherzinger [9] reported a 260% increase in elk numbers following cattle grazing in northeastern Oregon. In Montana, elk use of winter rangelands increased after livestock grazing the previous summer [143]. According to reviews, livestock grazing effects on elk habitats likely depend on the magnitude of forage quality improvements and forage quantity reductions; whether elk populations are limited by forage quality or forage quantity; the extent of overlap of elk and livestock diets; as well as season, weather, and ecological setting [46,58].

Because burns attract livestock [262], fire could increase potential for elk-livestock interactions. See Livestock presence in burns for more information on this topic.

In addition to the influence of livestock on elk habitat structure via overgrazing, competition for forage, and behavioral interactions, range management practices that reduce shrub and tree growth to produce more grass for livestock may influence elk habitats negatively. For example, large areas of southwestern pinyon-juniper woodlands have been converted to grasslands and weed infestations by various mechanical methods including chaining, cabling, crushing, and disking. For a review of livestock management effects on elk and other ungulates in the Southwest, see Severson and Medina [262]. For more information on cattle grazing effects on elk, see the review by Chaikina and Ruckstuhl [46].

Population management: Elk are hunted throughout most of their range [284]. Hunting can alter population density, adult sex ratios, and life span. Heavy hunting pressure on mature bull elk that alters age ratios of males may influence conception dates and thus birth dates of elk. Late conception dates and a prolonged and asynchronous calving period may result in later born calves and higher overwinter calf mortality (see Calf survival) [221,230]). Heavy hunting pressure may also alter conception dates by disturbing elk. In northern Utah, conception dates for a heavily hunted elk herd was bimodally distributed with a decrease in the frequency of conceptions around the opening dates of the regular bull hunting season, causing elk conception to be delayed but not prevented. The authors concluded that heavy hunting pressure interfered with normal breeding [283]. Hunting may also affect elk behavior, including changing activity times, movements, and habitats use. For more information on elk population management, see the review by Stalling and others [284].

Winter feeding of elk occurs at a number of locations in western North America, such as the Jackson Hole area, as a means of managing populations, which may affect elk habitat use, behavior, survival, reproduction, and growth. For more information, see the review by Smith [276].

FIRE EFFECTS AND MANAGEMENT

SPECIES: Cervus elaphus

- DIRECT FIRE EFFECTS
- INDIRECT FIRE EFFECTS
- FIRE REGIMES
- FIRE MANAGEMENT CONSIDERATIONS

DIRECT FIRE EFFECTS:
Fire has killed elk directly [92,268], but fire-caused mortality rates of large mammals are generally low (<1%) [92], and direct fire-caused mortality is thought to have little effect on large mammal populations [92,185]. The Greater Yellowstone Area fires of 1988 directly killed approximately 1% of the 31,000 elk summering within Yellowstone National Park [268].

Large mammal mortality is most likely when fire fronts are wide and fast moving, fires are actively crowning, and thick ground smoke occurs [92,268,328]. Necropsies revealed the primary cause of death of elk and other large mammals during the 1988 Yellowstone fires was asphyxiation by smoke inhalation [92,268].

As with other large ungulates, such as moose (*Alces americanus*), the number of fatalities caused by fire is likely related to season, population density, habitat type, fuel load, availability of escape terrain, and prevailing winds [47]. Elk calves may be most vulnerable to fire-caused mortality in spring during the hiding period, when they are relatively immobile. However, Collins [54] commented that young-of-the-year of most mammals, including elk, would have been able to escape an early-August mixed-severity wildfire on the Salmon National Forest, Idaho, in part because considerable escape terrain was available in the form of rock outcrops and slides. During the 1988 Yellowstone fires, topography, aspect, and habitat affected rates of fire spread and thus elk susceptibility to direct fire-caused mortality. Forty-one percent of elk carcass groups were on mountain sides or ridgetops, 26% were on level or rolling terrain, and 33% were in creek bottoms. Eighty-two percent of elk carcass groups were in conifer forest and 18% were found in grasslands, usually on the edge of a forest. Fire fronts >1 mile (2 km) wide and total fire runs of 4 to 13 miles (6-21 km) in a day were characteristic of the sites where elk and other large mammal mortality occurred. All dead elk were found in sites where estimated rates of fire spread ranged from 4.1 to 6.9 kilometers/hour; no elk mortality was observed in areas where slower rates of fire spread were estimated. More adult males died in the fires than expected based on the herd ratio ($P<0.002$). Bulls may have been more susceptible to direct fire-caused mortality because they tended to use mature forests, where fires spread more rapidly than in open habitats used by cow-calf groups [268].

During the 1988 Yellowstone fires, most direct mortality occurred in large groups. Postfire studies found groups of carcasses ranging from 1 to 146 dead elk [92,268]. The largest group consisted of 37 calves, 8 yearling females, 18 yearling males, 74 adult females, and 9 adult males found in a 390-foot (120 m) diameter area. This and 2 other large groups ranging from 18 to 33 individuals were apparently killed in a single firestorm, which was wide and fast moving, and had a thick, low-lying cloud of smoke in advance [92]. One group of elk was caught between the Mink fire and a back burn set by firefighters [268].

General observations suggest that elk use areas during and soon after fire. During the 1988 Yellowstone fires, an elk was observed feeding 250 feet (75 m) from flames and 5 elk were observed using small unburned patches within extensive burns soon after the fire fronts had passed [321]. Singer and Schullery [269] also commented that elk were observed moving calmly near actively burning areas during the fires.

INDIRECT FIRE EFFECTS:
Patton and Gordon [216] described elk as a fire-dependent species because of its association with fire-dependent and fire-adapted plant communities, and because elk populations often decrease when fire frequency in these plant communities decreases. Bendall [26] described elk as a "fire follower" due to the species' positive response to fire-caused changes in food. Another researcher described elk as being "ubiquitous" in burned areas [5]. The generalization that fire benefits elk is supported by some but not all empirical studies [266].

Fire's effects on elk habitats are complex and not thoroughly understood. Thus, results presented here should be interpreted with caution. According to Lyon and others [185], one of the major problems with generalizations about the effects of fire on elk is that they do not address variation in fire frequency, severity, duration, shape, size, season, and site characteristics. Furthermore, many studies are descriptive rather than quantitative, use small sample sizes, are short term, or include no controls and/or replicates [185]. Also, many studies are based on results of relative accumulations of elk pellet groups in different habitats; these tend to be biased against feeding areas. See the review by Severson and Medina [262] for more information on this topic. Reviews of fire effects in elk habitats used in this review included these sources: [26,119,185,196].

Postfire vegetation changes and succession: In general, the literature regarding fire effects on elk habitats indicates that fire sets back plant development and succession and removes accumulated litter, often increasing elk forage quality and/or forage quantity in the short term. Fire also tends to increase habitat patchiness, providing elk with abundant edge habitat and diverse vegetation. Elk appear most likely to benefit from patchy fire that creates early-successional habitats providing forage while leaving interspersed patches of forests and shrublands that provide cover. Elk are least likely to benefit from fire that results in large expanses of homogeneous vegetation [119,185]. The postfire successional stage when herbaceous cover has built up but before tree and shrub canopies close out the understory is generally considered "optimum" for elk [275,295]. See Successional status of elk habitats for more information. Fire may facilitate establishment of unpalatable or invasive plants, which may reduce elk forage availability [306].

Forage quantity: Many elk forage species increase in abundance after fire, although others decrease or remain unaffected. Often increases in forage quantity, when they occur, are short-lived, but fire effects may last up to 10 years or more depending in large part upon plant communities affected. Potential elk carrying capacity in summer increased from 8 to 28 elk/100 km² within 12 years after prescribed burning of 12,900 acres (5,200 ha) of subalpine coniferous forests and mixed shrub-herb plant communities in Banff National Park. Spring carrying capacity for elk rose from 13 to 45 elk/100 km² after the fires. Most of the increase (73%) in elk carrying capacity was attributable to changes within burned conifer forests, particularly Engelmann spruce/feathermoss forests. Seven to 10 years after burning, graminoid and forb biomass was higher in burned than unburned conifer forests ($P \leq 0.03$), whereas shrub biomass was not substantially changed after fire. The authors concluded that prescribed burning of coniferous forests substantially increased elk forage availability and resulted in greater abundance of herbaceous plant species that were more preferable to elk, with the effect of the treatment lasting at least a decade. However, prescribed burning of subalpine shrub (willow-bog birch) and shrub-herb (shrubby cinquefoil-wheatgrass and kinnikinnick-boreal wildrye) communities reduced the total cover of tall woody plants in the short-term and resulted in minimal or only short-term increases in herb biomass [254]. In big sagebrush-Idaho fescue communities in south-central Montana, graminoid cover tended to reach maximum levels (60-70%) 7 to 8 years after fire, whereas forb cover reached up to 60% immediately after fire and progressively declined. Shrubs were completely killed by fire, began to reestablish 1 to 2 years after burning, and increased substantially in cover 6 to 7 years after fire. Elk forage values peaked in the first postfire year, then declined but remained above prefire levels through postfire year 9 when the study ended [325]. Two growing seasons after a May prescribed fire in grand fir/Oregon boxwood habitat in the Lochsa River area, Idaho, elk herbaceous forage production increased 176% from prefire levels, whereas controls increased only 24%. Four growing seasons after the fire, forage production was only 19% greater than prefire levels, and controls were 10% greater than prefire levels. An increase in elk forage production during postfire year 2 was attributed to the maturing of biennials that germinated following the fire. However, by postfire year 4, biennials had declined and plant production differed only slightly from prefire conditions [171].

The response of individual elk forage species to fire depends on life history, structural and physiological adaptations to fire, plant community, and site characteristics. Some elk forage species, such as willows and quaking aspen [97], sprout after fire, whereas other species, such as curlleaf mountain-mahogany (*Cercocarpus ledifolius*) [54,99] and Pacific yew [292] are highly susceptible to fire-caused mortality. After prescribed burning in postfire successional shrub fields on elk winter range in northern Idaho, some elk browse species increased (e.g., redstem and snowbrush ceanothus), while others (e.g., thimbleberry) decreased compared to prefire levels. It took 9 growing seasons after the fire for total shrub cover in burned areas to exceed prefire cover; by postfire year 12, prefire cover was exceeded by 25% [170]. Forty acres (16 ha) of mature quaking aspen-Engelmann spruce forest, Douglas-fir/mallow ninebark forest, and hawthorn (*Crataegus*spp.) shrublands were clearcut and burned in early spring in the Absaroka Mountain Range in south-central Montana. Saskatoon serviceberry and chokecherry were prominent understory shrubs. Two years after the fire, density of quaking aspen and willows had increased due to sprouting. However, Saskatoon serviceberry and chokecherry density was reduced compared to prefire levels [97]. On the Caribou National Forest in southeastern Idaho, wild hollyhock (*Iliamna rivularis*) and fireweed, which were absent from unburned sites, increased after mixed-severity fall prescribed burning in a quaking aspen/Saskatoon serviceberry-mountain snowberry community. The authors concluded that burning in quaking aspen stands introduced highly preferred and nutritious elk forage that otherwise would not have occurred on these sites [77]. See FEIS reviews for fire effects on species of interest.

Fire effects on quaking aspen stands depend on the frequency and severity of the fire, the size of the burn, and the long-term effect on site productivity [344]. For example, understory production increased in quaking aspen stands along an elk migration route in the Jackson Hole area after a mixed-severity prescribed fire. The increase in production was still evident 12 years after the fire. In postfire year 12, understory production averaged 2,130 to 2,190 kg/ha and exceeded prefire production by 23% to 46%. Forbs, mostly fireweed (one of the most valuable forbs in elk diets in some areas (see Diet)), made up about 75%, grasses 20%, and shrubs 5% of the understory production after 12 years. Moderate and high severity burns produced the most undergrowth, composed mostly of forbs used as elk forage [21]. For more information on this and associated studies, see the Research Project Summary: Vegetation recovery following a mixed-severity fire in quaking aspen groves in western Wyoming (compiled by Gucker [101]).

Forage nutritional quality: Elk may benefit from increased digestibility and higher nutritional quality of forage on burned sites, but results vary. Studies have reported that nutrient levels in plants consumed by elk were unchanged, higher, or lower after fire, attributing the different effects to season, soil, weather, fuels, fire type, and other factors [26,185,325]. Although increased plant nutrient levels after fire may last up to 20 years [185], according to one review, most studies of moderate- or high-severity fires indicate that nutrient contents revert to prefire or control levels in 2 years or less. Short duration, low-severity fires may not result in an increase of nutrients in foliage [262].

Several studies indicated short-term increases in nutrients in elk forage after fire. In most cases, the increases lasted only 1 to 2 years. At Starkey Experimental Forest and Range, percent nitrogen and digestibility of forbs and percent nitrogen of graminoids in fir-Douglas-fir stands increased from 2 to 5 years following thinning and prescribed fire. By posttreatment year 5, these characteristics exceeded maximum values observed in control stands [178]. One year after prescribed fire in western redcedar/Oregon boxwood communities on elk winter range in northern Idaho, 4 elk browse species (redstem ceanothus, willow, serviceberry, and Rocky Mountain maple combined) were higher in moisture and crude protein content on burned sites than unburned sites. However, the effect was absent during postfire years 2 and 3 [12]. Near Saratoga, Wyoming, antelope bitterbrush-big sagebrush/bunchgrass communities were burned under prescription in mid-September. The fire was mixed-severity, and mortality of antelope bitterbrush, an important elk browse species, ranged from 10% to 50%. Antelope bitterbrush sprouted profusely during the first postfire growing season. Soils were warmer and spring growth of antelope bitterbrush started earlier on burned areas than unburned areas. Nitrogen increased in antelope bitterbrush from 1.4% to 1.9%, phosphorus increased from 0.11% to 0.17%, and in vitro digestible dry matter increased from 47.4% to 51.0% after fire, while gross energy decreased from 4,640 to 4,380 kcal/g the first growing season after fire. During the second growing season after fire, there were no differences in nutrient contents in burned versus unburned antelope bitterbrush [149]. On the Caribou National Forest, Idaho, elk forage quality was higher in quaking aspen/Saskatoon serviceberry-mountain snowberry (*Symphoricarpos oreophilus*) habitat after a mixed-severity prescribed fire than in adjacent unburned sites, but the result was short-lived. The summer after a fall prescribed fire, quaking aspen on burned areas had higher crude protein and phosphorus contents, higher in vitro digestible dry matter, lower calcium contents, and lower calcium:phosphorus ratios than quaking aspen on unburned areas. However, 3 weeks later only crude protein levels of quaking aspen remained higher on the burns. Saskatoon serviceberry, snowbrush, and chokecherry had higher crude protein levels on the burned areas during the first postfire summer, but during postfire year 2, forage quality of shrubs, grasses (blue wildrye (*Elymus glaucus*), and forbs (sticky geranium (*Geranium viscossissimum*), silvery lupine (*Lupinus argenteus*), and heartleaf arnica (*Arnica cordifolia*)) on the burns was similar to that under nearby unburned quaking aspen. Forbs were not studied during postfire year 1. The authors noted that quaking aspen habitats had a highly nutritious understory irrespective of burning [77]. In mesic mountain big sagebrush-antelope bitterbrush communities in south-central Wyoming, crude protein content of herbs was generally higher from late spring through early fall on burned sites 1 to 2 years after June and September wildfires and an April prescribed fire than on nearby unburned controls [59]. Two years after an October mixed-severity prescribed fire in Gambel oak shrublands in western Colorado, elk forage (forbs, grasses, and shrubs) in burned areas had higher levels of total cell contents, soluble carbohydrates, copper, and zinc than in unburned control areas. However, elk forage quantity was reduced [158].

Other studies reported that burning had little or no effect on elk forage quality, especially with increasing time since fire [33,116,199,264]. In Buffalo Valley, Wyoming, protein, acid detergent fiber, and total digestible nutrient contents of quaking aspen, willow, and chokecherry in 8 burned areas ranging from 1 to 22 years old did not differ from each other or from browse in unburned areas, except that chokecherry protein content was higher in some burned areas than in unburned areas [116]. During the 4 successive years after a late-summer lightning-caused wildfire in xeric ponderosa pine forest and adjacent montane grasslands used as winter-spring range by elk in the Selway-Bitterroot Wilderness in Idaho, mineral concentration in herbaceous plants tended to be similar between burned and unburned sites, although nitrogen and potassium were lower on burned sites than unburned controls the first year following the fire [199]. On the Blacktail Plateau, northern Yellowstone elk increased use of burned grasslands 2 and 3 years following the 1988 Yellowstone fires compared with before the fires ($P<0.05$), even though percent nitrogen, macronutrient concentrations, and digestibility of grasses were unchanged, and aboveground biomass of grasses increased only slightly (about 20%) 1 and 2 years after fire [264].

Forage palatability: Fire may increase elk forage palatability. In the Lochsa River area, elk browse use was greater on burned shrublands 1 and 2 growing seasons after fall and spring prescribed fires than on adjacent controls. Even species "normally considered unpalatable" such as oceanspray and lilac (*Syringa* spp.) were browsed by elk on burns, suggesting that palatability improved after fire. During postfire winter 5, there was still heavier browsing on the burned areas than controls, but it was confined to the species normally eaten [168]. Elk do not typically eat lodgepole pine bark, but 3 years after the 1988 Yellowstone fires, elk consumed the burned bark of lodgepole pine trees despite the apparent abundance of alternative forage plants in their winter ranges. Burned bark had increased digestibility and nutrient levels and reduced plant secondary compounds compared with unburned bark of live trees, although burned bark was not different from the unburned bark of dead trees. The authors suggested that elk selected burned bark based upon its nutritional quality compared to unburned live trees and its abundance relative to unburned bark of dead trees. Dense stands of burned lodgepole pine may have allowed elk to consume large quantities with little effort [339]. In contrast, although elk diets on the northern Yellowstone winter range were predicted to increase in diversity after the 1988 fires due to changes in palatability of burned forages, there was no difference in elk winter diet diversity before and 2 years after the fires [207].

Other changes: Fire can influence habitat selection by elk by altering browse structure (e.g., height, twig diameter, and leaf size). In the Lochsa River area, Idaho, prescribed fires in spring and fall decreased shrub height to a level accessible to elk. Four years after burning, 3 primary elk browse species (Rocky Mountain maple, willow, and serviceberry) averaged nearly 10.5 feet (3.2 m) tall, with about 80% of their twig production within reach of elk. The authors stated that "it appears that repeated burns at 10 to 15 year intervals will be necessary to keep the tall-growing shrubs at a usable height" for elk [168]. Other researchers also noted the importance of fire in making elk forage more accessible by either decreasing the height of browse (e.g., [33,77,97,170]) or by reducing the density of trees and shrubs that impede elk movement through a stand and thus access to forage (e.g., [77,149,157]). Near Saratoga, Wyoming, mid-September prescribed burning in antelope bitterbrush-big sagebrush/bunchgrass communities increased antelope bitterbrush accessibility to elk by reducing big sagebrush cover for at least 2 years [149]. Elk preferred burned Gambel oak stands 2, 5, and 10 years after an October mixed-severity prescribed fire in western Colorado. Two years after burning, elk used burns 140% more than controls ($P<0.10$). After 5 and 10 years, elk used burns 154% and 218% more than controls, respectively, although differences were not significant. Elk tended to favor burned Gambel oak stands in part because the mixed-severity fire created openings with interspersed patches of cover that increased elk access to browse within burned stands, while also providing hiding cover and shade [157]. On elk summer range in southeastern Idaho, foraging efficiency of free-ranging tame elk was greater 2 and 3 years after a "relatively severe" prescribed fire in quaking aspen forest than in nearby unburned quaking aspen forest, a difference attributed to larger leaves in the burned forest [44].

Fire makes current, nutritious growth in grasslands more accessible by reducing litter that inhibits elk grazing [184,344]. In a northwestern Montana alpine rough fescue-Idaho fescue-bluebunch wheatgrass community, Sun River elk winter range was burned under prescription during spring and fall using a backfire and a headfire. "Few" differences were found between seasons and type of fire. The first postfire winter, elk use of the winter range was minimal due to a mild winter and reduction of alpine rough fescue standing crop (the preferred winter elk forage) on burned plots. During the second postfire winter, elk increased use of the burned plots compared with the controls. The authors observed that elk grazed rough fescue plants with abundant litter less frequently than plants with sparse litter. Because alpine rough fescue standing crop was similar on burned and controls plots, the authors concluded that elk grazed preferentially on burns because of the reduction of litter [143]. Burning may also make forage more accessible by removing obstructions in the understory [33]. For more information on this topic, see Physical barriers.

Elk population response to postfire vegetation changes: Many studies report elk population increases after large wildfires at least in the short term (more than 1 year after fire but less than about 25 years after fire) (e.g., [5,83,108,191,218,253,261,266,287]). Elk reached peak numbers within 25 years after a large wildfire in Glacier National Park, when shrub fields persisted with young conifer stands, but as shrub fields were extensively replaced by conifers, the elk population declined [191]. In northwestern Alberta, the Brazeau River elk herd consisted of 15 individuals in 1913. An extensive wildfire in the 1920s along the Brazeau, Cardinal, and McLeod rivers apparently created favorable elk range, and by 1939 elk were "plentiful" [287]. A long-term study of the northern Yellowstone herd found that elk populations peaked within 6 years of the 1988 wildfires. Immediately following the fires, the elk population declined substantially, then increased rapidly, recovering to prefire levels by postfire year 6. Thereafter, the elk population generally declined until at least postfire year 16 due to a combination of a doubling in hunter harvests north of the park, severe winters, and increased gray wolf numbers after their reintroduction during postfire year 7 [83,266]. Taper and Gogan [298] compared predicted and observed elk population growth rates 7 years following the 1988 Yellowstone fires and found a mild, but short-lived, increase in elk growth rate due to fire. The first 2 years following the fire, growth rates were below predicted values, while in postfire years 3 and 4, growth rates were considerably above predicted values. The authors concluded that elk populations benefited most from the short-term enhancement to elk habitat resulting from the fires during postfire winters 3 and 4 [298]. See the 1988 Yellowstone fires case study for more information.

One long-term study showed that elk populations peaked within 19 years of a large wildfire. In June 1977, the La Mesa fire burned across 15,444 acres (6,250 ha) of ponderosa pine forests in the Jemez Mountains in New Mexico [4]. Less than 1 month after the fire, grass seed, primarily western wheatgrass, slender wheatgrass

(*Elymus trachycaulus*), and sheep fescue (*Festuca ovina*), was applied to "almost the entire burn area" [351]. A small number of elk had been reintroduced into the Jemez Mountains in the early 1940s, and 16 years prior to the fire, in 1961, there were 200 elk in the Jemez herd. The elk population increased rapidly after the fire and in postfire year 15, about 7,000 elk occurred in the Jemez herd, a 12% growth rate during 31 years. Elk winter use of the La Mesa fire area centered on Bandelier National Monument. Less than 100 elk wintered on Bandelier National Monument the winter immediately after the La Mesa fire. During the second postfire winter, 296 elk wintered on the monument. By postfire year 15, approximately 1,500 elk wintered on the monument, an annual growth rate of 21% and a 3.6-year population doubling time since the fire [5]. Population increases in the Bandelier herd were both intrinsic and a result of elk immigrating from surrounding areas, including an older burn [5,253]. Many elk moved from the older burn to the La Mesa burn during the second postfire winter, suggesting that conditions were more attractive on the La Mesa burn [253]. Allen [5] noted that the La Mesa fire converted "dense, monotypic ponderosa pine forests into a more productive and diverse mosaic of grassland, shrubland, and forests, resulting in a corresponding diversity of herbaceous and woody food available for elk". Nineteen years after the fire, he noted that the initial postfire flush of high plant productivity had passed, and vegetation had begun to succeed to ponderosa pine forest, which he predicted would support fewer elk [5].

Elk populations often increase after extensive prescribed fires (e.g., [218,261]), although increases in elk populations are not universal (e.g., [168,220]). The elk population near Toad River in northern British Columbia appeared to increase after prescribed burning of subalpine grassland slopes (year-round elk range) every 9 years for 80 years [261]. Peck [218] stated that increases in elk populations in northeastern British Columbia in the 1960s and 1970s appeared to be positively correlated with prescribed burning and wildfires on elk winter ranges, apparently benefiting from postfire successional grass and shrub communities. Conversely, on the Lochsa River elk winter range prescribed fire was expected to increase elk forage quantity and/or quality and thus increase the elk population. After burning approximately 40% of postfire successional shrub fields of ceanothus (*Ceanothus* spp.), Rocky mountain maple, willow, and serviceberry during 20 years, cow:calf ratios were equal to prefire ratios, and cow and bull numbers did not appear to be correlated with area burned [220], despite increased forage quantity in some areas (e.g., [13,167,169,170]). Nearly all (99%) of the fires took place in the spring on steep south-facing slopes, suggesting that burning may have been too limited seasonally and topographically to effect elk populations. The author noted that the effects of hunting may have overridden potential postfire increases in elk populations [220]. Although fire did not increase elk population size and productivity as expected, it is possible that such burning may have prevented or reduced elk productivity declines [58].

Elk use of postfire communities: In general, elk avoid burned areas until vegetation growth begins, and elk use of burned areas increases as forage becomes more abundant. As postfire succession proceeds, forage quantity and quality decline and elk use of burned areas is reduced [185]. However, elk use of burned areas varies widely among locations and plant communities due to variation in postfire vegetation growth rates, rates of succession, adjacent habitat, and prefire elk density and movements.

Many studies reported that elk preferred burned areas over unburned areas in forests and sagebrush habitats. Near Laramie and Saratoga, Wyoming, elk used plots burned in wildfires 1.7 to 12.3 times more than nearby, similarly-aged clearcut plots 5 and 10 years after disturbance. Elk appeared to prefer burns because of a greater variety of forage species and greater hiding cover in burned than clearcut plots [74]. For more information on this study, see Burn size and shape. Eight years after a high-severity, August wildfire in subalpine lodgepole pine forest near Fort Collins, Colorado, elk used the burned area more than adjacent, unburned lodgepole pine stands (P=0.01) from September to June, apparently because of abundant cover and seeded grasses in the burn [250]. Elk use of big sagebrush-Idaho fescue habitats in south-central Montana that were burned under prescription in October, March, and April increased 144% to 680%, peaking 1 to 4 years after the fires. Elk use of burned areas remained above preburn and control levels for at least 9 years after the fires, apparently due to increases in palatable grasses and forbs and decreases in less palatable shrubs [325]. During aerial surveys in Riding Mountain National Park, Manitoba, elk densities were greatest on 2-year-old burns, likely due to increased quaking aspen sprout production on burned areas (Blood 1966 cited in [97]). Free-ranging tame elk in southeastern Idaho preferred to forage in burned quaking aspen stands in summer 2 and 3 years after a severe, fall prescribed fire rather than in adjacent unburned stands [44].

Elk may avoid young burns until vegetation develops in the 2nd or 3rd postfire year. A prescribed late-summer fire in quaking aspen forest on elk winter range in Wyoming apparently made the area unattractive to elk during the 1st postfire winter, although elk use increased to preburn levels in the 2nd and 3rd years after fire [23]. There may have been too little time for plants to grow above the snow level before the 1st postfire winter [262]. Prior to an April prescribed fire in mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) communities on elk winter range in the Gold Creek drainage in south-central Montana, elk use of the habitat was low. Forage nutritional quality increased during the subsequent growing season but forage quantity was reduced, and elk did not use the burn that year. Elk use of burned sites increased 492% over preburn levels 1 year after the fire, due in part to increased forage production. Elk use declined to preburn levels over the next 2 to 9 years as forage production declined, even though the elk population increased during this period [324].

Elk use burns of a variety of ages, but tend to prefer young burns (about 2-17 years after fire) over old burns. Among 2- to >150-year-old burns (from both wild and prescribed fires) in grand fir and western redcedar forests in Idaho, elk pellet group counts were highest on 6-year-old burns, which also had the greatest browse canopy cover, and decreased at 25 years or more after fire, when trees became established and shrubs grew out of reach. Eighty-year-old burns and >125-year-old burns had similarly low elk use [98]. Wintering elk in the Tuchodi River area of northeastern British Columbia consistently preferred burns <7 years old. Ten- to 20-year-old burns were often used in proportion to availability, whereas 40-year-old and >99-year-old burns were avoided [219]. In winter in Riding Mountain National Park, Manitoba, elk selected 8- to 17-year-old burns, grasslands, and shrublands and avoided quaking aspen-white spruce, white spruce, and jack pine forests and bogs during 8 years. Elk also used older burns (>17 years old) and in 2 of 8 years preferred older burns, but when averaged over 8 years, the relationship was not significant [251].

Some studies found that elk used burned and unburned sites similarly [6,32,207,307,309]. The May 2000 Cerro Grand wildfire in the Jemez Mountains in New Mexico burned 43,000 acres (17,400 ha) of montane elk transitional range, with low (58% of the area) to high (33% of the area) fire severity. In most areas, shrubs and quaking aspen burned. After the fire, perennial ryegrass (*Lolium perenne*), common barley (*Hordeum vulgare*), mountain brome (*Bromus marginatus*), and slender wheatgrass were seeded in severely and moderately burned areas. Elk commonly used burned areas during all seasons, but use was similar to that of other habitats during postfire years 1 to 4 [32]. Two years after the 1988 Yellowstone fires, in summer, elk used burned and unburned patches in meadows similarly, burned and unburned forest edge patches similarly, and burned and unburned forest patches similarly based upon pellet group counts, despite predictions that they would prefer burned areas [207].

Elk may not prefer burned areas if palatable elk forage is not available. On the northern Yellowstone winter range near Hellroaring Creek, elk did not consume more forage in recently burned sagebrush/grassland areas compared to unburned areas. Plots were either burned 5 years prior to the study in a backfire ignited to stop an approaching fire in late summer 1988; burned in an experimental fire ignited in mid-September 1992; burned in 1988 and reburned in 1992; or a nearby unburned control. Elk used burned and unburned areas similarly, despite greater graminoid biomass, less standing dead biomass, and greater forage quality in newly burned areas. Density of silky lupine (*Lupinus sericeus*), a species unpalatable to elk, was 60% greater on burned plots than unburned plots and may have deterred elk grazing [307,309].

Prefire use of burned areas may influence elk use of sites after fire. On the Burdette winter range, western Montana, average elk pellet group densities 1 year after low-severity spring prescribed fires were generally greater on controls than burns. Burned areas included 2 old-growth ponderosa pine-Douglas-fir stands on southeastern and southwestern aspects and 2 shrubland habitats dominated by mallow ninebark, snowbrush ceanothus, Saskatoon serviceberry, chokecherry, and bitter cherry (*Prunus emarginata*) on southeastern and west-southwestern aspects. Differences were significant ($P<0.10$) only on open shrub fields on southwestern aspects, possibly because elk use of all habitats was moderate or less, the winter was mild, and elk were relatively dispersed. Among the burns, elk preferred those on southeastern aspects ($P<0.05$), where browse production was greatest. Because burns on southeastern aspects were near a traditional travel route, prefire use may have been important in elk use of these sites after fire [187].

Selection or avoidance of burned areas may be a function of alternative habitats and food sources in the proximity of burns [239]. Elk use did not increase in any of 3 winters following a late fall prescribed fire in bluebunch wheatgrass-Idaho fescue foothill range in southeastern Washington that removed all dead standing litter. Elk preferred instead to forage in adjacent unburned fertilized plots, even though green-up occurred several weeks earlier on burned plots the first spring following the fire [274]. On elk summer range in lodgepole pine-subalpine fir forests on the eastern slope of the Cascade Range, Washington, elk use of 2 areas burned in prescribed fires was less than that of similar unburned sites 2 years after the fires. The authors attributed low use of the burn either to relatively long distances to water or to low forage production in the burned area [34,303]. In Buffalo Valley, Wyoming, during "emergency" supplemental feedings in late winter and spring of a severe winter, elk home ranges were small and included 9- to 16-year-old burns in proportion to their availability. No elk home ranges included burns <5 years old. However, when elk were not fed during the following winter, elk home ranges were larger and incorporated a greater proportion of burns 1 to 5 years old during late winter and spring, although the difference was not statistically significant [116]. A reintroduced elk population at Fort Riley, Kansas, selected low-elevation areas, gentle slopes, edge habitat, and areas close to streams at the landscape and home range scales but did not select for areas burned under prescription in spring or fall as predicted. Areas were burned on a 3-year interval. At both spatial scales, elk used riparian woodlands more frequently than brome (*Bromus* spp.) and fescue tallgrass prairie and selected for agricultural fields when seasonally available. The authors suggested that the lack of elk preference for burned areas was due, in part, to the availability of alternate forage, particularly in agricultural fields. In addition, the authors suggested that spring and fall prescribed fire may have failed to increased the C_3 grasses and forbs often preferred by elk. However, if elk were not forage limited, any increase in forage biomass as a result of prescribed fire may not have influenced their habitat selection. The authors noted that, even though elk did not show a positive short-term response to fire in this study, periodic fires may be important for suppressing woody vegetation and maintaining a grassland system for elk over a long time period [56].

Elk density: Elk use of burned areas may depend on large-scale elk density. Two years after the 1988 fires in Yellowstone National Park, elk grazed on the abundant quaking aspen sprouts in burned sites but browsed unburned sites with similar intensity, perhaps because of high elk densities throughout the range [249]. Conversely, during 5 years in the Lochsa River area, Idaho, elk decreased use of seral shrub fields burned under prescription in spring and fall despite increased browse availability in burned areas, apparently because forage quantity was not limiting to the elk population prior to burning, and elk populations declined during the 5 years [169].

Elk resting and grazing in an unburned meadow adjacent to an area burned by a crown fire, Yellowstone National Park.
Photo courtesy of Rick McIntyre, National Park Service.

Season of use: Use of burns by elk varies among seasons. Burns may be preferred in winter when forage is limited but not in spring and summer when forage is abundant and widespread. Three and 4 winters after the

1988 Yellowstone fires, elk on the northern Yellowstone winter range grazed in burned sites more than expected based on their availability, presumably because forage abundance increased after fire. Use of burned areas was greatest in mid- to late winter after overall forage availability diminished. Elk did not select burned areas over unburned areas during spring green-up when abundant, high-quality forage was available throughout the area [217]. In another study 3 years after the 1988 Yellowstone fires, elk on sagebrush/Idaho fescue-wheatgrass winter range consumed more forage on burned areas than adjacent unburned areas, but elk on summer range did not. The authors suggested that this was because of differences in burn severity: Historically, consumption of grasses was 60% higher on summer rangelands, so winter range tended to have more fuel than summer range and burned more severely, which resulted in greater postfire production of elk forage [308]. Tracy [311] suggested that fire effects, if present at all, persisted for no more than 3 years in most Yellowstone grasslands. At Starkey Experimental Forest and Range, within a 30-mile² (78 km²) area enclosed by a fence, fuels in spruce budworm (*Choristoneura occidentalis*)-killed grand fir-Douglas-fir forests were reduced by thinning and broadcast burning or slash pile burning in September or October. Between 1 and 5 years after treatment, adult female elk tended to select thinned and burned stands and avoid control stands in spring when forage in treated stands was abundant, but tended to avoid burned stands and select controls in summer when forage in treated stands had declined [176,178]. The authors suggested that because spring often represents a critical period for elk nutrition, the positive response of elk to thinning and prescribed fire in spring "might be more energetically significant than the apparent avoidance of treated stands during summer" [176].

In contrast, other researchers found that elk selected burns in summer but avoided them in winter. Elk in Grand Teton and southern Yellowstone national parks used progressively more burned area from spring to early summer as elk migrated to high elevations. Burns were about 40 years old and consisted of open lodgepole pine and subalpine fir stands with Geyer's sedge (*Carex geyeri*) understories [53]. Twelve to 14 years after the 1988 Yellowstone fires, elk on the northern range of Yellowstone National Park selected burned forests during summer regardless of burn type (high-severity, mixed-severity, or undifferentiated burn), but during winter they used burned forests less than expected by chance. Elk may have selected burned forest in summer but not in winter because forbs present in the burns were important forage in summer but had largely senesced and decomposed by winter. Also, the burns may have had deeper snow, making foraging and travel more difficult in winter [36].

Snow depth, duration, and crusting on burns are often different from unburned forest, which may affect elk movements and use of burned areas [185]. During 2 winters and the intervening summer on the Avery and Lochsa winter ranges in northern Idaho, elk use of sites burned under prescription in spring 1 and 2 years prior to the study tended to be higher than use of adjacent unburned sites due to increased willow, mountain maple, and serviceberry density. However, deep snow during one winter apparently caused elk to use a control site more frequently than the adjacent burns [13]. Elk in the Tuchodi River area of northeastern British Columbia wintered primarily in 3- to 20-year-old burns with grass-shrub cover except during severe winter weather, when they used conifer stands [219]. Big Prairie elk on the Flathead National Forest, Montana, did not use a 15-year-old burn on winter range, in part because of deep snow [93]. In northern British Columbia near Toad River, prescribed burning of subalpine grassland slopes an average of every 9 years for 80 years on year-round elk range appeared to increase the elk population due to the "superabundant" forage on burned sites. However, during a severe winter, most of the burned area was unavailable to elk due to deep snow, and elk browsed in forests [261]. About 25% of the Blacktail Plateau, located in the approximate center of the northern Yellowstone winter range, burned in the 1988 Yellowstone fires [264]. Elk avoided burned forests on the Blacktail Plateau during postfire years 1 to 3 ($P<0.05$), apparently because of deeper, more dense snow and reduced forage biomass (Norland and others 1995 cited in [264]). Elk used a lodgepole pine-subalpine fir stand that was burned in a crown fire 6 years prior to the study that, due to elevation and aspect, had 28 inches (71 cm) of snow in late winter, whereas another part of the burn located 1 mile (2 km) away that had 40 inches (102 cm) of snow in late winter was not used [272]. The La Mesa fire in the Jemez Mountains, New Mexico, occurred at moderate elevations (6,600-8,500 feet (2000-2600 m)) and provided abundant forage where snow conditions typically allowed elk access to the burn. However, during the winter of postfire year 14, crusted snow apparently restricted elk use of the burn, resulting in use of habitats at lower elevations outside of the burn [5]. For more information on the effects of snow on elk movements, see Home range.

Although deep snow may preclude use of burns in winter, they offer valuable early spring range for elk because snow melts more rapidly on burned areas [26,153]. In Yellowstone National Park near Hellroaring Creek, elk most intensively grazed a site burned under prescription during the first month after snowmelt [307].

Burn size and shape: The size and shape of a burn determine the amount of edge habitat created and the degree of interspersion of communities after fire, which in turn influence elk populations. Discontinuous burning is most beneficial to elk and wildlife in general because it provides cover close to feeding habitat, increases variety of forage species, and staggers maturation rates of individual stands [185]. In a review of fire effects on ungulates, Higgins and others [119] stated that optimum benefits of fire for ungulates occur where fire creates a mosaic pattern of burned and unburned vegetation that provides new forage growth, seasonal habitats, and maintenance of vegetation in early stages of succession. Elk populations in Bandelier National Monument increased 15-fold in 15 years after the La Mesa fire due in part to the fire converting dense, monotypic ponderosa pine forest into a diverse mosaic of grasslands, shrublands, and forests [5]. Elk populations increased in Glacier National Park after wildfire, when habitats favorable to elk such as those comprised of young conifer stands and mosaics of shrub and conifer communities were more abundant [191]. Boyce and Merrill [37] hypothesized that elk benefited from the 1988 Yellowstone fires due to the altered spatial pattern and juxtaposition of habitats that created a complex mosaic with an increased amount of edge. However, Pearson and others [217] found that 2 and 4 winters after the fires, the spatial arrangement of burned area on the landscape (i.e., whether the burned areas were fragmented or clumped) did not influence elk use of or grazing intensity on burned sites.

Elk more readily use burned areas if their cover requirements are met within or in close proximity to the burned area. A review reported that elk use of burns decreased with increasing distance to cover. Elk preferred burns <8.6 acres (3.5 ha) [153]. In Glacier National Park, elk populations declined "dramatically" after a wildfire that removed most conifer habitat on winter range. Peak elk numbers occurred when burns were partially reinvaded by conifers [191]. Elk used the perimeter and interior of a 470-acre (190 ha), 8-year-old burn near Fort Collins, Colorado, perhaps because snags provided cover within the burn [250]. Near Laramie and Saratoga, Wyoming, elk used plots burned in wildfires more than nearby, similarly-aged clearcut plots during 2 years, in part because of greater hiding cover provided by snags in burns (633-722 snags/ha) compared to clearcuts (0-66 snags/ha) [74].

A large, homogenous fire may have a negative effect on elk if the fire removes too much cover or forage, thus making elk more vulnerable to predation and hunting. In the northern Yellowstone elk herd, the 1988 fires appeared to increase vulnerability of elk calves to predation. Overall, predation rates doubled following the fires (29%) compared to before the fires (13%). The authors suggested that elk calves may have been less well hidden from predators because of reduced cover in the burns [267]. After the Moose Creek fire, a mixed-severity August wildfire on the Salmon National Forest, Idaho, elk use of the area was "negligible" in the winter and spring immediately following the fire and was substantially reduced during postfire year 1 compared with prefire use. Prefire cover within and adjacent to the burned area was limited due to previous logging activity and the natural sparseness of the forest. The fire removed much of the remaining cover and only one "sizeable" patch of cover remained. The authors noted that despite road closures, hunting pressure on elk using the burn during the fall immediately after the fire was high [54]. See Predation risk for more information.

Large, homogenous fires may be particularly deleterious to elk during severe winters. Using a model, Turner and others [316] found that under the most mild winter conditions (equivalent to the most mild winter recorded during the 1900s), little mortality was predicted in the first winter after the 1988 Yellowstone fires even when 60% of the landscape was burned. However, under average or severe winter conditions during the first postfire winter, when no resources were assumed available in burned areas, the model predicted that elk survival decreased as burned area increased. During the second postfire winter, when resources had increased in burned areas, the model predicted that elk survival increased with increasing fire size [316]. See Malnutrition and weather for more information on this study. Although a large fire could reduce the interspersion of food and cover for elk by producing uniformity of vegetation, Lyon and others [185] stated that fires rarely burn evenly and usually create a mosaic in vegetation beneficial to elk.

Elk feeding in a burn at the Brazoria National Wildlife Refuge, Texas.
US Fish and Wildlife Service photo.

Elk condition: Because biomass and nutrient content of forage plants can increase after fire on elk rangelands, elk condition, reproduction, and survival may increase in burned areas [325]. Singer and Harter [264] stated that condition of wintering elk is typically enhanced on burned grasslands, even when burning does not increase protein concentrations in grassland forage, perhaps because of increased forage biomass or browse availability [44,264]. For example, Rowland and others [252] detected no difference in the nutritive quality of winter forage in ponderosa pine-bunchgrass communities 3 years after the La Mesa fire and an area unburned for 20 years. However, sheep fescue and slender wheatgrass (seeded on the burn immediately after the fire) dominated elk diets in the burned area, whereas nearly equal proportions of browse and grass were eaten by elk on the unburned area. The grass-dominated diet of elk using the burn had higher digestible energy than that of elk using the unburned area [252], which led to higher body weights and better nutritional status [334]. Calves, adult females, and yearling males using the burn weighed significantly more; cows averaged 19% heavier, and yearling males averaged 11% heavier [253,334]. Because elk in burned and unburned areas shared the same summer and fall ranges, differences in animal condition were attributed to winter forage on the burn [334].

Elk interactions with fuels and fire effects: Elk herbivory, like ungulate herbivory in general, affects vegetation development and productivity in forests and rangelands. Although one study found no interactions between elk herbivory and fire [264], other studies have found significant interactions, attributing them to elk densities, habitat use, landscape patterns, and fire frequency and severity [346].

Prior to fire, elk may alter the abundance and kinds of fuels by grazing and/or browsing preferred forage and thus altering abundance and kinds of fuels [185]. By removing fine fuels, elk may reduce the likelihood of surface fires and simultaneously enhance the development of unpalatable trees that may act as ladder fuels [346]. Wisdom and others [346] made the following generalizations regarding the interactions between fire and herbivory by elk, mule deer, and cattle in forested landscape in western North America:

- Intensive herbivory favors selective and rapid removal of highly palatable deciduous trees and shrubs. In turn, selective removal of these species may increase establishment and growth of unpalalatable species.
- Fire exclusion from western forests favors development of shade-tolerant conifers in the understory. Intense herbivory exacerbates this effect, while a combination of low-level herbivory and fire exclusion favors codominance of unpalalatable conifers and palatable shrubs in the understory.
- Crown fire or timber harvest substantially reduces or eliminates the conifer understory and, if combined with intense herbivory, favors dominance by grasses and forbs. Crown fire or timber harvest in combination with low-level herbivory favors dominance of highly palatable shrubs and deciduous trees.
- Surface fires, regardless of the level of herbivory, eliminate understory conifers, substantially reduce shrubs, and favor understory dominance by grasses and forbs [346].

Postfire elk browsing pressure and elk density influence postfire response of quaking aspen stands (e.g., [18,145,146,336,337]). In unburned quaking aspen stands on the Coconino National Forest, Arizona, sprouting was negligible. Where elk were excluded, severely burned sites (100% topkill of mature quaking aspen) had 10 times more aboveground biomass of quaking aspen sprouts 3 years after fire than moderately burned (50% topkill of mature aspen) sites. Where elk browsing occurred, quaking aspen sprouting was much less: In severely burned, browsed sites, aboveground biomass of sprouts was 1% of that in severely burned, unbrowsed sites; in moderately burned, browsed sites, aboveground biomass of sprouts was 26% of that in moderately burned, unbrowsed sites. In severely burned sites, elk browsed quaking aspen sprouts selectively with the result that, 3 years after the fire, sprouts in browsed, moderately burned sites were 3 times more dense than in browsed, severely burned sites [18].

High elk density in burned quaking aspen stands may lead to overbrowsing and thus hinder quaking aspen regeneration. In the Rocky Mountain national parks of Canada and the United States, the use of prescribed fire on landscapes with high elk densities was found to hinder quaking aspen regeneration because quaking aspen stems were browsed before they could exceed elk's reach [336,337]. In the Jackson Hole area, prescribed fire was applied in August in quaking aspen forest on elk winter range. One year later, quaking aspen sprout production on moderate- and high-severity burns was less than that on controls. Sprout production peaked on both moderate- and high-severity burns in postfire year 2. By postfire year 3, quaking aspen sprout production on the burns had declined [22]. Elk use of quaking aspen sprouts was heavy after the fire. Quaking aspen sprout densities 6 years after fire ranged from 4,300 to 10,300 sprouts/hectare, approximately the same as before the fire. At postfire year 12, densities ranged from 1,500 to 2,400 sprouts/hectare, 20% to 38% less than prefire densities, indicating that most quaking aspen sprouts were eliminated or severely suppressed by heavy elk browsing after the fire. The control area had 8,500 sprouts/hectare at the beginning of the study and 5,150 sprouts/hectare 12 years later, a 39% reduction that was also attributed to elk browsing [21]. Bartos and others [21] questioned the use of prescribed fire in areas subject to heavy ungulate use. In this case, rather than rejuvenate the quaking aspen stands, fire may have sped up their deterioration. For more information on this and associated studies, see the Research Project Summary: Vegetation recovery following a mixed-severity fire in quaking aspen groves in western Wyoming (compiled by Gucker [101]).

The influence of elk on quaking aspen response to fire may be reduced in areas where elk densities are low and/or quaking aspen is abundant. In Jefferson County, Montana, although mean quaking aspen sprout height (35 inches (88 cm)) was lower in elk and other ungulate-browsed quaking aspen stands burned under prescription in fall than in burned, unbrowsed quaking aspen stands (43 inches (108 cm); P=0.012), mean quaking aspen sprout height did not appear to be reduced enough to prevent regeneration of the stand. Mean quaking aspen sprout density was similar between burned-and-browsed and burned-only treatments (range: 21,800-29,700 sprouts/ha). The authors suggested that quaking aspen can be successfully regenerated after fire in areas with elk densities <1 elk/km^2 [81]. Kimble and others [148] noted that even though elk numbers on the northern Yellowstone elk range have declined since gray wolf reintroduction, quaking aspen recruitment has not increased at the landscape level on the Gallatin National Forest north of Yellowstone National Park. However, the authors noted that elk densities, which remained >2.4 elk/km^2, could still be too high for quaking aspen regeneration to increase. The authors further stated that because quaking aspen is highly preferred elk forage in winter and stands occupy such a small proportion of the landscape, low densities of elk may still suppress recruitment [148]. For more information regarding fire effects on quaking aspen, see the FEIS review.

Elk use of burned quaking aspen stands may be reduced in the presence of gray wolves. For more information, see Elk, gray wolf, and fire interactions. Elk overbrowsing may also hinder postfire regeneration of willows. Two years after the 1988 Yellowstone fires, increased productivity of Wolf's (*Salix wolfii*), Booth's (*S. boothii*), and Geyer (*Salix geyeriana*) willow was expected. Protein and digestibility generally increased in burned willows, as did leaf sizes and shoot length, as predicted. However, willow production increased on only 50% of the sites because elk use of willows increased substantially after the fires, such that burned willows were shorter than unburned willows 3 years after the fires [207].

Brown [41] suggested that small burns are especially vulnerable to damage by elk and other ungulates because browsing is concentrated in small areas. For more information, see Fire management considerations.

Other factors: Several factors interact with fire to influence elk use of burned areas, including interactions with gray wolves and livestock, travel patterns, and physical barriers.

Elk, gray wolf, and fire interactions: Although elk forage quality may increase after fire, elk populations may not be able to take advantage of the improvement because of high predation risk in burns. After gray wolf reintroduction, elk herbivory was less is quaking aspen stands burned in a stand-replacing wildfire during the 1988 Yellowstone fires than in unburned stands: Browsing levels on quaking aspen stands in the burned area declined from nearly 100% just prior to gray wolf introduction to zero, 7 years after gray wolf introduction. Elk browsing levels in the unburned area remained ≥73% during the same time period [104]. In west-central Alberta, elk summered in an area burned by the Dogrib fire, a 27,000-acre (11,000 ha) wildfire, 3 years previously. The burn was either unlogged (58%), logged the winter following the fire (postfire logged, 25%), or logged within 20 years prior to the fire and then burned (prefire logged, 17%). Elk avoided postfire logged stands and selected prefire logged stands and unlogged burned stands despite high forage abundance in postfire logged stands, apparently because of high gray wolf predation risk in postfire logged stands. Gray wolves selected postfire logged stands in part because they traveled on roads associated with logging activity [111]. In Banff National Park, Alberta, 50 miles² (130 km²) of the Ya Ha Tinda elk herd summer range was cumulatively burned under prescription during 33 years. The burns were predicted to increase elk migrating to the park. However, gray wolf populations were increasing at the same time, and the proportion of the Ya Ha Tinda herd migrating onto summer range declined by approximately 75% [114]. Elk were apparently attracted to low-elevation burned areas that also had high predation risk by gray wolves. The resulting predation reduced the migratory elk population [113]. Hebblewhite and others [114] concluded that in the presence of gray wolf predation, fire may have weak positive effects or even negative effects on elk. For more information on this study, see Travel patterns.

In contrast to the above, elk may select burns at certain times of year because they are avoided by predators, a pattern shown by the northern Yellowstone elk herd 11 to 14 years after the 1988 fires. In summer, gray wolf activity was centered around dens and rendezvous sites, and gray wolves tended to avoid burned forest. Elk in turn avoided the wolves by using more burned forest than they had before gray wolf reintroduction. In winter, elk did not separate themselves as much from areas used by gray wolves, but they did select more open habitats than before gray wolf reintroduction. Thus, elk appeared to select habitats to avoid gray wolves during summer but may have relied on other antipredator strategies, such as grouping, in winter [188].

Livestock presence in burns: Because elk often avoid cattle, domestic sheep, and other livestock (see Livestock grazing), the presence of livestock may reduce elk use of burned areas. Elk at Starkey Experimental Forest and Range tended to avoid burned and thinned spruce budworm-killed grand fir-Douglas-fir forests used by cattle [176]. Elk use of burned areas in ponderosa pine forest in Arizona during summer and fall was less than use of unburned controls at the end of a 20-year study. The relatively low elk use was attributed in part to domestic sheep use of the 20-year-old burn for a few weeks in late spring and early summer [179]. Elk use of ponderosa pine forest near Flagstaff, Arizona, that had been burned in a high-severity May wildfire increased for the first 2 years after fire, then leveled off during the third year, possibly due to reinstated cattle grazing on the burned areas at this time [155].

Travel patterns: Fire in elk habitats may influence elk movements and home ranges. Elk only occurred in Boyes Prairie, Humbolt County, California, after a forest fire "drove a few elk" into the surrounding vicinity. The elk apparently remained there, and 12 years later the number of elk utilizing the prairie had increased to 180 animals [109]. Three subadult bulls summering near each other responded differently to the 1988 Yellowstone fires that burned about 57% of their prefire home ranges. One bull moved 6 miles (9 km) in an attempt to flee the fire. The fire caught up and passed his prefire home range and he remained in the burn outside his prefire home range for 12 days before returning to it. Another bull moved 4 miles (7 km) from his prefire home range to escape the fires, rutted there, and then returned to his prefire home range. The third bull moved 5 miles (8 km) from his prefire home range and did not return [321]. In Banff National Park, the Ya Ha Tinda elk herd changed migratory dynamics during 33 years during which 50 miles² (130 km²) of summer range were cumulatively burned under prescription and 4.4 miles² (11.5 km²) of winter range were cumulatively fertilized, mowed, and logged. Over the 33 years of treatment, the proportion of the population migrating declined 75%, with the result that most elk resided year-round on winter range and population growth rate increased. The authors noted possible confounding effects, however: Elk may have avoided summer range due to increasing gray wolf populations there, and they may have remained on winter range because they had become habituated to hay feeding there [114].

Physical barriers: Postfire accumulations of deadfall might discourage use of burned habitats by elk and other ungulates by creating impassable areas [26,185,225]. Thirteen years after fire on the northern Yellowstone winter range, elk avoided piles of coarse woody debris created from fallen conifers, mostly Douglas-fir, killed by the fire [243]. Felled trees in a "spotty" 5-acre (2 ha) 105-year-old lodgepole pine-subalpine fir-Engelmann spruce "thicket" on the eastern slope of the Cascade Range "blocked elk access" to the burn [34]. In contrast, Turner [317] stated that elk used burned forest in Yellowstone National Park even when fallen trees and dense lodgepole pines might have been expected to impede their use of these areas. In northwestern Yellowstone National Park, summering elk did not avoid areas of dense coarse woody debris in young lodgepole pine forests 15 years after the 1988 Yellowstone fires despite the presence of 100 to 2,134 logs/hectare [89]. Mao and others [188] hypothesized that the presence of downed trees in burned forest in Yellowstone National Park may benefit elk by enhancing their ability to defend themselves against gray wolves: elk may back up against trees or downfall to prevent wolf attacks from behind.

In contrast to the above, fire may also benefit elk by removing the deadfall that obstructs movements [185]. Prescribed burning in quaking aspen/Saskatoon serviceberry-mountain snowberry stands in southeastern Idaho reduced obstructions in the understory, which increased accessibility to forage by elk for at least postfire years 1 and 2 [33]. Low-severity prescribed spring burning of shrub fields in north-central Idaho's Selway-Bitterroot National Forest resulted in abundant dead standing brush that acted as a "shield" protecting sprouting shrubs from elk, thus allowing the sprouting shrubs to grow out of reach of elk within 2 to 3 years. In contrast, summer burning removed the dead standing material and allowed elk full access to the sprouting shrubs, which were then pruned by browsing and kept within elk's reach for perhaps 10 to 15 years [333].

Diseases and parasites: Fire may reduce the numbers of external and internal parasites that affect elk and other ungulates, although the effect is likely brief [26,185]. Severe winter tick (*Dermacentor albipictus*) infestations may be detrimental to elk [230,302], and fire may reduce winter tick populations. A May prescribed fire in mature quaking aspen forest and willow habitat on Elk Island National Park, Alberta, reduced the number of engorged adult female ticks and larvae immediately after the burn. Winter ticks were killed by the fire. Winter tick survival depended upon the percent of duff consumed by the fire. Survival was highest where the burn was patchy and the least duff burned [80]. Fire's long-term effects on winter tick populations were unknown as of this writing (2011).

Giant liver flukes may be detrimental to elk, and fire in aquatic habitats may help reduce populations of this parasite. Elk become infected by feeding on aquatic vegetation in marshes or ponds where the final larval stage of the fluke is found together with aquatic snails (*Lymnaea* spp.), the parasite's intermediate hosts [302]. In order to reduce giant liver fluke populations in east-central Alberta, dead aquatic vegetation was burned and snail, elk, and other ungulate populations were reduced. After treatment, giant liver flukes were eliminated from ungulates in the area (Stock 1978, Pybus 1990b, cited in [302]).

Some disease-causing bacteria, such as *Mycobacterium* spp., the genus of bacteria that causes bovine tuberculosis and paratuberculosis, are shed in feces and transmitted to other animals by ingestion of contaminated forage [302]. Boyce [35] speculated that fire may reduce the transmission of diseases and parasites to elk by destroying contaminated feces.

Fire may indirectly affect disease transmission by altering elk use of habitat shared with livestock, although Henry's study in the Jackson Hole area [116] did not demonstrate this pattern.

Case study: 1988 Yellowstone fires: Several thousand elk in 9 herds, including the northern Yellowstone elk herd (the third largest elk herd in North America), use portions of Yellowstone National Park [36,207]. Approximately 17,000 to 23,000 elk spend October or November to April or May on the park's low- to midelevation (7,900- 9,200 feet (2,400-2800 m)) winter ranges and >32,000 elk spend May to September at mid- to high elevation summer ranges on the park's subalpine plateau [331].

Presettlement fires in the Greater Yellowstone Area occurred at 20- to 50-year intervals in Douglas-fir forest and 200- to 300-year intervals in lodgepole pine, Engelmann spruce, and subalpine fir forests [150]. In the 1900s, wildfire frequency and size were reduced due to fewer natural fire starts and fire suppression [125,270]. Fewer fires resulted in a large increase in big sagebrush and conifer encroachment onto the edges of grasslands and into quaking aspen stands [270].

During the summer of 1988, eight major fires spread across Yellowstone National Park from July to mid-September [310,331]. Over 5,400 miles² (14,100 km²) burned in the Greater Yellowstone Area, including 42% of Yellowstone National Park [37,264]. Fires occurred on 5 of 7 elk summer ranges and all 4 elk winter ranges, where 2% to 50% of the areas burned [268]. For the northern Yellowstone elk herd, 33% of elk summer range and 22% of elk winter range burned during the 1988 fires [331]. Only 9% of the grasslands normally used by elk on the northern range during winter burned [37].

The 1988 fires resulted from a combination of drought, above-average temperatures, and numerous dry thunderstorms with lightning strikes and high winds [264,268,331]. During the summer of 1988, fuel moisture levels were only 2% to 3%, and June and July temperatures averaged 8.6 to 2.7 °C above normal, respectively. Fire starts were frequent from July through September of 1988 because a series of abnormally dry cold fronts passed through the park, igniting fires but bringing almost no rain. Winds during the passage of these fronts were as high as 57 miles/hour (96 km/hour). This resulted in fires spotting 1 mile (2 km) ahead of fronts, with fires moving as fast as 2 miles/hour (3 km/hour). Fire fronts advanced as much as 5 to 10 miles/day (8-16 km/day) [331]. The 1988 fires were of mixed severity: 75% of the land area that was subjected to crown fire was within 660 feet (200 m) of a less severely burned or unburned patch, and 50% was within 160 feet (50 m) [150]. The fires were considered a 250- to 400-year event for the area [264]. The last fires on the scale of the 1988 fires occurred during the 1700s [150,310].

The elk population was suspected to be at or above carrying capacity in 1988 due to a series of mild winters in the 1980s [264,266,273]. Elk density on the northern Yellowstone winter range was estimated at 16 to 17 elk/km² [266]. The year of the fires, the northern Yellowstone elk herd experienced the most severe drought on record. Drought, fire, and the subsequent severe winter contributed to unprecedented elk migrations, large elk harvests outside the park, and high mortality of elk the winter immediately following the fires [264]. Specifically, during the first postfire winter, 38% to 43% of the northern Yellowstone elk population died: 14% to 16% of the population was harvested by hunters outside of the park and 24% to 27% of the population died of winter malnutrition. Elk winterkill in the Madison-Firehole elk range, where fire had affected 41% of the area, was approximately 50%. This is in contrast to the 2 mild winters prior to the fire, when elk mortality was <5% [268].

Elk moved onto winter ranges 4 to 6 weeks earlier than normal during the first postfire winter, and more elk migrated out of the park than in prior winters. About 54% of the northern Yellowstone elk herd migrated north across the park boundaries, to access unburned areas where snow was not deep; this area represented only 18% of the winter range. This was only the third time since 1916 that >50% of the elk herd migrated out of the park. Prior to the fires, migrations north of the park averaged 15% of the population [266]. The large migration was probably related to the drought effects on forage abundance, the burning of winter ranges, and a deep snowpack [268]. In early winter, elk were apparently able to find forage in burned areas, but as snow deepened, forage became less accessible, and elk use of the burns was reduced. Bulls were less likely to migrate from burned and partially burned areas than cows. Because they remained in greater numbers in these areas, they died at higher rates [268], presumably from malnutrition. Adult bull survival was only half (46%) the survival of adult cows (84%) during the first postfire year [266].

Following immediate postfire declines, elk populations subsequently increased rapidly, recovering to prefire levels by postfire year 6. Summer survival of elk calves was low both the first and second years after fire, thus slowing the initial herd recovery. However, higher calf:cow ratios were observed from postfire years 3 through 6. Thereafter, the elk population increases stopped due to a combination of increased hunting mortality north of the park, more severe winters, and the effects of gray wolf reintroduction during postfire year 7 [266]. Studies examining fire effects and elk response to the 1988 fires are cited throughout this review. See also the book: *After the Fires: The Ecology of Change in Yellowstone National Park* (edited by Wallace [329]) for a review of fire effects for more than a decade after the 1988 fires.

FIRE REGIMES:

Historically, elk occurred in most habitats in the United States except the humid ecosystems of the Southeast and the deserts of the Southwest [275]. Thus, they were probably adapted to a wide range of fire regimes. Elk occur in habitats with short (e.g., northern prairie grasslands and bluebunch wheatgrass grasslands) to long (e.g., Sitka spruce-western hemlock forests) fire-return intervals, and in areas with understory fire regimes (e.g., coast redwood and Rocky Mountain Douglas-fir forests), mixed-severity fire regimes (e.g., riparian shrublands and ponderosa pine-Douglas-fir forests), and stand-replacement fire regimes (e.g., Wyoming sagebrush steppe and mountain hemlock forests). The Fire Regime Table summarizes characteristics of fire regimes for vegetation communities in which elk may occur. See also Severson and Medina [262] for information on fire regimes in elk habitats of the Southwest. Find further fire regime information for the plant communities in which this species may occur by entering the species name in the FEIS home page under "Find Fire Regimes".

Fire exclusion during the 1900s resulted in increased density of trees in formerly open stands and maturation of shrub and quaking aspen communities. This caused elk rangeland deterioration and loss of quality habitat throughout the species' range [10,275,341]. For example, Hall [103] found herbaceous production in Blue Mountain ponderosa pine forests decreased from 500 to 600 lbs/acre to 50 to 100 lbs/acre following canopy closure resulting from fire exclusion in the early 1900s. He estimated that by 1970, fire exclusion and increasing fir cover had resulted in an understory forage loss capable of supporting 10,000 elk in the Blue Mountains of Oregon alone. Fire exclusion has increased fuel loads in many elk habitats, potentially leading to increased likelihood and/or severity of fires in some areas [306], which could be beneficial or detrimental to elk populations. See Succession for more information.

FIRE MANAGEMENT CONSIDERATIONS:

Elk use postfire habitats, and elk populations often increase after fire (see Elk population response to postfire vegetation changes). Researchers have reported increases in elk forage quantity and nutritive quality after fire (see Postfire vegetation changes and succession), and fire in elk habitats may enhance elk body condition (see Elk condition). As a result, prescribed fire has been used extensively in elk habitats. For example, during 33 years in Banff National Park, 50 miles^2 (130 km^2) was cumulatively burned under prescription on elk summer range [114]. On elk winter range in northern Idaho, 45 miles^2 (117 km^2) was cumulatively burned under prescription during 7 years [168]. Prescribed fire is used in forests and shrublands used by elk to increase or maintain early-successional stages [196,262,306]. On grasslands used by elk, prescribed fire is used to reduce litter that inhibits elk grazing and to prevent incursion by seedling trees [184]. Wisdom and Cook [344] cautioned that the long-term effects of burning on the composition and productivity of elk forages are highly variable and may be unpredictable and/or undesirable, but Lyon and Christensen [184] concluded that despite some disparity in reported results, burning in most western habitats has been favorable for elk. McMahon and deCalesta [196] propose that negative impacts of prescribed fire can be minimized and positive impacts optimized because prescribed fires can be conducted with lower severity and over smaller areas than wildfires, and managers can choose the appropriate season, topography, and moisture conditions to meet wildlife habitat needs.

Fire timing: Spring prescribed fire is often recommended in elk habitats. This allows for some plant growth in the same growing season, thus providing forage for elk soon after fire and into the subsequent winter. Late summer or fall burning in elk habitats may delay forage growth until the following spring and reduce winter forage availability [143,166]. For example, Jourdonnais and Bedunah [143] recommended early spring prescribed fires in alpine rough fescue grasslands in Montana in part because removing vegetation with fall fires would leave no forage for elk during the first postfire winter.

Postfire plant community composition is influenced by timing of the fire relative to plant phenology. Although late fall burning of bluebunch wheatgrass-Idaho fescue foothill range in southeastern Washington did not apparently benefit elk, the authors recommended avoiding summer burning, because severe fires might damage Idaho fescue, the most important forage species for elk in the area [274]. In the Lochsa River area in northern Idaho, shrubs that were burned under prescription in fall almost always had fewer sprouts the next year than did spring-burned plants, although fall-burned plants tended to have longer sprouts, so that about the same quantity of new growth was produced [167]. Leege [167] suggested that more sprouts rather than long sprouts would be more beneficial to elk and thus recommended prescribed burning in spring. Fire may be detrimental to elk populations in areas where elk use mature forests for forage and cover year-round, such as in the Coast Range of southwestern Oregon (e.g., [282]). In the Southern Rocky Mountain Trench in British Columbia, Demarchi and Lofts [79] noted that several shrub species (Saskatoon serviceberry, antelope bitterbrush, baldhip rose (*Rosa gymnocarpa*), redstem ceanothus, snowbrush ceanothus, and kinnikinnick) in communities that provided the main winter forage for elk responded differently to spring prescribed burning, and they recommended caution when trying to manage several shrub species at the same time. For information on phenology and life history characteristics of plant species consumed by elk, see FEIS reviews of species of interest.

The effect of prescribed fire on elk populations depends in part on postfire weather (see Season of use). Peck and Peek [219] suggested that because deep snow can limit elk use of open, burned habitats, resource managers should consider the availability of alternative habitats with varied microclimates when considering a prescribed burning program. Forage was abundant on most subalpine grassland slopes that were burned under prescription near Toad River in northern British Columbia; however, it was unavailable to elk when snow was deep. Thus, Seip and Bunnell [261] suggested that prescribed burning should be used in areas that will be windswept and remain snow-free during severe winters. Snow is often deeper at high elevations than low elevations, suggesting that prescribed burns at low elevations may be most beneficial to elk during winter [63].

Fire type: Fire severity and frequency affect elk forage response. Weaver [333] stated that low-severity prescribed spring burning of brushfields in north-central Idaho's Selway-Bitterroot National Forest created abundant dead standing brush that acted as a "shield" protecting new sprouts from elk, thus allowing the sprouting shrubs to grow out of reach within 2 to 3 years. In contrast, summer burning removed the dead standing material and allowed elk full access to the sprouting browse, which was then pruned by the animal's browsing and kept within elk's reach for perhaps 10 to 15 years. In addition, the authors noted that redstem ceanothus, important elk browse, required high soil temperatures to break seed dormancy and stimulate germination. Soil temperatures during spring fires were too low to accomplish this, whereas summer fires resulted in "superb" redstem ceanothus germination and sprouting [333]. Wagle [328] stated that, although fires that kill much of the overstory vegetation favor elk and other large ungulates, a mixture of low-severity fires with small high-severity patches may be most beneficial to elk because they tend to create and maintain the greatest habitat diversity.

Frequent fire may eliminate some important elk forage species. For example, quaking aspen may fail to sprout after fires at 2- to 3-year intervals [40]. In the Northern Great Plains, where snow is deep, optimum elk habitat may not be reached until 30 or more years after fire when woody plants used as cover have developed on grassland sites. However, the absence of fire from grasslands for >50 years may result in conifer encroachment, canopy closure, and reduction of herbs and shrubs, thus reducing elk habitat quality [119]. Near Toad River in northern British Columbia, the elk population increased where subalpine grassland slopes were burned every 9 years for 80 years on year-round elk range. However, the authors suggested that more frequent fires could be detrimental because elk may need forested areas for cover or to provide browse in winter [261].

Fire size: Research on relationships between fire size and elk population has produced a variety of results, probably because this relationship is influenced by elk density, season of use, and migration patterns. Having a variety of sizes of burned areas within a landscape may be most beneficial to elk. Grand fir and Douglas-fir stands thinned and burned under prescription in September or October provided better foraging opportunities for elk during spring at Starkey Experimental Forest and Range, whereas nearby controls provided better foraging opportunities during summer, suggesting that maintaining a mosaic of burned and unburned, late-successional habitat may be of greater benefit to elk than burning a large proportion of a landscape [176,178]. Bulls may forage in small burns, but small burns may be too small to be used securely by nursery herds [96]. According to

Wright [353], a patchy burn with about 20% unburned vegetation is most desirable for elk and other wildlife because it would leave adequate cover and abundant forage.

According to Cook [58], one difficulty with using prescribed fire to benefit elk is that it is usually conducted at such small scales that benefits to elk tend to be spatially and temporally limited. He suggested that the large elk populations common across the West may not be particularly responsive to prescribed burning at small scales. He also described the dilemma that the value of prescribed fire probably is greatest where elk are highly concentrated, such as on winter ranges, but burning in these areas risks damaging the plant community through heavy grazing and browsing, particularly in small burns. Prescribed burning of small areas on summer range may provide fewer benefits to elk than burning of winter range because relatively few animals are affected [58]. Large-scale prescribed burning on summer ranges may be beneficial, but according to Cook [58] would likely "not be a viable option in most management settings". In Banff National Park, 33 years of prescribed fires in a cumulative area of 50 miles² (130 km²) apparently did not result in increased elk populations; instead the effects of winter range improvements and habituation to supplemental hay during winter appeared to explain increased elk populations [114].

Toweill and Thomas [306] suggested that, although large-scale wildfire is a natural event that has altered forest vegetation on a broad scale historically, it is not necessarily desirable for elk. In northwestern Alberta, Stelfox [287] commented that, because fires may reduce range conditions for elk for a short period, small fires may increase suitable elk range, whereas large fires may be detrimental. Blank [33] suggested that prescribed fire would likely be most beneficial for elk in relatively small patches at close spacing, with some areas treated every year or two, creating a mosaic of variable-aged plant communities that would have maximum edge and habitat diversity, increased production of preferred forage, and increased forage diversity. Because elk cope with changing forage conditions by exploiting different forage classes at different times of year (see Diet) [121], Van Dyke and others [322] suggested that prescribed burns are likely to be most effective if they are relatively small (70-500 acres (30-200 ha)) and widely spaced throughout a mosaic of habitat types.

Small burns may be especially vulnerable to overbrowsing by elk, especially in areas with large elk populations, such as elk winter range [42]. A review of studies in 6 Rocky Mountain national parks in the United States and Canada concluded that fire in landscapes containing high elk densities (>3 elk/km²) were likely to reduce quaking aspen and willow in burns in the long term because of intense postfire browsing [337]. Where excessive browsing by elk is expected, Brown [42] suggested that the best solution to disperse elk may be to burn large areas using a single fire that creates a mosaic of vegetation or to burn a number of small areas in close proximity during a single year. Asherin [12] also suggested using several small prescribed fires scattered over an area of winter range in order to distribute elk over the entire winter range and disperse browsing pressure in burned and adjacent unburned areas. Noting extremely high elk concentrations on burned, dry, upland south and southwest-facing slopes where prescribed fires were concentrated because they were relatively easy to burn caused Peck and Peek [219] to suggest that future prescribed fires be expanded beyond these upland sites, such as to wetter sites on northern aspects, in an attempt to disperse elk. Durham and Marlow [81] suggested that two, 500-acre (200 ha) fires in quaking aspen forest across 2 drainages with <0.36 elk/m² appeared to be sufficient to distribute elk and other ungulates and regenerate quaking aspen stands. However, the size of the burn may be less important than elk density in determining fire effects. Romme and others [249] found no differences in elk browsing intensity among 2-year-old quaking aspen stands burned in the 1988 Yellowstone fires and unburned stands near (<1 km) or far (>4 km) from burned areas. It appeared that elk browsed nearly all quaking aspen sprouts that were accessible in both burned and unburned stands. Elk densities were high and the authors speculated that with lower elk densities, browsing may be more selective [249].

Some other researchers reported that a single large burn rather than many small burns in a landscape may be most beneficial to elk. Using simulation experiments, Wu and others [354] concluded that a prescribed fire program that produced numerous, randomly dispersed, small burned patches would likely lead to greater elk mortality if it were followed by a severe winter, than would a prescribed fire program producing a single, large burned patch of the same total acreage, unless the single large patch was in a critical geographic location such as the limited low-elevation areas that remain snow-free during a severe winter. However, because elk often avoid large openings and favor edge habitats, large burns may not be fully utilized by elk. Retaining standing dead trees after fire may increase use of large burns. See Burn size and shape for more information on this topic. In large burns where cover is limited, planting of trees and shrubs may also increase suitability of burned areas for elk [54].

Other considerations: Burns may attract elk to areas where they are subject to high predation. Time-series modeling in the Bow Valley of Banff National Park and the adjacent Ya Ha Tinda area in Alberta suggested that burning in areas with high wolf density can reduce elk population growth rates (White and others 2005 cited in [113]). Prescribed fires that overlap with areas of high predation risk, such as low-elevation areas, apparently attracted elk where they were then killed by gray wolves. This suggested that prescribed burns in areas of low predation risk, such as high-elevation montane habitats on summer range, might maximize benefits to migratory elk. However, fire in upper-elevation montane habitats was historically infrequent and thus low elk densities in these habitats likely occurred historically [113].

Prescribed burning and its associated human activities in elk range may be harmful to elk populations in the short term by increasing stress levels and altering movements and behaviors (see Human disturbance).

The presence of cattle and other livestock may reduce the benefits of prescribed fire to elk, because elk often avoid cattle [176,179]. See Livestock presence in burns for more information.

APPENDIX: FIRE REGIME TABLE

SPECIES: Cervus elaphus

The following table provides fire regime information that may be relevant to elk habitats. Find further fire regime information for the plant communities in which this species may occur by entering the species name in the FEIS home page under "Find Fire Regimes".

Fire regime information on vegetation communities in which elk may occur. This information is taken from the LANDFIRE Rapid Assessment Vegetation Models [161], which were developed by local experts using available literature, local data, and/or expert opinion. This table summarizes fire regime characteristics for each plant community listed. The PDF file linked from each plant community name describes the model and synthesizes the knowledge available on vegetation composition, structure, and dynamics in that community. Cells are blank where information is not available in the Rapid Assessment Vegetation Model.

Pacific Northwest California Southwest Great Basin

Northern and Central Rockies

Pacific Northwest

- Northwest Grassland
- Northwest Shrubland
- Northwest Woodland
- Northwest Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval	Minimum interval	Maximum interval

			(years)	(years)	(years)
Northwest Grassland					
[Marsh](#)	Replacement	74%	7		
	Mixed	26%	20		
[Bluebunch wheatgrass](#)	Replacement	47%	18	5	20
	Mixed	53%	16	5	20
[Idaho fescue grasslands](#)	Replacement	76%	40		
	Mixed	24%	125		
[Alpine and subalpine meadows and grasslands](#)	Replacement	68%	350	200	500
	Mixed	32%	750	500	>1,000
Northwest Shrubland					
[Salt desert scrubland](#)	Replacement	13%	200	100	300
	Mixed	87%	31	20	100
[Salt desert shrub](#)	Replacement	50%	>1,000	500	>1,000
	Mixed	50%	>1,000	500	>1,000
[Wyoming big sagebrush semidesert](#)	Replacement	86%	200	30	200
	Mixed	9%	>1,000	20	
	Surface or low	5%	>1,000	20	
[Wyoming sagebrush steppe](#)	Replacement	89%	92	30	120
	Mixed	11%	714	120	
[Low sagebrush](#)	Replacement	41%	180		
	Mixed	59%	125		
[Mountain big sagebrush (cool sagebrush)](#)	Replacement	100%	20	10	40

Northwest Woodland					
Western juniper (pumice)	Replacement	33%	>1,000		
	Mixed	67%	500		
Oregon white oak-ponderosa pine	Replacement	16%	125	100	300
	Mixed	2%	900	50	
	Surface or low	81%	25	5	30
Pine savannah (ultramafic)	Replacement	7%	200	100	300
	Surface or low	93%	15	10	20
Ponderosa pine	Replacement	5%	200		
	Mixed	17%	60		
	Surface or low	78%	13		
Oregon white oak	Replacement	3%	275		
	Mixed	19%	50		
	Surface or low	78%	12.5		
Subalpine woodland	Replacement	21%	300	200	400
	Mixed	79%	80	35	120
Northwest Forested					
Sitka spruce-western hemlock	Replacement	100%	700	300	>1,000
Douglas-fir (Willamette Valley foothills)	Replacement	18%	150	100	400
	Mixed	29%	90	40	150
	Surface or low	53%	50	20	80
Oregon coastal tanoak	Replacement	10%	250		

	Mixed	90%	28	15	40
Ponderosa pine (xeric)	Replacement	37%	130		
	Mixed	48%	100		
	Surface or low	16%	300		
Dry ponderosa pine (mesic)	Replacement	5%	125		
	Mixed	13%	50		
	Surface or low	82%	8		
Douglas-fir-western hemlock (dry mesic)	Replacement	25%	300	250	500
	Mixed	75%	100	50	150
Douglas-fir-western hemlock (wet mesic)	Replacement	71%	400		
	Mixed	29%	>1,000		
Mixed conifer (southwestern Oregon)	Replacement	4%	400		
	Mixed	29%	50		
	Surface or low	67%	22		
California mixed evergreen (northern California and southern Oregon)	Replacement	6%	150	100	200
	Mixed	29%	33	15	50
	Surface or low	64%	15	5	30
Mountain hemlock	Replacement	93%	750	500	>1,000
	Mixed	7%	>1,000		
Lodgepole pine (pumice soils)	Replacement	78%	125	65	200
	Mixed	22%	450	45	85
Pacific silver fir (low elevation)	Replacement	46%	350	100	800

	Mixed	54%	300	100	400
Pacific silver fir (high elevation)	Replacement	69%	500		
	Mixed	31%	>1,000		
Subalpine fir	Replacement	81%	185	150	300
	Mixed	19%	800	500	>1,000
Mixed conifer (eastside dry)	Replacement	14%	115	70	200
	Mixed	21%	75	70	175
	Surface or low	64%	25	20	25
Mixed conifer (eastside mesic)	Replacement	35%	200		
	Mixed	47%	150		
	Surface or low	18%	400		
Red fir	Replacement	20%	400	150	400
	Mixed	80%	100	80	130
Spruce-fir	Replacement	84%	135	80	270
	Mixed	16%	700	285	>1,000

California

- California Grassland
- California Shrubland
- California Woodland
- California Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
California Grassland					
California grassland	Replacement	100%	2	1	3

Herbaceous wetland	Replacement	70%	15		
	Mixed	30%	35		
Wet mountain meadow-Lodgepole pine (subalpine)	Replacement	21%	100		
	Mixed	10%	200		
	Surface or low	69%	30		
California Shrubland					
Coastal sage scrub	Replacement	100%	50	20	150
Coastal sage scrub-coastal prairie	Replacement	8%	40	8	900
	Mixed	31%	10	1	900
	Surface or low	62%	5	1	6
Saltbush	Replacement	70%	100	60	200
	Mixed	30%	235	10	
Chaparral	Replacement	100%	50	30	125
California Woodland					
California oak woodlands	Replacement	8%	120		
	Mixed	2%	500		
	Surface or low	91%	10		
Ponderosa pine	Replacement	5%	200		
	Mixed	17%	60		
	Surface or low	78%	13		
California Forested					

California mixed evergreen	Replacement	10%	140	65	700
	Mixed	58%	25	10	33
	Surface or low	32%	45	7	
Coast redwood	Replacement	2%	≥1,000		
	Surface or low	98%	20		
Mixed conifer (north slopes)	Replacement	5%	250		
	Mixed	7%	200		
	Surface or low	88%	15	10	40
Mixed conifer (south slopes)	Replacement	4%	200		
	Mixed	16%	50		
	Surface or low	80%	10		
Aspen with conifer	Replacement	24%	155	50	300
	Mixed	15%	240		
	Surface or low	61%	60		
Jeffrey pine	Replacement	9%	250		
	Mixed	17%	130		
	Surface or low	74%	30		
Interior white fir (northeastern California)	Replacement	47%	145		
	Mixed	32%	210		
	Surface or low	21%	325		
Red fir-white fir	Replacement	13%	200	125	500
	Mixed	36%	70		
	Surface or	51%	50	15	50

	low				
Red fir-western white pine	Replacement	16%	250		
	Mixed	65%	60	25	80
	Surface or low	19%	200		

Southwest

- Southwest Grassland
- Southwest Shrubland
- Southwest Woodland
- Southwest Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Southwest Grassland					
Shortgrass prairie	Replacement	87%	12	2	35
	Mixed	13%	80		
Plains mesa grassland	Replacement	81%	20	3	30
	Mixed	19%	85	3	150
Plains mesa grassland with shrubs or trees	Replacement	76%	20		
	Mixed	24%	65		
Montane and subalpine grasslands	Replacement	55%	18	10	100
	Surface or low	45%	22		
Montane and subalpine grasslands with shrubs or trees	Replacement	30%	70	10	100
	Surface or low	70%	30		
Southwest Shrubland					
Southwestern shrub steppe	Replacement	72%	14	8	15

	Mixed	13%	75	70	80
	Surface or low	15%	69	60	100
Southwestern shrub steppe with trees	Replacement	52%	17	10	25
	Mixed	22%	40	25	50
	Surface or low	25%	35	25	100
Low sagebrush shrubland	Replacement	100%	125	60	150
Interior Arizona chaparral	Replacement	100%	125	60	150
Mountain sagebrush (cool sage)	Replacement	75%	100		
	Mixed	25%	300		
Gambel oak	Replacement	75%	50		
	Mixed	25%	150		
Mountain-mahogany shrubland	Replacement	73%	75		
	Mixed	27%	200		
Southwest Woodland					
Mesquite bosques	Replacement	32%	135		
	Mixed	67%	65		
Madrean oak-conifer woodland	Replacement	16%	65	25	
	Mixed	8%	140	5	
	Surface or low	76%	14	1	20
Pinyon-juniper (mixed fire regime)	Replacement	29%	430		
	Mixed	65%	192		

	Surface or low	6%	>1,000		
Pinyon-juniper (rare replacement fire regime)	Replacement	76%	526		
	Mixed	20%	>1,000		
	Surface or low	4%	>1,000		
Ponderosa pine/grassland (Southwest)	Replacement	3%	300		
	Surface or low	97%	10		
Bristlecone-limber pine (Southwest)	Replacement	67%	500		
	Surface or low	33%	>1,000		
Southwest Forested					
Riparian forest with conifers	Replacement	100%	435	300	550
Riparian deciduous woodland	Replacement	50%	110	15	200
	Mixed	20%	275	25	
	Surface or low	30%	180	10	
Ponderosa pine-Gambel oak (southern Rockies and Southwest)	Replacement	8%	300		
	Surface or low	92%	25	10	30
Ponderosa pine-Douglas-fir (southern Rockies)	Replacement	15%	460		
	Mixed	43%	160		
	Surface or low	43%	160		
Southwest mixed conifer (warm, dry with aspen)	Replacement	7%	300		
	Mixed	13%	150	80	200
	Surface or low	80%	25	2	70

Southwest mixed conifer (cool, moist with aspen)	Replacement	29%	200	80	200
	Mixed	35%	165	35	
	Surface or low	36%	160	10	
Aspen with spruce-fir	Replacement	38%	75	40	90
	Mixed	38%	75	40	
	Surface or low	23%	125	30	250
Stable aspen without conifers	Replacement	81%	150	50	300
	Surface or low	19%	650	600	>1,000
Lodgepole pine (Central Rocky Mountains, infrequent fire)	Replacement	82%	300	250	500
	Surface or low	18%	>1,000	>1,000	>1,000
Spruce-fir	Replacement	96%	210	150	
	Mixed	4%	>1,000	35	>1,000

Great Basin

- Great Basin Grassland
- Great Basin Shrubland
- Great Basin Woodland
- Great Basin Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Great Basin Grassland					
Great Basin grassland	Replacement	33%	75	40	110
	Mixed	67%	37	20	54
Mountain meadow (mesic to dry)	Replacement	66%	31	15	45

	Mixed	34%	59	30	90
Great Basin Shrubland					
Creosotebush shrublands with grasses	Replacement	57%	588	300	>1,000
	Mixed	43%	769	300	>1,000
Blackbrush	Replacement	100%	833	100	>1,000
Salt desert scrubland	Replacement	13%	200	100	300
	Mixed	87%	31	20	100
Salt desert shrub	Replacement	50%	>1,000	500	>1,000
	Mixed	50%	>1,000	500	>1,000
Basin big sagebrush	Replacement	80%	50	10	100
	Mixed	20%	200	50	300
Wyoming big sagebrush semidesert	Replacement	86%	200	30	200
	Mixed	9%	>1,000	20	>1,000
	Surface or low	5%	>1,000	20	>1,000
Wyoming big sagebrush semidesert with trees	Replacement	84%	137	30	200
	Mixed	11%	≥1,000	20	>1,000
	Surface or low	5%	>1,000	20	>1,000
Wyoming sagebrush steppe	Replacement	89%	92	30	120
	Mixed	11%	714	120	
Interior Arizona chaparral	Replacement	88%	46	25	100
	Mixed	12%	350		
Mountain big sagebrush	Replacement	100%	48	15	100

Mountain big sagebrush with conifers	Replacement	100%	49	15	100
Mountain sagebrush (cool sage)	Replacement	75%	100		
	Mixed	25%	300		
Gambel oak	Replacement	75%	50		
	Mixed	25%	150		
Mountain shrubland with trees	Replacement	22%	105	100	200
	Mixed	78%	29	25	100
Black and low sagebrushes	Replacement	33%	243	100	
	Mixed	67%	119	75	140
Black and low sagebrushes with trees	Replacement	37%	227	150	290
	Mixed	63%	136	50	190
Curlleaf mountain-mahogany	Replacement	31%	250	100	500
	Mixed	37%	212	50	
	Surface or low	31%	250	50	
Great Basin Woodland					
Juniper and pinyon-juniper steppe woodland	Replacement	20%	333	100	≥1,000
	Mixed	31%	217	100	≥1,000
	Surface or low	49%	135	100	
Ponderosa pine	Replacement	5%	200		
	Mixed	17%	60		
	Surface or low	78%	13		
Great Basin Forested					

Interior ponderosa pine	Replacement	5%	161		800
	Mixed	10%	80	50	80
	Surface or low	86%	9	8	10
Ponderosa pine-Douglas-fir	Replacement	10%	250		≥1,000
	Mixed	51%	50	50	130
	Surface or low	39%	65	15	
Great Basin Douglas-fir (dry)	Replacement	12%	90		600
	Mixed	14%	76	45	
	Surface or low	75%	14	10	50
Aspen with conifer (low to midelevations)	Replacement	53%	61	20	
	Mixed	24%	137	10	
	Surface or low	23%	143	10	
Douglas-fir (warm mesic interior)	Replacement	28%	170	80	400
	Mixed	72%	65	50	250
Aspen with conifer (high elevations)	Replacement	47%	76	40	
	Mixed	18%	196	10	
	Surface or low	35%	100	10	
Stable aspen-cottonwood, no conifers	Replacement	31%	96	50	300
	Surface or low	69%	44	20	60
Spruce-fir-pine (subalpine)	Replacement	98%	217	75	300
	Mixed	2%	>1,000		
Aspen with spruce-fir	Replacement	38%	75	40	90

	Mixed	38%	75	40	
	Surface or low	23%	125	30	250
Stable aspen without conifers	Replacement	81%	150	50	300
	Surface or low	19%	650	600	>1,000

Northern and Central Rockies

- Northern and Central Rockies Grassland
- Northern and Central Rockies Shrubland
- Northern and Central Rockies Woodland
- Northern and Central Rockies Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Northern and Central Rockies Grassland					
Northern prairie grassland	Replacement	55%	22	2	40
	Mixed	45%	27	10	50
Mountain grassland	Replacement	60%	20	10	
	Mixed	40%	30		
Northern and Central Rockies Shrubland					
Riparian (Wyoming)	Mixed	100%	100	25	500
Salt desert shrub	Replacement	50%	>1,000	500	>1,000
	Mixed	50%	>1,000	500	>1,000
Wyoming big sagebrush	Replacement	63%	145	80	240
	Mixed	37%	250		
Basin big sagebrush	Replacement	60%	100	10	150

	Mixed	40%	150		
Low sagebrush shrubland	Replacement	100%	125	60	150
Mountain shrub, nonsagebrush	Replacement	80%	100	20	150
	Mixed	20%	400		
Mountain big sagebrush steppe and shrubland	Replacement	100%	70	30	200
Northern and Central Rockies Woodland					
Ancient juniper	Replacement	100%	750	200	≥1,000
Northern and Central Rockies Forested					
Ponderosa pine (Northern Great Plains)	Replacement	5%	300		
	Mixed	20%	75		
	Surface or low	75%	20	10	40
Ponderosa pine (Northern and Central Rockies)	Replacement	4%	300	100	≥1,000
	Mixed	19%	60	50	200
	Surface or low	77%	15	3	30
Ponderosa pine (Black Hills, low elevation)	Replacement	7%	300	200	400
	Mixed	21%	100	50	400
	Surface or low	71%	30	5	50
Ponderosa pine (Black Hills, high elevation)	Replacement	12%	300		
	Mixed	18%	200		
	Surface or low	71%	50		
Ponderosa pine-Douglas-fir	Replacement	10%	250		≥1,000
	Mixed	51%	50	50	130

	Surface or low	39%	65	15	
Western redcedar	Replacement	87%	385	75	≥1,000
	Mixed	13%	>1,000	25	
Douglas-fir (xeric interior)	Replacement	12%	165	100	300
	Mixed	19%	100	30	100
	Surface or low	69%	28	15	40
Douglas-fir (warm mesic interior)	Replacement	28%	170	80	400
	Mixed	72%	65	50	250
Douglas-fir (cold)	Replacement	31%	145	75	250
	Mixed	69%	65	35	150
Grand fir-Douglas-fir-western larch mix	Replacement	29%	150	100	200
	Mixed	71%	60	3	75
Mixed conifer-upland western redcedar-western hemlock	Replacement	67%	225	150	300
	Mixed	33%	450	35	500
Western larch-lodgepole pine-Douglas-fir	Replacement	33%	200	50	250
	Mixed	67%	100	20	140
Grand fir-lodgepole pine-larch-Douglas-fir	Replacement	31%	220	50	250
	Mixed	69%	100	35	150
Persistent lodgepole pine	Replacement	89%	450	300	600
	Mixed	11%	>1,000		
Whitebark pine-lodgepole pine (upper subalpine, Northern and Central Rockies)	Replacement	38%	360		
	Mixed	62%	225		

Lower subalpine lodgepole pine	Replacement	73%	170	50	200
	Mixed	27%	450	40	500
Lower subalpine (Wyoming and Central Rockies)	Replacement	100%	175	30	300
Upper subalpine spruce-fir (Central Rockies)	Replacement	100%	300	100	600

*Fire Severities—
Replacement: Any fire that causes greater than 75% top removal of a vegetation-fuel type, resulting in general replacement of existing vegetation; may or may not cause a lethal effect on the plants.
Mixed: Any fire burning more than 5% of an area that does not qualify as a replacement, surface, or low-severity fire; includes mosaic and other fires that are intermediate in effects.
Surface or low: Any fire that causes less than 25% upper layer replacement and/or removal in a vegetation-fuel class but burns 5% or more of the area [106,160].

REFERENCES:

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1. Ager, Alan A.; Johnson, Bruce K.; Kern, John W.; Kie, John G. 2003. Daily and seasonal movements and habitat use by female Rocky Mountain elk and mule deer. Journal of Mammalogy. 84(3): 1076-1088. [83326]

2. Albert, Steven; Luna, Nelson; Jensen, Roger; Livingston, Larry. 2004. Restoring biodiversity to pinon-juniper woodlands. Ecological Restoration. 22(1): 18-23. [47398]

3. Alldredge, Mathew W.; Peek, James M.; Wall, William A. 2002. Nutritional quality of forages used by elk in northern Idaho. The Journal of Range Management. 55(3): 253-259. [41663]

4. Allen, Craig D., ed. 1996. Fire effects in southwestern forests: Proceedings, 2nd La Mesa fire symposium; 1994 March 29-31; Los Alamos, NM. Gen. Tech. Rep. RM-GTR-286. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 216 p. [27279]

5. Allen, Craig D. 1996. Elk response to the La Mesa Fire and current status in the Jemez Mountains. In: Allen, Craig D., ed. Fire effects in southwestern forests: Proceedings, 2nd La Mesa Fire symposium; 1994 March 29-31; Los Alamos, NM. RM-GTR-286. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 179-195. [27292]

6. Amiro, Brian D.; de Groot, William J.; Bothwell, Peter; Westhaver, Alan L.; Achuff, Peter L. 2004. Impacts of fire and elk herbivory in the montane ecoregion of Jasper National Park, Alberta, Canada. In: Engstrom, R. Todd; Galley, Krista E. M.; de Groot, William J., eds. Fire in temperate, boreal, and montane ecosystems: Proceedings of the 22nd Tall Timbers fire ecology conference: an international symposium; 2001 October 15-18; Kananaskis Village, AB. No. 22. Tallahassee, FL: Tall Timbers Research: 258-264. [52332]

7. Anderson, Dean P.; Forester, James D.; Turner, Monica G.; Frair, Jacqui L.; Merrill, Evelyn H.; Fortin, Daniel; Mao, Julie S.; Boyce, Mark S. 2005. Factors influencing female home range sizes in elk (Cervus elaphus) in North American landscapes. Landscape Ecology. 20: 257-271. [82404]

8. Anderson, Dean P.; Turner, Monica G.; Forester, James D.; Zhu, Jun; Boyce, Mark S.; Beyer, Hawthorne; Stowell, Laine. 2005. Scale-dependent summer resource selection by reintroduced elk in Wisconsin, USA. The Journal of Wildlife Management. 69(1): 298-310. [83323]

9. Anderson, E. William; Scherzinger, Richard J. 1975. Improving quality of winter forage for elk by cattle grazing. The Journal of Range Management. 28(2): 120-125. [316]

10. Anderson, Roger C. 1982. An evolutionary model summarizing the roles of fire, climate, and grazing animals in the origin and maintenance of grasslands: an end paper. In: Estes, J.; Tyrl, R.; Brunken, J., eds. Grasses and grasslands: systematics and ecology. Norman, OK: University of Oklahoma Press: 297-308. [21327]

11. Arno, Stephen F.; Harrington, Michael G. 1995. Use thinning and fire to improve forest health and wildlife habitat. Tree Farmer. May/June: 6-8, 23. [26069]

12. Asherin, Duane A. 1973. Prescribed burning effects on nutrition, production and big game use of key northern Idaho browse species. Moscow, ID: University of Idaho. 96 p. Dissertation. [360]

13. Asherin, Duane A. 1975. Changes in elk use and available browse production on north Idaho winter ranges following prescribed burning. In: Hieb, Susuan R., ed. Proceedings, elk logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho: 122-134. [17049]

14. Atwood, Todd C.; Gese, Eric M.; Kunkel, Kyran E. 2009. Spatial partitioning of predation risk in a multiple predator-multiple prey system. The Journal of Wildlife Management. 73(6): 876-884. [83341]

15. Ayotte, Jeremy B.; Parker, Katherine L.; Arocena, Joselito M.; Gillingham, Michael P. 2006. Chemical composition of lick soils: functions of soil ingestion by four ungulate species. Journal of Mammalogy. 87(5): 878-888. [78499]

16. Ayotte, Jeremy B.; Parker, Katherine L.; Gillingham, Michael P. 2008. Use of natural licks by four species of ungulates in northern British Columbia. Journal of Mammalogy. 89(4): 1041-1050. [78554]

17. Bailey, Arthur W. 1975. Rangeland resources on Alberta's east slope. Agriculture Bulletin. 26: 3-6. [53376]

18. Bailey, Joseph K.; Whitham, Thomas G. 2002. Interactions among fire, aspen, and elk affect insect diversity: reversal of a community response. Ecology. 83(6): 1701-1712. [47402]

19. Baker, D. L.; Hobbs, N. T. 1982. Composition and quality of elk summer diets in Colorado. The Journal of Wildlife Management. 46(3): 694-703. [68336]

20. Baker, Robert J.; Bradley, Lisa C.; Bradley, Robert D.; Dragoo, Jerry W.; Engstrom, Mark D.; Hoffmann, Robert S.; Jones, Cheri A.; Reid, Fiona; Rice, Dale W.; Jones, Clyde. 2003. Revised checklist of North American mammals north of Mexico, 2003. Occasional Papers No. 229. Lubbock, TX: Museum of Texas Tech University. 23 p. [50946]

21. Bartos, Dale L.; Brown, James K.; Booth, Gordon D. 1994. Twelve years biomass response in aspen communities following fire. Journal of Range Management. 47: 79-83. [22891]

22. Bartos, Dale L.; Mueggler, Walter F. 1979. Influence of fire on vegetation production in the aspen ecosystem in western Wyoming. In: Boyce, Mark S.; Hayden-Wing, Larry D., eds. North American elk, ecology, behavior and management. Laramie, WY: University of Wyoming: 75-78. [5101]

23. Basile, Joseph V. 1979. Elk-aspen relationships on a prescribed burn. Res. Note INT-271. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 7 p. [4347]

24. Baskin, Yvonne. 1999. Yellowstone fires: a decade later. Bioscience. 49(2): 93-97. [29468]

25. Beck, Jeffrey L.; Peek, James M. 2005. Great Basin summer range forage quality: do plant nutrients meet elk requirements? Western North American Naturalist. 65(4): 516-527. [83211]

26. Bendell, J. F. 1974. Effects of fire on birds and mammals. In: Kozlowski, T. T.; Ahlgren, C. E., eds. Fire and ecosystems. New York: Academic Press: 73-138. [16447]

27. Bender, Louis C. 1996. Harem sizes and adult sex ratios in elk (Cervus elaphus). The American Midland Naturalist. 136(1): 199-202. [83237]

28. Bender, Louis C.; Haufler, Jonathan B. 1999. Relationships between social group size of elk (Cervus elaphus) and habitat cover in Michigan. The American Midland Naturalist. 135(2): 261-265. [83299]

29. Bender, Louis C.; Haufler, Jonathan B. 1999. Social group patterns and associations of nonmigratory elk (Cervus elaphus) in Michigan. The American Midland Naturalist. 142(1): 87-95. [83255]

30. Beyer, Hawthorne L.; Merrill, Evelyn H.; Varley, Nathan; Boyce, Mark S. 2007. Willow on Yellowstone's northern range: evidence for a trophic cascade? Ecological Applications. 17(6): 1563-1571. [83719]

31. Bian, Ling; West, Eric. 1997. GIS modeling of elk calving habitat in a prairie environment. Photogrammetric Engineering and Remote Sensing. 63(2): 161-167. [44461]

32. Biggs, James R.; VanLeeuwen, Dawn M.; Holechek, Jerry L.; Valdez, Raul. 2010. Multi-scale analyses of habitat use by elk following wildfire. Northwest Science. 84(1): 20-32. [81592]

33. Blank, Deborah L. 1984. Forage quality of burned and nonburned aspen communities. Logan, UT: Utah State University. 74 p. Thesis. [471]

34. Boltz, Michael John. 1979. Impacts of prescribed burns and clearcuts upon summer elk food habits, diet quality, and distribution in central Washington. Pullman, WA: Washington State University. 129 p. Thesis. [60992]

35. Boyce, Mark S. 1989. The Jackson elk herd: Intensive wildlife management in North America. New York: Cambridge University Press. 324 p. [82093]

36. Boyce, Mark S.; Mao, Julie S.; Merrill, Evelyn H.; Fortin, Daniel; Turner, Monica G.; Fryxell, John; Turchin, Peter. 2003. Scale and heterogeneity in habitat selection by elk in Yellowstone National Park. Ecoscience. 10(4): 421-431. [82405]

37. Boyce, Mark S.; Merrill, Evelyn H. 1996. Predicting effects of 1988 fires on ungulates in Yellowstone National Park. In: Effects of grazing by wild ungulates in Yellowstone National Park. Technical Report NPS/NRYELL/NRTR/96-10. Washington, DC: U.S. Department of the Interior, National Park Service, Yellowstone National Park: 361-365. [30344]

38. Boyd, Diane K.; Ream, Robert R.; Pletscher, Daniel H.; Fairchild, Michael W. 1994. Prey taken by colonizing wolves and hunters in the Glacier National Park area. The Journal of Wildlife Management. 58(2): 289-295. [83397]

39. Boyd, Raymond J. 1970. Elk of the White River Plateau, Colorado. Technical Publication No. 25. Denver, CO: Colorado Division of Game, Fish and Parks. 126 p. [35816]

40. Brinkman, Kenneth A.; Roe, Eugene I. 1975. Quaking aspen: silvics and management in the Lake States. Agric. Handb. 486. Washington, DC: U.S. Department of Agriculture, Forest Service. 52 p. [5107]

41. Brown, James K. 1985. Fire effects and application of prescribed fire in aspen. In: Saunders, Ken; Durham, Jack; [and others], eds. Rangeland fire effects: Proceedings of the symposium; 1984 November 27-29; Boise, ID. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Idaho State Office: 38-47. [3658]

42. Brown, James K. 1985. Role and use of fire in aspen. In: Foresters' future: leaders or followers?: Proceedings of the 1985 Society of American Foresters national convention; 1985 July 28-31; Fort Collins, CO. SAF Publ. 85-13. Bethesda, MD: Society of American Foresters: 101-105. [5104]

43. Burcham, Milo; Edge, W. Daniel; Marcum, C. Les. 1999. Elk use of private land refuges. Wildlife Society Bulletin. 27(3): 833-839. [83583]

44. Canon, S. K.; Urness, P. J.; DeByle, N. V. 1987. Habitat selection, foraging behavior, and dietary nutrition of elk in burned aspen forest. Journal of Range Management. 40(5): 443-438. [3453]

45. Carbyn, Ludwig N. 1983. Wolf predation on elk in Riding Mountain National Park, Manitoba. The Journal of Wildlife Management. 47(4): 963-976. [83280]

46. Chaikina, Natalia A.; Ruckstuhl, Kathreen E. 2006. The effect of cattle grazing on native ungulates: the good, the bad, and the ugly. Rangelands. 28(3): 8-14. [63224]

47. Child, Kenneth N. 2007. Incidental mortality. In: Franzmann, Albert W.; Schwartz, Charles C.; McCabe, Richard E., eds. Ecology and management of the North American moose. 2nd ed. Boulder, CO: University Press of Colorado: 275-302. [79101]

48. Christensen, Alan G.; Lyon, L. Jack; Unsworth, James W. 1993. Elk management in the Northern Region: considerations in forest plan updates or revisions. Gen. Tech. Rep. INT-303. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 10 p. [22550]

49. Christianson, David A.; Creel, Scott. 2007. Review of environmental factors affecting elk winter diets. The Journal of Wildlife Management. 71(1): 164-176. [83214]

50. Christianson, David; Creel, Scott. 2010. A nutritionally mediated risk effect of wolves on elk. Ecology. 91(4): 1184-1191. [83212]

51. Cole, Eric K.; Pope, Michael D.; Anthony, Robert G. 1997. Effects of road management on movement and survival of Roosevelt elk. The Journal of Wildlife Management. 61(4): 1115-1126. [83279]

52. Cole, Eric K.; Pope, Michael D.; Anthony, Robert G. 2004. Influence of road management on diurnal habitat use of Roosevelt elk. Northwest Science. 78(4): 313-321. [83266]

53. Cole, Glen F. 1969. The elk of Grand Teton and southern Yellowstone national parks. Research Report GRTE-N-I. [Reissue]. Washington, DC: U.S. Department of the Interior, National Park Service, Office of Natural Science Studies. Washington, DC: National Park Service. 80 p. [82320]

54. Collins, Thomas C. 1980. A report on the Moose Creek fire of August, 1979. North Fork, ID: U.S. Department of Agriculture, Forest Service, Salmon National Forest, North Fork Range District.

Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 27 p. [+ appendices]. [666]

55. Collins, William B.; Urness, Philip J. 1983. Feeding behavior and habitat selection of mule deer and elk on northern Utah summer range. The Journal of Wildlife Management. 47(3): 646-663. [6915]

56. Conard, Jonathan Mark. 2009. Genetic variability, demography, and habitat selection in a reintroduced elk (Cervus elaphus) population. Manhattan, KS: Kansas State University. 150 p. Dissertation. [82011]

57. Cook, C. Wayne. 1972. Comparative nutritive values of forbs, grasses and shrubs. In: McKell, Cyrus M.; Blaisdell, James P.; Goodin, Joe R., tech. eds. Wildland shrubs--their biology and utilization: An international symposium: Proceedings; 1971 July; Logan, UT. Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 303-310. [22763]

58. Cook, John G. 2002. Nutrition and food. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press: 259-350. [81796]

59. Cook, John G.; Hershey, Terry J.; Irwin, Larry L. 1994. Vegetative response to burning on Wyoming mountain-shrub big game ranges. Journal of Range Management. 47(4): 296-302. [23449]

60. Cook, Rachel C.; Cook, John G.; Mech, L. David. 2004. Nutritional condition of northern Yellowstone elk. Journal of Mammalogy. 85(4): 714-722. [83378]

61. Cooperrider, Allen Y. 2002. Elk and ecosystem management. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press: 515-530. [81802]

62. Coughenour, Michael B.; Singer, Francis J. 1996. Elk population processes in Yellowstone National Park under the policy of natural regulation. Ecological Applications. 6(2): 573-593. [83235]

63. Coughenour, Michael B.; Singer, Francis J. 1996. Yellowstone elk population responses to fire--a comparison of landscape carrying capacity and spatial-dynamic ecosystem modeling approaches. In: Greenlee, Jason, ed. The ecological implications of fire in Greater Yellowstone: Proceedings, 2nd biennial conference on the Greater Yellowstone Ecosystem; 1993 September 19-21; Yellowstone National Park, WY. Fairfield, WA: International Association of Wildland Fire: 169-179. [27844]

64. Craighead, John J.; Atwell, Gerry; O'Gara, Bart W. 1972. Elk migrations in and near Yellowstone National Park. Wildlife Monographs. 29: 3-48. [83220]

65. Creel, Scott; Christianson, David. 2009. Wolf presence and increased willow consumption by Yellowstone elk: implications for trophic cascades. Ecology. 90(9): 2454-2466. [77025]

66. Creel, Scott; Creel, Michael. 2009. Density dependence and climate effects in Rocky Mountain elk: an application of regression with instrumental variables for population time series with sampling error. Journal of Animal Ecology. 78: 1291-1297. [83233]

67. Creel, Scott; Winnie, John A., Jr. 2005. Responses of elk herd size to fine-scale spatial and temporal variation in the risk of predation by wolves. Animal Behaviour. 69: 1181-1189. [83382]

68. Creel, Scott; Winnie, John, Jr.; Maxwell, Bruce; Hamlin, Ken; Creel, Michael. 2005. Elk alter habitat selection as an antipredator response to wolves. Ecology. 86(12): 3387-3397. [83332]

69. Cronin, Matthew A. 1992. Intraspecific variation in mitochondrial DNA of North American cervids. Journal of Mammalogy. 73(1): 70-82. [78057]

70. Crouch, Glenn L. 1985. Effects of clearcutting a subalpine forest in central Colorado on wildlife habitat. Res. Pap. RM-258. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p. [8225]

71. Cunningham, Julie A.; Hamlin, Kenneth L.; Lemke, Thomas O. 2009. Fetal sex ratios in southwestern Montana elk. The Journal of Wildlife Management. 73(5): 639-646. [83239]

72. Dalke, Paul D.; Beeman, Robert D.; Kindel, Frederic J.; Robel, Robert J.; Williams, Thomas R. 1965. Seasonal movements of elk in the Selway River drainage, Idaho. The Journal of Wildlife Management. 29(2): 333-338. [83399]

73. Dalke, Paul D.; Beeman, Robert D.; Kindel, Frederic J.; Robel, Robert J.; Williams, Thomas R. 1965. Use of salt by elk in Idaho. The Journal of Wildlife Management. 29(2): 319-332. [83191]

74. Davis, Peter R. 1977. Cervid response to forest fire and clearcutting in southeastern Wyoming. The Journal of Wildlife Management. 41(4): 785-788. [224]

75. de Vos, A.; Brokx, P.; Geist, V. 1967. A review of social behavior of the North American cervids during the reproductive period. The American Midland Naturalist. 77(2): 390-417. [78496]

76. DeByle, Norbert V. 1985. Managing wildlife habitat with fire in the aspen ecosystem. In: Lotan, James E.; Brown, James K., compilers. Fire's effects on wildlife habitat--symposium proceedings; 1984 March 21; Missoula, MT. Gen. Tech. Rep. INT-186. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 73-82. [8336]

77. DeByle, Norbert V.; Urness, Philip J.; Blank, Deborah L. 1989. Forage quality in burned and unburned aspen communities. Res. Pap. INT-404. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p. [6588]

78. DelGiudice, Glenn D.; Rodiek, Jon E. 1984. Do elk need free water in Arizona? Wildlife Society Bulletin. 12(2): 142-146. [83215]

79. Demarchi, Dennis A.; Lofts, Susan. 1985. The effects of spring burning on the productivity and nutrient concentration of several shrub species in the southern Rocky Mountain Trench. MOE Technical Report 19. Victoria, BC: British Columbia Ministry of Environment, Wildlife Branch, Wildlife Habitat and Inventory Section. 89 p. [28269]

80. Drew, Mark L.; Samuel, W. M.; Lukiwski, G. M.; Willman, J. N. 1985. An evaluation of burning for control of winter ticks, Dermacentor albipictus, in central Alberta. Journal of Wildlife Diseases. 21(3): 313-315. [79624]

81. Durham, Daniel A.; Marlow, Clayton B. 2010. Aspen response to prescribed fire under managed cattle grazing and low elk densities in southwest Montana. Northwest Science. 84(1): 141-150. [82410]

82. Easterly, Thomas G.; Jenkins, Kurt J. 1991. Forage production and use on bighorn sheep winter range following spring burning in grassland and ponderosa pine habitats. Prairie Naturalist. 23(4): 193-200. [19277]

83. Eberhardt, L. L.; White, P. J.; Garrott, R. A.; Houston, D. B. 2007. A seventy-year history of trends in Yellowstone's northern elk herd. The Journal of Wildlife Management. 71(2): 594-602. [83765]

84. Edge, W. Daniel; Marcum, C. Les; Olson, Sally L. 1985. Effects of logging activities on home-range fidelity of elk. The Journal of Wildlife Management. 49(3): 741-744. [83265]

85. Edge, W. Daniel; Marcum, C. Les; Olson-Edge, Sally L. 1987. Summer habitat selection by elk in western Montana: a multivariate approach. The Journal of Wildlife Management. 51(4): 844-851. [14372]

86. Evans, Shaney B.; Mech, L. David; White, P. J.; Sargeant, Glen A. 2006. Survival of adult female elk in Yellowstone following wolf restoration. The Journal of Wildlife Management. 70(5): 1372-1378. [83284]

87. Fisher, Jason T.; Wilkinson, Lisa. 2005. The response of mammals to forest fire and timber harvest in the North American boreal forest. Mammal Review. 35(1): 51-81. [55373]

88. Flook, Donald R. 1964. Range relationships of some ungulates native to Banff and Jasper National Parks, Alberta. In: Crisp, D. J., ed. Grazing in terrestrial and marine environments: A symposium of the British Ecological Society: Proceedings; 1962 April 11-14; Bangor, UK. No. 4. Oxford: Blackwell: 119-128. [15688]

89. Forester, James D.; Anderson, Dean P.; Turner, Monica G. 2007. Do high-density patches of coarse wood and regenerating saplings create browsing refugia for aspen (Populus trmuloides Michx.) in Yellowstone National Park (USA)? Forest Ecology and Management. 253: 211-219. [82411]

90. Fortin, Daniel; Beyer, Hawthorne L.; Boyce, Mark S.; Smith, Douglas W.; Duchesne, Thierry; Mao, Julie S. 2005. Wolves influence elk movements: behavior shapes a trophic cascade in Yellowstone National Park. Ecology. 86(5): 1320-1330. [83221]

91. Franklin, William L.; Lieb, James W. 1979. The social organization of a sedentary population of North American elk: a model for understanding other populations. In: Boyce, M. S.; Hayden-Wing, L. D., eds. North American elk: ecology, behavior and management: Proceedings of a symposium; 1978 April 3-5; Laramie, WY. Laramie, WY: University of Wyoming: 185-198. [82331]

92. French, Marilynn Gibbs; French, Steven P. 1996. Large mammal mortality in the 1988 Yellowstone fires. In: Greenlee, Jason, ed. The ecological implications of fire in Greater Yellowstone: Proceedings, 2nd biennial conference on the Greater Yellowstone Ecosystem; 1993 September 19-21; Yellowstone National Park, WY. Fairfield, WA: International Association of Wildland Fire: 113-115. [27835]

93. Gaffney, William S. 1941. The effects of winter elk browsing, South Fork of the Flathead River, Montana. The Journal of Wildlife Management. 5(4): 427-453. [5028]

94. Garrott, Robert A.; Eberhardt, L. Lee; White, Patrick; Rotella, Jay. 2003. Climate-induced variation in vital rates of an unharvested large-herbivore population. Canadian Journal of Zoology. 81: 33-45. [83282]

95. Geist, Valerius. 1998. Red deer. In: Deer of the world: Their evolution, behaviour, and ecology. Mechanicsburg, PA: Stackpole Books: 170-222. [78069]

96. Geist, Valerius. 2002. Adaptive behavioral strategies. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press:

389-434. [81798]

97. Gordon, Floyd A. 1976. Spring burning in an aspen-conifer stand for maintenance of moose habitat, West Boulder River, Montana. In: Proceedings, Montana Tall Timbers fire ecology conference and Intermountain Fire Research Council fire and land management symposium; 1974 October 8-10; Missoula, MT. No. 14. Tallahassee, FL: Tall Timbers Research Station: 501-538. [13529]

98. Green, Pat; Talbert, Dennis. 1994. Soil and vegetation response to prescribed burning for winter range enhancement. In: Baumgartner, David M.; Lotan, James E.; Tonn, Jonalea R., compilers. Interior cedar-hemlock-white pine forests: ecology and management: Symposium proceedings; 1993 March 2-4; Spokane, WA. Pullman, WA: Washington State University, Department of Natural Resources: 345-346. [25818]

99. Gruell, G.; Bunting, S.; Neuenschwander, L. 1985. Influence of fire on curlleaf mountain-mahogany in the Intermountain West. In: Lotan, James E.; Brown, James K., compilers. Fire's effects on wildlife habitat--symposium proceedings; 1984 March 21; Missoula, MT. Gen. Tech. Rep. INT-186. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 58-72. [1051]

100. Gruell, George E. 1982. Fires' influence on vegetative succession--wildlife habitat implications and management opportunities. In: Eustace, C. D., compiler. Proceedings, Montana Chapter of the Wildlife Society. Billings, MT: The Wildlife Society: 43-50. [47049]

101. Gucker, Corey L., compiler. 2005. Research Project Summary: Vegetation recovery following a mixed-severity fire in quaking aspen groves of western Wyoming. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: www.fs.fed.us/database/feis/. [69806]

102. Hakim, Salah A. 1979. Range condition on the Threemile Game Range in western Montana. Missoula, MT: University of Montana. 62 p. Thesis. [82039]

103. Hall, Frederick C. 1977. Ecology of natural underburning in the Blue Mountains of Oregon. R6-ECOL-79-001. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 11 p. [8481]

104. Halofsky, Joshua S.; Ripple, William J.; Beschta, Robert L. 2008. Recoupling fire and aspen recruitment after wolf reintroduction in Yellowstone National Park, USA. Forest Ecology and Management. 256(5): 1004-1008. [71537]

105. Hancock, Norman V. 1957. A preliminary report of elk reproduction in Utah with special reference to precociousness in the yearling female. Proceedings, Western Association of State Game and Fish Commissioners. 37:195-197. [83376]

106. Hann, Wendel; Havlina, Doug; Shlisky, Ayn; [and others]. 2010. Interagency fire regime condition class (FRCC) guidebook, [Online]. Version 3.0. In: FRAMES (Fire Research and Management Exchange System). National Interagency Fuels, Fire & Vegetation Technology Transfer (NIFTT) (Producer). Available: http://www.fire.org/niftt/released/FRCC_Guidebook_2010_final.pdf. [81749]

107. Happe, Patricia J.; Jenkins, Kurt J.; Starkey, Edward E.; Sharrow, Steven H. 1990. Nutritional quality and tannin astringency of browse in clear-cuts and old-growth forests. The Journal of Wildlife Management. 54(4): 557-566. [13290]

108. Harper, James A. 1969. Relations of elk to reforestation in the Pacific Northwest. In: Black, Hugh C., ed. Wildlife and reforestation in the Pacific Northwest: Proceedings of a symposium; 1968 September 12-13; Corvallis, OR. Corvallis, OR: Oregon State University, School of Forestry: 67-71. [7949]

109. Harper, James A.; Harn, Joseph H.; Bentley, Wallace W.; Yocom, Charles F. 1967. The status and ecology of the Roosevelt elk in California. Wildlife Monographs. 16: 3-49. [83304]

110. Hazell, Megan. 2006. Behavioural responses of elk to the spatial distribution of resources. Guelph, ON: University of Guelph. 81 p. Thesis. [83216]

111. Hebblewhite, M.; Munro, R. H.; Merrill, E. H. 2009. Trophic consequence of postfire logging in a wolf-ungulate system. Forest Ecology and Management. 257(3): 1053-1062. [74080]

112. Hebblewhite, Mark. 2005. Predation by wolves interacts with the North Pacific Oscillation (NPO) on a western North American elk population. Journal of Animal Ecology. 74: 226-233. [83231]

113. Hebblewhite, Mark. 2007. Predator-prey management in the national park context: lessons from a transboundary wolf, elk, moose, caribou system. In: Predator-prey workshop: Transactions, 72nd North American wildlife and natural resources conference; 2007 March 20-24; Portland OR. Washington, DC: Wildlife Management Institute: 348-365. [83343]

114. Hebblewhite, Mark; Merrill, Evelyn H.; Morgantini, Luigi E.; White, Clifford A.; Allen, James R.; Bruns, Eldon; Thurston, Linda; Hurd, Tomas E. 2006. Is the migratory behavior of montane elk herds in peril? The case of Alberta's Ya Ha Tinda elk herd. Wildlife Society Bulletin. 34(5): 1280-1294. [82434]

115. Hebblewhite, Mark; Pletscher, Daniel H. 2002. Effects of elk group size on predation by wolves. Canadian Journal of Zoology. 80(5): 800-809. [83380]

116. Henry, Francis Drew. 2009. Elk winter habitat selection and movements in the Buffalo Valley of Wyoming with respect to habitat treatments and supplemental feeding. Ames, IA: Iowa State University. 57 p. Thesis. [82452]

117. Hernandez, Lucina; Laundre, John W. 2005. Foraging in the 'landscape of fear' and its implications for habitat use and diet quality of elk (Cervus elpahus) and bison (Bison bison). Wildlife Biology. 11(3): 215-220. [83320]

118. Hershey, Terry L.; Leege, Thomas A. 1976. Influences of logging on elk on summer range in north-central Idaho. In: Hieb, S., ed. Proceedings, elk-logging roads symposium. Moscow, ID: University of Idaho: 73-80. [16145]

119. Higgins, Kenneth F.; Kruse, Arnold D.; Piehl, James L. 1989. Effects of fire in the Northern Great Plains. Ext. Circ. EC-761. Brookings, SD: South Dakota State University, Cooperative Extension Service; South Dakota Cooperative Fish and Wildlife Research Unit. 47 p. [14749]

120. Hines, W. W.; Lemos, J. C. 1979. Reproductive performance by two age classes of male Roosevelt elk in southwestern Oregon. Research Report No. 8. Portland, OR: Oregon Department of Fish and Wildlife. 54 p. [83372]

121. Hobbs, N. Thompson; Baker, Dan L.; Ellis, James E.; Swift, David M. 1981. Composition and quality of elk winter diets in Colorado. The Journal of Wildlife Management. 45(1): 156-171. [7421]

122. Holechek, Jerry L. 1984. Comparative contribution of grasses, forbs, and shrubs to the nutrition of range ungulates. Rangelands. 6(6): 261-263. [21183]

123. Hornbeck, Garry E. 1985. Population characteristics of elk, Cervus elaphus, in Spruce Woods, southwestern Manitoba. The Canadian Field-Naturalist. 99(2): 218-223. [83227]

124. Houston, D. B.; Schreiner, E. G.; Moorhead, B. B.; Krueger, K. A. 1990. Elk in Olympic National Park: will they persist over time? Natural Areas Journal. 10(1): 6-11. [13010]

125. Houston, Douglas B. 1973. Wildfires in northern Yellowstone National Park. Ecology. 54(5): 1111-1117. [5781]

126. Howell, Judd A.; Brooks, George C.; Semenoff-Irving, Marcia; Greene, Correigh. 2002. Population dynamics of tule elk at Point Reyes National Seashore, California. The Journal of Wildlife Management. 66(2): 478-490. [83285]

127. Hudson, R. J.; Kozak, H. M.; Adamczewski, J. Z.; Olsen, C. D. 1991. Reproductive performance of farmed wapiti (Cervus elaphus nelsoni). Small Ruminant Research. 4: 19-28. [83373]

128. Hudson, Robert J.; Haigh, Jerry C. 2002. Physical and physiological adaptations. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press: 199-258. [81794]

129. Huggard, David J. 1993. Effect of snow depth on predation and scavenging by gray wolves. The Journal of Wildlife Management. 57(2): 382-388. [78545]

130. Huggard, David J. 1993. Prey selectivity of wolves in Banff National Park. II. Age, sex, and condition of elk. Canadian Journal of Zoology. 71(1): 140-147. [83396]

131. Irwin, Larry L. 2002. Migration. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press: 493-514. [81801]

132. Irwin, Larry L.; Peek, James M. 1983. Elk habitat use relative to forest succession in Idaho. The Journal of Wildlife Management. 47(3): 664-672. [12893]

133. Irwin, Larry L.; Peek, James M. 1983. Elk, Cervus elaphus, foraging related to forest management and succession in Idaho. The Canadian Field-Naturalist. 97(4): 443-447. [16524]

134. Jacobs, James S.; Sheley, Roger L. 2003. Prescribed fire effects on Dalmatian toadflax. Journal of Range Management. 56(2): 193-197. [44751]

135. Jenkins, K. J.; Wright, R. G. 1988. Resource partitioning and competition among cervids in the northern Rocky Mountains. Journal of Applied Ecology. 25: 11-24. [16289]

136. Jenkins, Kurt J.; Starkey, Edward E. 1984. Habitat use by Roosevelt elk in unmanaged forests of the Hoh Valley, Washington. The Journal of Wildlife Management. 48(2): 642-646. [83309]

137. Jenkins, Kurt J.; Starkey, Edward E. 1993. Winter forages and diets of elk in old-growth and regenerating coniferous forests in western Washington. The American Midland Naturalist. 130(2): 299-313. [82438]

138. Jenkins, Kurt J.; Wright, R. Gerald. 1986. Dietary niche relationships among cervids relative to winter snowpack in northwestern Montana. Canadian Journal of Zoology. 65: 1397-1401. [83217]

139. Jenkins, Kurt; Starkey, Edward. 1996. Simulating secondary succession of elk forage values in a managed forest landscape, western Washington. Environmental Managment. 20(5): 715-724. [82418]

140. Johnson, Donald E. 1951. Biology of the elk calf, Cervus canadensis Nelsoni. The Journal of Wildlife Managment. 15(4): 396-410. [83301]

141. Johnston, Kevin M.; Schmitz, Oswald J. 1997. Wildlife and climate change: assessing the sensitivity of selected species to simulated doubling of atmospheric CO2. Global Change Biology. 3: 531-544. [83234]

142. Jones, Paul F.; Hudson, Robert J. 2002. Winter habitat selection at three spatial scales by American elk, Cervus elaphus, in west-central Alberta. The Canadian Field-Naturalist. 116(2): 183-191. [82048]

143. Jourdonnais, Craig S.; Bedunah, Donald J. 1990. Prescribed fire and cattle grazing on an elk winter range in Montana. Wildlife Society Bulletin. 18(3): 232-240. [17644]

144. Kathnelson, Sandra Lynne. 1996. Gender-biased maternal investment in wapiti (Cervus elaphus). Edmonton, AB: University of Alberta. 77 p. Thesis. [83240]

145. Kay, Charles E. 1997. The condition and trend of aspen, Populus tremuloides, in Kootenay and Yoho National Parks: implications for ecological integrity. The Canadian Field Naturalist. 111(4): 607-616. [30112]

146. Kay, Charles E.; Bartos, Dale L. 2000. Ungulate herbivory on Utah aspen: assessment of longterm exclosures. Journal of Range Management. 53(2): 145-153. [36034]

147. Kimball, John F., Jr.; Wolfe, Michael L. 1974. Population analysis of a northern Utah elk herd. The Journal of Wildlife Management. 38(2): 161-174. [83392]

148. Kimble, David S.; Tyers, Daniel B.; Sowell, Bok F. 2011. Quaking aspen ecology on Forest Service lands north of Yellowstone National Park. In: Wambolt, Carl L.; Kitchen, Stanley G.; Frisina, Michael R.; Sowell, Bok; Keigley, Richard B.; Palacios, Patsy; Robinson, Jill, comps. Proceedings--shrublands: wildlands and wildlife habitats; 15th wildland shrub symposium; 2008 June 17-19; Bozeman, MT. Natural Resources and Environmental Issues, Volume XVI. Logan, UT: Utah State University, College of Natural Resources, S. J. and Jessie E. Quinney Natural Resources Research Library: 51-57. [83468]

149. Kituku, Vincent M.; Powell, Jeff; Smith, Michael A.; Olson, Richard A. 1992. Increasing bitterbrush nutrient quality with 2,4-D, mowing, and burning in southcentral Wyoming. Journal of Range Management. 45(5): 488-492. [19833]

150. Knight, Dennis H. 1993. Effects of the 1988 fires. Yellowstone Science. 2(1): 15-18. [25727]

151. Knight, Richard R. 1970. The Sun River elk herd. Wildlife Monographs. 23: 3-66. [83198]

152. Kohlmann, Stephan G. 1999. Adaptive fetal sex allocation in elk: evidence and implications. The Journal of Wildlife Management. 63(4): 1109-1117. [83241]

153. Kramp, Betty A.; Patton, David R.; Brady, Ward W. 1983. The effects of fire on wildlife habitat and species. Wildlife Unit Tech. Rep. RUN WILD: Wildlife/habitat relationships. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region, Wildlife Unit. 29 p. [152]

154. Kruse, Arnold D.; Higgins, Kenneth F. 1998. Effects of prescribed fire upon wildlife habitat in northern mixed-grass prairie. In: Alexander, M. E.; Bisgrove, G. F., technical coordinators. The art and science of fire management: Proceedings of the 1st Interior West Fire Council annual meeting and workshop; 1988 October 24-27; Kananaskis Village, AB. Information Report NOR-X-309. Edmonton, AB: Forestry Canada, Northwest Region, Northern Forestry Centre: 182-193. [40285]

155. Kruse, William H. 1972. Effects of wildfire on elk and deer use of a ponderosa pine forest. Res. Note RM-226. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p. [5045]

156. Kufeld, Roland C. 1973. Foods eaten by the Rocky Mountain elk. Journal of Range Management. 26(2): 106-113. [1385]

157. Kufeld, Roland C. 1983. Responses of elk, mule deer, cattle, and vegetation to burning, spraying and chaining of Gambel oak rangeland. Tech. Publ. 34. Fort Collins, CO: Colorado Division of Wildlife. 47 p. [253]

158. Kufeld, Roland C.; Stewart, Larry. 1975. Experimental improvement of oakbrush on deer, elk and cattle ranges--Hightower Mountain. Project No. W-101-R-17: Game Range Investigations. Work Plan No. 4: Job No. 3. Job Progress Report: April 1, 1974 through March 31, 1975. Denver, CO: Colorado Department of Fish and Game: 25-92. [16427]

159. Kunkel, Kyran; Pletscher, Daniel H. 1999. Species-specific population dynamics of cervids in a multipredator ecosystem. The Journal of Wildlife Management. 63(4): 1082-1093. [78159]

160. LANDFIRE Rapid Assessment. 2005. Reference condition modeling manual (Version 2.1), [Online]. In: LANDFIRE. Cooperative Agreement 04-CA-11132543-189. Boulder, CO: The Nature Conservancy; U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior (Producers). 72 p. Available: https://www.landfire.gov/downloadfile.php?file=RA_Modeling_Manual_v2_1.pdf [2007, May 24]. [66741]

161. LANDFIRE Rapid Assessment. 2007. Rapid assessment reference condition models, [Online]. In: LANDFIRE. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Lab; U.S. Geological Survey; The Nature Conservancy (Producers). Available: https://www.landfire.gov/models_EW.php [2008, April 18] [66533]

162. Larkin, Jeffrey L.; Cox, John J.; Wichrowski, Michael W.; Dzialak, Matthew R.; Maehr, David S. 2004. Influences on release-site fidelity of translocated elk. Restoration Ecology. 12(1): 97-105. [82272]

163. Lavelle, Darlene Anne. 1986. Use and preference of spotted knapweed (Centaurea maculosa) by elk (Cervus elaphus) and mule deer (Odocoileus hemionus) on two winter ranges in western Montana. Missoula, MT: University of Montana. 72 p. Thesis. [37896]

164. Leckenby, Donavin A. 1984. Elk use and availability of cover and forage habitat components in the Blue Mountains, northeastern Oregon, 1976-1982. Wildlife Research Report No. 14. Portland, OR: Oregon Department of Fish and Wildlife, Research Development. 40 p. [83393]

165. Leege, Thomas A., compiler. 1984. Guidelines for evaluating and managing summer elk habitat in northern Idaho. Wildlife Bulletin Number 11. [Federal Aid Project W-160-R]. Boise, ID: Idaho Fish and Game Department. 37 p. [13681]

166. Leege, Thomas A. 1968. Prescribed burning for elk in northern Idaho. In: Proceedings, annual Tall Timbers fire ecology conference; 1968 March 14-15; Tallahassee, FL. No 8. Tallahassee, FL: Tall Timbers Research Station: 235-253. [5287]

167. Leege, Thomas A. 1969. Burning seral brush ranges for big game in northern Idaho. Transactions, North American Wildlife and Natural Resources Conference. 34: 429-438. [144]

168. Leege, Thomas A. 1972. Northern elk ranges improved by burning. Idaho Wildlife Review. 24(4): 7-10. [16753]

169. Leege, Thomas A. 1975. Relationship of logging to decline of Pete King elk herd. In: Hieb, Susuan R., ed. Proceedings, elk logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho: 6-10. [17048]

170. Leege, Thomas A. 1978. Changes in browse intercept, production and seedlings after burning--Holly Creek. Job Completion Report: Federal Aid to Wildlife Restoration Project W-160-R. Elk ecology--Study I: Range rehabilitation by spring burning. Job No. 2: July 1, 1965 to June 30, 1978. Boise, ID: Idaho Department of Fish and Game. 11 p. [17170]

171. Leege, Thomas A.; Godbolt, Grant. 1985. Herbaceous response following prescribed burning and seeding of elk range in Idaho. Northwest Science. 59(2): 134-143. [1436]

172. Leege, Thomas A.; Hickey, William O. 1977. Elk-snow-habitat relationships in the Pete King drainage, Idaho. Wildlife Bulletin No. 6. Boise, ID: Idaho Department of Fish and Game. 23 p. [Job Completion Report: Federal Aid Project W-160-R. Elk ecology: Study III, Jobs 1-2]. [42138]

173. Lehmkuhl, John F. 2002. The effects of spring burning and grass seeding in forest clearcuts on native plants and conifer seedlings in coastal Washington. Northwest Science. 76(1): 46-60. [82417]

174. Lehmkuhl, John F.; Kie, John G.; Bender, Louis C.; Servheen, Gregg; Nyberg, Harvey. 2001. Evaluating the effects of ecosystem management activities on elk, mule deer, and white-tailed deer in the interior Columbia River basin, USA. Forest Ecology and Management. 153(1-3): 89-104. [83567]

175. Lockman, David C. 1978. Wildlife use of the Red Desert/checkerboard area. In: Johnson, Kendall L., ed. Wyoming shrublands: Proceedings of the 7th Wyoming shrub ecology workshop; 1978 May 31-June 1; Rock Springs, WY. Laramie, WY: University of Wyoming, Range Management Division, Wyoming Shrub Ecology Workshop: 55-56. [1465]

176. Long, Ryan A.; Rachlow, Janet L.; Kie, John G. 2008. Effects of season and scale on response of elk and mule deer to habitat manipulation. The Journal of Wildlife Management. 72(5): 1133-1142. [82412]

177. Long, Ryan A.; Rachlow, Janet L.; Kie, John G. 2009. Sex-specific responses of North American elk to habitat manipulation. Journal of Mammalogy. 90(2): 423-432. [82413]

178. Long, Ryan A.; Rachlow, Janet L.; Kie, John G.; Vavra, Martin. 2008. Fuels reduction in a western coniferous forest: effects on quantity and quality of forage for elk. Rangeland Ecology and Management. 61: 302-313. [70956]

179. Lowe, Philip O.; Ffolliott, Peter F.; Dieterich, John H.; Patton, David R. 1978. Determining potential wildlife benefits from wildfire in Arizona ponderosa pine forests. Gen. Tech. Rep. RM-52. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p. [4481]

180. Lyon, L. Jack. 1976. Elk use as related to characteristics of clearcuts in western Montana. In: Hieb, S. R., ed. Elk-logging-roads: Proceedings of the symposium; 1976 December 16-17; Moscow, ID. Moscow, ID: University of Idaho: 69-72. [7954]

181. Lyon, L. Jack. 1979. Influences of logging and weather on elk distribution in western Montana. Res. Pap. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 11 p. [7958]

182. Lyon, L. Jack. 1980. Coordinating forestry and elk management. Transactions, 45th North American Wildlife and Natural Resources Conference. 45: 278-287. [2828]

183. Lyon, L. Jack. 1980. Influences of timber harvesting and residue management on big game. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: Symposium proceedings; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 441-453. [10313]

184. Lyon, L. Jack; Christensen, Alan G. 2002. Elk and land management. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. 1st ed. Washington, DC: Smithsonian Institution Press: 557-582. [81804]

185. Lyon, L. Jack; Crawford, Hewlette S.; Czuhai, Eugene; Fredriksen, Richard L.; Harlow, Richard F.; Metz, Louis J.; Pearson, Henry A. 1978. Effects of fire on fauna: a state-of-knowledge review--National fire effects workshop; 1978 April 10-14; Denver, CO. Gen. Tech. Rep. WO-6. Washington, DC: U.S. Department of Agriculture, Forest Service. 41 p. [25066]

186. Mackie, Richard J. 1970. Range ecology and relations of mule deer, elk, and cattle in the Missouri River Breaks, Montana. Wildlife Monographs No. 20. Washington, DC: The Wildlife Society. 79 p. [5897]

187. Makela, Paul D. 1990. Effects of prescribed burning on the Burdette Creek winter range. Missoula, MT: University of Montana. 112 p. Thesis. [20681]

188. Mao, Julie S.; Boyce, Mark S.; Smith, Douglas W.; Singer, Francis J.; Vales, David J.; Vore, John M.; Merrill, Evelyn H. 2005. Habitat selection by elk before and after wolf reintroduction in Yellowstone National Park. The Journal of Wildlife Management. 69(4): 1691-1707. [82440]

189. Marcum, C. Les. 1975. Summer-fall habitat selection and use by a western Montana elk herd. Missoula, MT: University of Montana. 188 p. Dissertation. [51342]

190. Marcum, C. Les; Scott, Michael D. 1985. Influences of weather on elk use of spring-summer habitat. The Journal of Wildlife Management. 49(1): 73-76. [83312]

191. Martinka, C. J. 1976. Fire and elk in Glacier National Park. In: Proceedings, Tall Timbers fire ecology conference and fire and land management symposium; 1974 October 8-10; Missoula, MT. No. 14. Tallahassee, FL: Tall Timbers Research Station: 377-389. [7523]

192. McCorquodale, Scott M. 1987. Fall-winter habitat use by elk in the shrub-steppe of Washington. Northwest Science. 61(3): 171-173. [3983]

193. McCorquodale, Scott M. 2003. Sex-specific movements and habitat use by elk in the Cascade Range of Washington. The Journal of Wildlife Management. 67(4): 729-741. [83334]

194. McCorquodale, Scott M.; Raedeke, Kenneth J.; Taber, Richard D. 1986. Elk habitat use patterns in the shrub-steppe of Washington. The Journal of Wildlife Management. 50(4): 664-669. [1593]

195. McCorquodale, Scott M.; Raedeke, Kenneth J.; Taber, Richard D. 1989. Home ranges of elk in an arid environment. Northwest Science. 63(1): 29-34. [83222]

196. McMahon, Thomas E.; deCalesta, David S. 1990. Effects of fire on fish and wildlife. In: Walstad, John D.; Radosevich, Steven R.; Sandberg, David V., eds. Natural and prescribed fire in Pacific Northwest forests. Corvallis, OR: Oregon State University Press: 233-250. [47606]

197. Mech, L. David; Smith, Douglas W.; Murphy, Kerry M.; MacNulty, Daniel R. 2001. Winter severity and wolf predation on a formerly wolf-free elk herd. The Journal of Wildlife Management. 65(4): 998-1003. [83339]

198. Meredith, E. P.; Rodzen, J. A.; Banks, J. D.; Schaefer, R.; Ernest, H. B.; Famula, T. R.; May, B. P. 2007. Microsatellite analysis of three subspecies of elk (Cervus elaphus) in California. Journal of Mammalogy. 88(3): 801-808. [83207]

199. Merrill, Evelyn H.; Mayland, Henry F.; Peek, James M. 1980. Effects of a fall wildfire on herbaceous vegetation on xeric sites in the Selway-Bitterroot Wilderness, Idaho. Journal of Range Management. 33(5): 363-367. [1642]

200. Merrill, Evelyn; Raedeke, Kenneth; Taber, Richard. 1987. Population dynamics and habitat ecology of elk in the Mount St. Helens blast zone. Seattle, WA: University of Washington, College of Forest Resources, Wildlife Science Group. 186 p. [82037]

201. Miller, Valerie A. 1990. Knapweed as forage for big game in the Kootenays. In: Roche, Ben F.; Roche, Cindy Talbott, eds. Range weeds revisited: Proceedings of a symposium: A 1989 Pacific Northwest range management short course; 1989 January 24-26; Spokane, WA. Pullman, WA: Washington State University, Department of Natural Resource Sciences, Cooperative Extension: 35-37. [14832]

202. Millspaugh, Sarah H.; Whitlock, Cathy; Bartlein, Patrick J. 2004. Postglacial fire, vegetation, and climate history of the Yellowstone-Lamar and central plateau provinces, Yellowstone National Park. In: Wallace, Linda L., ed. After the fires: The ecology of change in Yellowstone National Park. New Haven, CT: Yale University Press: 10-28. [83631]

203. Mitchell, Glenn E. 1950. Wildlife-forest relationships in the Pacific Northwest region. Journal of Forestry. 48: 26-30. [6923]

204. Morgantini, Luigi E.; Hudson, Robert J. 1985. Changes in diets of wapiti during a hunting season. Journal of Range Management. 38(1): 77-79. [11492]

205. NatureServe. 2012. NatureServe Explorer: An online encyclopedia of life, [Online]. Version 7.1. Arlington, VA: NatureServe (Producer). Available http://www.natureserve.org/explorer. [69873]

206. Nelson, Jack R.; Leege, Thomas A. 1982. Nutritional requirements and food habits. In: Thomas, Jack Ward; Toweill, Dale E., eds. Elk of North America: ecology and management. Harrisburg, PA: Stackpole Books: 323-368. [14494]

207. Norland, J. E.; Singer, F. J.; Mack, L. 1996. Effects of the Yellowstone fires of 1988 on elk habitats. In: Greenlee, Jason, ed. The ecological implications of fire in Greater Yellowstone: Proceedings, 2nd biennial conference on the Greater Yellowstone Ecosystem; 1993 September 19-21; Yellowstone National Park, WY. Fairfield, WA: International Association of Wildland Fire: 223-232. [27859]

208. Noyes, James H.; Johnson, Bruce K.; Bryant, Larry D.; Findholt, Scott L.; Thomas, Jack Ward. 1996. Effects of bull age on conception dates and pregnancy rates of cow elk. The Journal of Wildlife Management. 60(3): 508-517. [83250]

209. Noyes, James H.; Johnson, Bruce K.; Dick, Brian L.; Kie, John G. 2002. Effects of male age and female nutritional condition on elk reproduction. The Journal of Wildlife Management. 66(4): 1301-1307. [83251]

210. O'Gara, Bart W. 2002. Taxonomy. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press: 3-66. [81782]

211. O'Gara, Bart W.; Dundas, Robert G. 2002. Distribution: past and present. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press: 67-120. [81793]

212. Oedekoven, Olin O.; Lindzey, Frederick G. 1987. Winter habitat-use patterns of elk, mule deer, and moose in southwestern Wyoming. The Great Basin Naturalist. 47(4): 638-643. [4058]

213. Packard, Fred Mallery. 1947. A study of the deer and elk herds of Rocky Mountain National Park, Colorado. Journal of Mammalogy. 28(1): 4-12. [83386]

214. Patterson, Beau. 1996. Movements and forest habitat selection of elk in the southeast Bighorn Mountains. Laramie, WY: University of Wyoming. 83 p. Thesis. [82457]

215. Patton, David R. 1976. Timber harvesting increases deer and elk use of a mixed conifer forest. Res. Note RM-329. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 3 p. [14448]

216. Patton, David R.; Gordon, Janet. 1995. Fire, habitats, and wildlife. Final report. Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Coconino National Forest. 85 p. Unpublished report on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. [61019]

217. Pearson, Scott M.; Turner, Monica G.; Wallace, Linda L.; Romme, William H. 1995. Winter habitat use by large ungulates following fire in northern Yellowstone National Park. Ecological Applications. 5(3): 744-755. [26077]

218. Peck, V. Ross. 1988. Fire and elk in northeastern British Columbia: the historical context. In: Feller, M. C.; Thomson, S. M., eds. Wildlife and range prescribed burning workshop proceedings; 1987 October 27-28; Richmond, BC. Vancouver, BC: The University of British Columbia, Faculty of Forestry: 142-162. [3109]

219. Peck, V. Ross; Peek, James M. 1991. Elk, Cervus elaphus, habitat use related to prescribed fire, Tuchodi River, British Columbia. The Canadian Field-Naturalist. 105(3): 354-362. [18204]

220. Peek, James M. 1989. Another look at burning shrubs in northern Idaho. In: Baumgartner, David M.; Breuer, David W.; Zamora, Benjamin A.; Neuenschwander, Leon F.; Wakimoto, Ronald H., comps. Prescribed fire in the Intermountain region: Forest site preparation and range improvement: Symposium proceedings; 1986 March 3-5; Spokane, WA. Pullman, WA: Washington State University, Department of Natural Resources, Cooperative Extension: 157-159. [81960]

221. Peek, James M. 2003. Wapiti (Cervus elaphus). In: Feldhamer, George A.; Thompson, Bruce C.; Chapman, Joseph A., eds. Wild mammals of North America: Biology, management, and conservation. 2nd ed. Baltimore, MD: The Johns Hopkins University Press: 877-888. [82099]

222. Peek, James M.; Scott, Michael D.; Nelson, Louis J.; Pierce, D. John. 1982. Role of cover in habitat management for big game in northwestern United States. Transactions, 47th North American

Wildlife and Natural Resources Conference. Washington, DC: Wildlife Management Institute. 47: 363-373. [13901]

223. Petersburg, Mylea L.; Alldredge, A. William; de Vergie, William J. 2000. Emigration and survival of 2-year-old male elk in northwestern Colorado. Wildlife Society Bulletin. 28(3): 708-716. [82437]

224. Phillips, Gregory E.; Alldredge, A. William. 2000. Reproductive success of elk following disturbance by humans during calving season. The Journal of Wildlife Management. 64(2): 521-530. [83254]

225. Phillips, T. A. 1973. The effects of fire on vegetation and wildlife on a lodgepole pine burn in Chamberlain Basin, Idaho. Range Improvement Notes. 18(1): 1-9. [16548]

226. Picton, Harold D. 1960. Migration patterns of the Sun River elk herd, Montana. The Journal of Wildlife Management. 24(3): 279-290. [83381]

227. Polziehn, R. O.; Hamr, J.; Mallory, F. F.; Strobeck, C. 1998. Phylogenetic status of North American wapiti (Cervus elaphus) subspecies. Canadian Journal of Zoology. 76: 998-1010. [83206]

228. Proffitt, Kelly M.; Grigg, Jamin L.; Garrott, Robert A.; Hamlin, Kenneth L.; Cunningham, Julie; Gude, Justin A.; Jourdonnais, Craig. 2010. Changes in elk resource selection and distributions associated with a late-season elk hunt. The Journal of Wildlife Management. 74(2): 210-218. [83584]

229. Proffitt, Kelly M.; Grigg, Jamin L.; Hamlin, Kenneth L.; Garrott, Robert A. 2009. Contrasting effects of wolves and human hunters on elk behavioral responses to predation risk. The Journal of Wildlife Management. 73(3): 345-356. [83582]

230. Raedeke, Kenneth J.; Millspaugh, Joshua J.; Clark, Patrick E. 2002. Population characteristics. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press: 449-492. [81800]

231. Ralphs, Robert M., tech. ed. 1981. Elk habitat relationships of central Idaho. [Boise, ID]: [Idaho Department of Fish and Game]. 57 p. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. [16521]

232. Rearden, Spencer N. 2005. Juvenile survival and birth-site selection of Rocky Mountain elk in northeastern Oregon. Corvallis, OR: Oregon State University. 105 p. Thesis. [83281]

233. Reichelt, Leslie Ronald. 1973. Characteristics of elk calving sites along the West Fork of the Madison River. Bozeman, MT: Montana State University. 39 p. Thesis. [83400]

234. Reynolds, Hudson G. 1962. Use of natural openings in a ponderosa pine forest of Arizona by deer, elk and cattle. Res. Notes RM-78. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p. [82083]

235. Reynolds, Hudson G. 1964. Elk and deer habitat use of a pinyon-juniper woodland in southern New Mexico. In: Clambey, Gary K.; Pemble, Richard H., eds. The prairie: past, present and future: Proceedings of the 9th North American prairie conference; 1984 July 29 - August 1; Moorhead, MN. Fargo, ND: Tri-College University Center for Environmental Studies: 438-444. [10733]

236. Reynolds, Hudson G. 1966. Use of openings in spruce-fir forests of Arizona by elk, deer, and cattle. Res. Note RM-66. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p. [82090]

237. Rhodes, Bruce D.; Sharrow, Steven H. 1990. Effect of grazing by sheep on the quantity and quality of forage available to big game in Oregon's Coast Range. Journal of Range Management. 43(3): 235-237. [11763]

238. Rice, Peter M.; Toney, J. Christopher; Bedunah, Donald J.; Carlson, Clinton E. 1997. Elk winter forage enhancement by herbicide control of spotted knapweed. Wildlife Society Bulletin. 25(3): 627-633. [37470]

239. Riggs, Robert A.; Bunting, Stephen C.; Daniels, Steven E. 1996. Prescribed fire. In: Krausman, Paul R., ed. Rangeland wildlife. Denver, CO: The Society for Range Management: 295-320. [82031]

240. Ripple, William J.; Beschta, Robert L. 2003. Wolf reintroduction, predation risk, and cottonwood recovery in Yellowstone National Park. Forest Ecology and Management. 184: 299-313. [46086]

241. Ripple, William J.; Beschta, Robert L. 2004. Wolves, elk, willows, and trophic cascades in the upper Gallatin Range of southwestern Montana, USA. Forest Ecology and Management. 200: 161-181. [83581]

242. Ripple, William J.; Beschta, Robert L. 2006. Linking wolves to willows via risk-sensitive foraging by ungulates in the northern Yellowstone ecosystem. Forest Ecology and Management. 230: 96-106. [62649]

243. Ripple, William J.; Larsen, Eric J. 2001. The role of postfire coarse woody debris in aspen regeneration. Western Journal of Applied Forestry. 16(2): 61-64. [39279]

244. Ripple, William J.; Larsen, Eric J.; Renkin, Roy A.; Smith, Douglas W. 2001. Trophic cascades among wolves, elk and aspen on Yellowstone National Park's northern range. Biological Conservation. 102(3): 227-234. [41183]

245. Roberts, Hadley B. 1974. Effects of logging on elk calving habitat: Moyer Creek, Salmon National Forest, Idaho. Salmon, ID: Salmon National Forest. 22 p. [+ appendix]. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. [82063]

246. Robinson, Barry G.; Hebblewhite, Mark; Merrill, Evelyn H. 2010. Are migrant and resident elk (Cervus elaphus) exposed to similar forage and predation risk on their sympatric winter range? Oecologia. 164: 265-275. [83218]

247. Romme, William H.; Knight, Dennis H. 1982. Landscape diversity: the concept applied to Yellowstone Park. Bioscience. 32(8): 664-670. [16202]

248. Romme, William H.; Turner, Monica G. 1991. Implications of global climate change for biogeographic patterns in the Greater Yellowstone Ecosystem. Conservation Biology. 5(3): 373-386. [21677]

249. Romme, William H.; Turner, Monica G.; Wallace, Linda L.; Walker, Jennifer S. 1995. Aspen, elk, and fire in northern Yellowstone National Park. Ecology. 76(7): 2097-2106. [25945]

250. Roppe, Jerry A.; Hein, Dale. 1978. Effects of fire on wildlife in a lodgepole pine forest. The Southwestern Naturalist. 23(2): 279-287. [261]

251. Rounds, Richard C. 1981. First approximation of habitat selectivity of ungulates on extensive winter ranges. The Journal of Wildlife Management. 45(1): 187-196. [78201]

252. Rowland, M. M.; Alldredge, A. W.; Ellis, J. E.; Weber, B. J.; White, G. C. 1983. Comparative winter diets of elk in New Mexico. The Journal of Wildlife Management. 47(4): 924-932. [44982]

253. Rowland, Mary M. 1983. A fire for winter elk. New Mexico Wildlife Magazine. 28(6): 2-5. [5160]

254. Sachro, L. L.; Strong, W. L.; Gates, C. C. 2005. Prescribed burning effects on summer elk forage availability in the subalpine zone, Banff National Park, Canada. Journal of Environmental Management. 77: 183-193. [60352]

255. Sargeant, Glen A.; Oehler, Michael W., Sr. 2007. Dynamics of newly established elk populations. The Journal of Wildlife Management. 71(4): 1141-1148. [83244]

256. Sawyer, Hall; Nielson, Ryan M.; Lindzey, Fred G.; Keith, Lorraine; Powell, Jake H.; Abraham, Anu A. 2007. Habitat selection of Rocky Mountain elk in a nonforested environment. The Journal of Wildlife Management. 71(3): 868-874. [83401]

257. Schreiner, Edward G.; Krueger, Kirsten A.; Happe, Patricia J.; Houston, Douglas B. 1996. Understory patch dynamics and ungulate herbivory in old-growth forests of Olympic National Park, Washington. Canadian Journal of Forest Research. 26: 255-265. [26590]

258. Schroer, Greg L.; Jenkins, Kurt J.; Moorhead, Bruce B. 1993. Roosevelt elk selection of temperate rain forest seral stages in western Washington. Northwest Science. 67(1): 23-29. [20563]

259. Schwartz, John E., II; Mitchell, Glen E. 1945. The Roosevelt elk on the Olympic Peninsula, Washington. The Journal of Wildlife Management. 9(4): 295-319. [8878]

260. Scotter, George W. 1980. Management of wild ungulate habitat in the western United States and Canada: a review. Journal of Range Management. 33(1): 16-27. [78771]

261. Seip, Dale R.; Bunnell, Fred L. 1985. Range burning, Stone's sheep, and the leaky bucket. In: Lotan, James E.; Brown, James K., compilers. Fire's effects on wildlife habitat--symposium proceedings; 1984 March 21; Missoula, MT. Gen. Tech. Rep. INT-186. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 44-47. [8340]

262. Severson, Kieth E.; Medina, Alvin L. 1983. Deer and elk habitat management in the Southwest. Journal of Range Management. Monograph No. 2. Denver, CO: Society for Range Management. 64 p. [2110]

263. Shively, Kirk J.; Alldredge, A. William; Phillips, Gregory E. 2005. Elk reproductive response to removal of calving season disturbance by humans. The Journal of Wildlife Management. 69(3): 1073-1080. [83247]

264. Singer, F. J.; Harter, M. K. 1996. Comparative effects of elk herbivory and 1988 fires on northern Yellowstone National Park grasslands. Ecological Applications. 6(1): 185-199. [26712]

265. Singer, Francis J. 1979. Habitat partitioning and wildfire relationships of cervids in Glacier National Park, Montana. The Journal of Wildlife Management. 43(2): 437-444. [4074]

266. Singer, Francis J.; Coughenour, Michael B.; Norland, Jack E. 2004. Elk biology and ecology before and after the Yellowstone fires of 1988. In: Wallace, Linda L., ed. After the fires: The ecology of change in Yellowstone National Park. New Haven, CT: Yale University Press: 117-139. [81963]

267. Singer, Francis J.; Harting, Albert; Symonds, Kate K.; Coughenour, Michael B. 1997. Density dependence, compensation, and environmental effects on elk calf mortality in Yellowstone National

Park. The Journal of Wildlife Management. 61(1): 12-25. [82464]

268. Singer, Francis J.; Schreier, William; Oppenheim, Jill; Garton, Edward O. 1989. Drought, fires, and large mammals. BioScience. 39(10): 716-722. [67678]

269. Singer, Francis J.; Schullery, Paul. 1989. Yellowstone wildlife: populations in process. Western Wildlands. 15(2): 18-22. [67676]

270. Singer, Francis J.; Swift, David M.; Coughenour, Michael B.; Varley, John D. 1998. Thunder on the Yellowstone revisited: an assessment of management of native ungulates by natural regulation. Wildlife Society Bulletin. 26(3): 375-390. [83718]

271. Singer, Francis J.; Zeigenfuss, Linda C.; Cates, Rex G.; Barnett, David T. 1998. Elk, multiple factors, and persistence of willows in national parks. Wildlife Society Bulletin. 26(3): 419-428. [78276]

272. Singer, Francis James. 1975. Wildfire and ungulates in the Glacier National Park area, northwestern Montana. Moscow, ID: University of Idaho. 53 p. Thesis. [19355]

273. Singer, Francis. 1991. Ungulate populations models and carrying capacity: Predicting effects of fires, new winter range, and proposed wolf reintroduction. Park Science. 11(1): 8-9. [13928]

274. Skovlin, Jon M.; Edgerton, Paul J.; McConnell, Burt R. 1983. Elk use of winter range as affected by cattle grazing, fertilizing, and burning in southeastern Washington. Journal of Range Management. 36(2): 184-189. [2154]

275. Skovlin, Jon M.; Zager, Peter; Johnson, Bruce K. 2002. Elk habitat selection and evaluation. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press: 531-556. [81803]

276. Smith, Bruce L. 2001. Winter feeding of elk in western North America. The Journal of Wildlife Management. 65(2): 173-190. [38912]

277. Smith, Bruce L.; Anderson, Stanley H. 1996. Patterns of neonatal mortality of elk in northwest Wyoming. Canadian Journal of Zoology. 74(7): 1229-1237. [83296]

278. Smith, Bruce L.; Anderson, Stanley H. 1998. Juvenile survival and population regulation of the Jackson elk herd. The Journal of Wildlife Management. 62(3): 1036-1045. [83286]

279. Smith, Bruce L.; Anderson, Stanley H. 2001. Does dispersal help regulate the Jackson elk herd? Wildlife Society Bulletin. 29(1): 331-341. [83297]

280. Smith, Bruce L.; Robbins, Russell L.; Anderson, Stanley H. 1996. Adaptive sex ratios: another example? Journal of Mammalogy. 77(3): 818-825. [83236]

281. Smith, Douglas W.; Drummer, Thomas D.; Murphy, Kerry M.; Guernsey, Debra S.; Evans, Shaney B. 2004. Winter prey selection and estimation of wolf kill rates in Yellowstone National Park, 1995-2000. The Journal of Wildlife Management. 68(1): 153-166. [83395]

282. Smithey, Douglas A.; Wisdom, Michael J.; Hines, William W. 1985. Roosevelt elk and black-tailed deer response to habitat changes related to old-growth forest conversion in southwestern Oregon. In: Nelson, R. Wayne, ed. Proceedings of the 1984 western states and provinces elk workshop; 1984 April 17-19; Edmonton, AB. Edmonton, AB: Alberta Fish and Wildlife Division; Western Association of Fish & Wildlife Agencies: 41-55. [82288]

283. Squibb, Ronald C.; Kimball, John F., Jr.; Anderson, David R. 1986. Bimodal distribution of estimated conception dates in Rocky Mountain elk. The Journal of Wildlife Management. 50(1): 118-122. [83242]

284. Stalling, David H.; Wolfe, Gary J.; Crockett, Dan K. 2002. Regulating the hunt. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press: 749-792. [81806]

285. Stelfox, J. G.; Lynch, G. M.; McGillis, J. R. 1976. Effects of clearcut logging on wild ungulates in the central Albertan foothills. Forestry Chronicle. 52(2): 65-70. [13506]

286. Stelfox, John G. 1962. Effects on big game of harvesting coniferous forests in western Alberta. The Forestry Chronicle. 38(1): 94-107. [83264]

287. Stelfox, John G. 1964. Elk in northwest Alberta. Land-Forest-Wildlife. 6(5): 14-23. [82030]

288. Stelfox, John G.; Taber, Richard D. 1969. Big game in the northern Rocky Mountain coniferous forest. In: Taber, Richard D., ed. Coniferous forests of the northern Rocky Mountains: Proceedings of the 1968 symposium; 1968 September 17-20; Missoula, MT. Missoula, MT: University of Montana Foundation, Center for Natural Resources: 197-222. [7546]

289. Stevens, Richard. 2004. Incorporating wildlife habitat needs into restoration and rehabilitation projects. In: Monsen, Stephen B.; Stevens, Richard; Shaw, Nancy L., comps. Restoring western ranges and wildlands. Gen. Tech. Rep. RMRS-GTR-136-vol. 1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 155-174. [52826]

290. Stewart, Kelley M.; Bowyer, R. Terry; Dick, Brian L.; Johnson, Bruce K.; Kie, John G. 2005. Density-dependent effects on physical condition and reproduction in North American elk: an experimental test. Oecologia. 143(1): 85-93. [83252]

291. Stewart, Kelley M.; Bowyer, R. Terry; Kie, John G.; Cimon, Norman J.; Johnson, Bruce K. 2002. Temporospatial distributions of elk, mule deer, and cattle: resource partitioning and competitive displacement. Journal of Mammalogy. 83(1): 229-244. [45202]

292. Stickney, Peter F. 1981. Vegetative recovery and development. In: DeByle, Norbert V., ed. Clearcutting and fire in the larch/Douglas-fir forests of western Montana--A multifaceted research summary. Gen. Tech. Rep. INT-99. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 33-40. [34969]

293. Strohmeyer, Deborah C.; Peek, James M. 1996. Wapiti home range and movement patterns in a sagebrush desert. Northwest Science. 70(2): 79-87. [83256]

294. Stubblefield, Cynthia H.; Vierling, Kerri T.; Rumble, Mark A. 2006. Landscape-scale attributes of elk centers of activity in the central Black Hills of South Dakota. The Journal of Wildlife Management. 70(4): 1060-1069. [83591]

295. Swanson, Donald Oscar. 1970. Roosevelt elk-forest relationships in the Douglas-fir region of the southern Oregon Coast Range. Ann Arbor, MI: University of Michigan, Ann Arbor. 173 p. Dissertation. [83259]

296. Sweeney, James M.; Steinhoff, H. W. 1976. Elk movements and calving as related to snow cover. In: Steinhoff, Harold W.; Ives, Jack D., eds. Ecological impacts of snowpack augmentation in the San Juan Mountains, Colorado. Final report: San Juan Ecology Project. Fort Collins, CO: Colorado State University: 415-436. [82033]

297. Taber, Richard D. 1973. Effects of even-age forest management on big game. In: Hermann, Richard K.; Lavender, Denis P., eds. Even-age management: Proceedings of a symposium; 1972 August 1; [Corvallis, OR]. Paper 848. Corvallis, OR: Oregon State University, School of Forestry: 59-74. [16240]

298. Taper, Mark L.; Gogan, Peter J. 2002. The northern Yellowstone elk: density dependence and climatic conditions. The Journal of Wildlife Management. 66(1): 106-122. [82436]

299. Telfer, Edmund S. 1993. Browse and herbage yield following clearing in the Alberta montane aspen ecoregion. Alces. 29: 55-61. [78818]

300. Thompson, Michael J. 1996. Winter foraging response of elk to spotted knapweed removal. Northwest Science. 70(1): 10-19. [26561]

301. Thorne, E. Tom; Dean, Ron E.; Hepworth, William G. 1976. Nutrition during gestation in relation to successful reproduction in elk. The Journal of Wildlife Management. 40(2): 330-335. [83248]

302. Thorne, E. Tom; Williams, Elizabeth S.; Samuel, William M.; Kistner, T. P. 2002. Diseases and parasites. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. 1st ed. Washington, DC: Smithsonian Institution Press: 351-388. [81797]

303. Tiedemann, Arthur R.; Woodard, Paul M. 2002. Multiresource effects of a stand-replacement prescribed fire in the Pinus contorta-Abies lasiocarpa vegetation zone of central Washington. Gen. Tech. Rep. PNW-GTR-535. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p. [43123]

304. Timmermann, H. R. 1991. Ungulates and aspen management. In: Navratil, S.; Chapman, P. B., eds. Aspen management for the 21st century: Proceedings of a symposium; 1990 November 20-21; Edmonton, AB. Edmonton, AB: Forestry Canada, Northwest Region, Northern Forestry Centre; Poplar Council of Canada: 99-110. [18550]

305. Toweill, Dale E.; Thomas, Jack Ward, eds. 2002. North American Elk: ecology and management. Washington, DC: Smithsonian Institution Press. 962 p. [79700]

306. Toweill, Dale E.; Thomas, Jack Ward. 2002. The future of elk and elk management. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: ecology and management. Washington, DC: Smithsonian Institution Press: 793-841. [81807]

307. Tracy, Benjamin F. 2004. Fire effects, elk, and ecosystem resilience in Yellowstone's sagebrush grasslands. In: Wallace, Linda L., ed. After the fires: The ecology of change in Yellowstone National Park. New Haven, CT: Yale University Press: 102-116. [82007]

308. Tracy, Benjamin F.; McNaughton, Samuel J. 1996. Comparative ecosystem properties in summer and winter ungulate ranges following the 1988 fires in Yellowstone National Park. In: Greenlee, Jason, ed. The ecological implications of fire in Greater Yellowstone: Proceedings, 2nd biennial conference on the Greater Yellowstone Ecosystem; 1993 September 19-21; Yellowstone National Park, WY. Fairfield, WA: International Association of Wildland Fire: 181-191. [27847]

309. Tracy, Benjamin F.; McNaughton, Samuel J. 1997. Elk grazing and vegetation responses following a late season fire in Yellowstone National Park. Plant Ecology. 130(2): 111-119. [28963]

310. Tracy, Benjamin Franklin. 1996. Fire effects in the grasslands of Yellowstone National Park. Syracuse, NY: Syracuse University. 174 p. Dissertation. [82008]

311. Tracy, Benjamin. 1997. Fire effects in Yellowstone's grasslands. Yellowstone Science. 5(3): 2-5. [28317]

312. Trainer, Charles Edward. 1971. The relationship of physical condition and fertility of female Roosevelt elk (Cervus canadensis roosevelti) in Oregon. Corvallis, OR: Oregon State University. 93 p. Thesis. [83374]

313. Trammel, Michael A.; Butler, Jack L. 1995. Effects of exotic plants on native ungulate use of habitat. The Journal of Wildlife Management. 59(4): 808-816. [28316]

314. Trottier, G. C.; Rollansa, S. R.; Hutchison, R. C. 1983. Range, habitat and foraging relationships of ungulates in Riding Mountain National Park. Large Mammal Systems Studies: Report Number 14. Edmonton, AB: Canadian Wildlife Service. 52 p. [83369]

315. Turley, Deborah; Roundy, Bruce A.; Walker, Scott C. 2003. True mountain mahogany community and shrub size responses to browsing. Journal of Range Management. 56(6): 600-607. [47264]

316. Turner, Monica G.; Wu, Yegang; Wallace, Linda L.; Romme, William H.; Brenkert, Antoinette. 1994. Simulating winter interactions among ungulates, vegetation, and fire in northern Yellowstone Park. Ecological Applications. 4(3): 472-496. [27846]

317. Turner, Monica. 2009. Ecological effects of the '88 Yellowstone fires. Yellowstone Science. 17(2): 24-29. [81512]

318. Tyser, Robin W.; Key, Carl H. 1988. Spotted knapweed in natural area fescue grasslands: an ecological assessment. Northwest Science. 62(4): 151-160. [5485]

319. Unsworth, James W.; Kuck, Lonn; Garton, Edward O.; Butterfield, Bart R. 1998. Elk habitat selection on the Clearwater National Forest, Idaho. The Journal of Wildlife Management. 62(4): 1255-1263. [83544]

320. Unsworth, James W.; Kuck, Lonn; Scott, Michael D.; Garton, Edward O. 1993. Elk mortality in the Clearwater drainage of northcentral Idaho. The Journal of Wildlife Management. 57(3): 495-502. [21741]

321. Vales, David J.; Peek, James M. 1996. Responses of elk to the 1988 Yellowstone fires and drought. In: Greenlee, Jason, ed. The ecological implications of fire in Greater Yellowstone: Proceedings, 2nd biennial conference on the Greater Yellowstone Ecosystem; 1993 September 19-21; Yellowstone National Park, WY. Fairfield, WA: International Association of Wildland Fire: 159-167. [27843]

322. Van Dyke, Fred G.; Dibenedetto, Jeffrey P.; Thomas, Steven C. 1991. Vegetation and elk response to prescribed burning in south-central Montana. In: Keiter, Robert B.; Boyce, Mark S., eds. The Greater Yellowstone Ecosystem: Redefining America's wilderness heritage. New Haven, CT: Yale University Press: 163-179. [83165]

323. Van Dyke, Fred. 2007. Colonization of non-traditional range in dispersing elk, Cervis elaphus nelsoni, populations. The Canadian Field-Naturalist. 121(2): 133-141. [83257]

324. Van Dyke, Fred; Darragh, Jeffrey A. 2006. Short- and longer-term effects of fire and herbivory on sagebrush communities in south-central Montana. Environmental Management. 38(3): 365-376. [63225]

325. Van Dyke, Fred; Deboer, Michael J.; Van Beek, Grant M. 1996. Winter range plant production and elk use following prescribed burning. In: Greenlee, Jason, ed. The ecological implications of

fire in Greater Yellowstone: Proceedings, 2nd biennial conference on the Greater Yellowstone Ecosystem; 1993 September 19-21; Yellowstone National Park, WY. Fairfield, WA: International Association of Wildland Fire: 193-200. [27855]

326. Vavra, Martin. 2005. Livestock grazing and wildlife: developing compatibilities. Rangeland Ecology and Management. 58(2): 128-134. [54778]

327. Visscher, D. R.; Merrill, E. H. 2009. Temporal dynamics of forage succession for elk at two scales: implications of forest management. Forest Ecology and Management. 257(1): 96-106. [73178]

328. Wagle, R. F. 1981. Fire: its effects on plant succession and wildlife in the Southwest. Some effects of fire on plant succession and variability in the Southwest from a wildlife management viewpoint. RR 281. Tucson, AZ: University of Arizona. 82 p. [4031]

329. Wallace, Linda L., ed. 2004. After the fires: The ecology of change in Yellowstone National Park. New Haven, CT: Yale University Press. 390 p. [61291]

330. Wallace, Linda L.; Coughenour, Michael B.; Turner, Monica G.; Romme, William H. 2004. Fire patterns and ungulate survival in northern Yellowstone Park: The results of two independent models. In: Wallace, Linda L., ed. After the fires: The ecology of change in Yellowstone National Park. New Haven, CT: Yale University Press: 299-317. [82006]

331. Wallace, Linda L.; Singer, Francis J.; Schullery, Paul. 2004. The fires of 1988: a chronology and invitation to research. In: Wallace, Linda L., ed. After the fires: The ecology of change in Yellowstone National Park. New Haven, CT: Yale University Press: 3-9. [82275]

332. Wallace, Mark Christopher. 1991. Elk habitat use in the White Mountains, Arizona. Tucson, AZ: University of Arizona. 185 p. Disseration. [83384]

333. Weaver, Stephen M. 1987. Fire and elk: summer prescription burning on elk winter range, a new direction in habitat management on the Nez Perce National Forest. Bugle: The Quarterly Journal of the Rocky Mountain Elk Foundation. 4(2): 41-42. [98]

334. Weber, Bruce J.; Wolfe, Michael L.; White, Gary C.; Rowland, Mary M. 1984. Physiologic response of elk to differences in winter range quality. The Journal of Wildlife Management. 48(1): 248-253. [82408]

335. White, Clifford A.; Feller, Michael C. 2001. Predation risk and elk-aspen foraging patterns. In: Shepperd, Wayne D.; Binkley, Dan; Bartos, Dale L.; Stohlgren, Thomas J.; Eskew, Lane G., comps. Sustaining aspen in western landscapes: symposium proceedings; 2000 June 13-15; Grand Junction, CO. Proceedings RMRS-P-18. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 61-80. [40297]

336. White, Clifford A.; Feller, Michael C.; Bayley, Suzanne. 2003. Predation risk and the functional response of elk-aspen herbivory. Forest Ecology and Management. 181: 77-97. [45216]

337. White, Clifford A.; Olmsted, Charles E.; Kay, Charles E. 1998. Aspen, elk, and fire in the Rocky Mountain national parks of North America. Wildlife Society Bulletin. 26(3): 449-462. [30387]

338. White, Gary C.; Freddy, David J.; Gill, R. Bruce; Ellenberger, John H. 2001. Effect of adult sex ratio on mule deer and elk productivity in Colorado. The Journal of Wildlife Management. 65(3): 543-551. [83249]

339. White, P. J.; Garrott, Robert A. 1993. Why do elk eat burned bark? Yellowstone Science. 1(4): 2-5. [24392]

340. White, P. J.; Proffitt, Kelly M.; Mech, L. David; Evans, Shaney B.; Cunningham, Julie A.; Hamlin, Kenneth L. 2010. Migration of northern Yellowstone elk: implications of spatial structuring. Journal of Mammalogy. 91(4): 827-837. [83298]

341. Widenmaier, Kerri J.; Strong, Wayne L. 2010. Tree and forest encroachment into fescue grasslands on the Cypress Hills plateau, Alberta, Canada. Forest Ecology and Management. 259(10): 1870-1879. [81389]

342. Wilson, Don E.; Reeder, DeeAnn M., eds. 2005. Mammal species of the world: A taxonomic and geographic reference, [Online]. 3rd ed. Baltimore, MD: Johns Hopkins University Press. 2,142 p. In: Databases. Washington, DC: Smithsonian National Museum of Natural History, Department of Vertebrate Zoology, Division of Mammals (Producer). Available: http://vertebrates.si.edu/mammals/msw/ [69038]

343. Winnie, John, Jr.; Creel, Scott. 2007. Sex-specific behavioural responses of elk to spatial and temporal variation in the threat of wolf predation. Animal Behaviour. 73(1): 215-225. [83319]

344. Wisdom, Michael J.; Cook, John G. 2000. North American elk. In: Demarais, Stephen; Krausman, Paul R., eds. Ecology and management of large animals in North America. Upper Saddle River, NJ: Prentice Hall: 694-735. [82279]

345. Wisdom, Michael J.; Johnson, Bruce K.; Vavra, Martin; Boyd, Jennifer M.; Coe, Priscilla K.; Kie, John G.; Ager, Alan A. 2004. Cattle and elk responses to intensive timber harvest. In: Rahm, Jennifer, ed. Resource stewardship in the 21st century: a voyage of rediscovery; Transactions, 69th North American wildlife and natural resources conference; 2004 March 16-20; Spokane, WA. Washington, DC: Wildlife Management Institute: 728-758. [83277]

346. Wisdom, Michael J.; Vavra, Martin; Boyd, Jennifer M.; Hemstrom, Miles A.; Ager, Alan A.; Johnson, Bruce K. 2006. Understanding ungulate herbivory--episodic disturbance effects on vegetation dynamics: knowledge gaps and management needs. Wildlife Society Bulletin. 34(2): 283-292. [82462]

347. Witmer, G. W.; deCalesta, D. S. 1983. Habitat use by female Roosevelt elk in the Oregon Coast Range. The Journal of Wildlife Management. 47(4): 933-939. [83317]

348. Witmer, Gary W.; deCalesta, David S. 1985. Effect of forest roads on habitat use by Roosevelt elk. Northwest Science. 59(2): 122-125. [83253]

349. Witt, Brenden R. 2008. Range size and habitat use of elk in the Glass Mountains, Texas. Alpine, TX: Sul Ross State University. 58 p. Thesis. [83137]

350. Wolff, Jerry O.; Van Horn, Toni. 2003. Vigilance and foraging patterns of American elk during the rut in habitats with and without predators. Canadian Journal of Zoology. 81(2): 266-271. [83340]

351. Wolters, Gale L. 1996. Elk effects on Bandelier National Monument meadows and grasslands. In: Allen, Craig D., ed. Fire effects in Southwestern forests: Proceedings, 2nd La Mesa fire symposium; 1994 March 29-31; Los Alamos, NM. RM-GTR-286. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 196-205. [27293]

352. Wright, Anthony L.; Kelsey, Rick G. 1997. Effects of spotted knapweed on a cervid winter-spring range in Idaho. Journal of Range Management. 50(5): 487-496. [27926]

353. Wright, Henry A. 1974. Range burning. Journal of Range Management. 27(1): 5-11. [2613]

354. Wu, Yegang; Turner, Monica G.; Wallace, Linda L.; Romme, William H. 1996. Elk survival following the 1988 Yellowstone fires: a simulation experiment. Natural Areas Journal. 16(3): 198-207. [26886]

355. Yeo, Jeffrey J.; Peek, James M. 1994. Successional patterns of antlered game in cedar-hemlock forests. In: Baumgartner, David M.; Lotan, James E.; Tonn, Jonalea R., compilers. Interior cedar-hemlock-white pine forests: ecology and management: Symposium proceedings; 1993 March 2-4; Spokane, WA. Pullman, WA: Washington State University, Department of Natural Resources: 199-205. [25803]

356. Yeo, Jeffrey J.; Peek, James M.; Wittinger, William T.; Kvale, Craig T. 1993. Influence of rest-rotation cattle grazing on mule deer and elk habitat use in east-central Idaho. Journal of Range Management. 46(3): 245-250. [83538]

357. Young, Vernon A.; Robinette, W. Leslie. 1939. A study of the range habits of elk on the Selway Game Preserve. Bulletin No. 9. Moscow, ID: University of Idaho, School of Forestry. 47 p. [6831]

358. Zager, Peter; Beecham, John. 2006. The role of American black bears and brown bears as predators on ungulates in North America. Ursus. 17(2): 95-108. [78654]

359. Zouhar, Kristin; Smith, Jane Kapler; Sutherland, Steve; Brooks, Matthew L. 2008. Wildland fire in ecosystems: fire and nonnative invasive plants. Gen. Tech. Rep. RMRS-GTR-42-vol. 6. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 355 p. [70897]

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