Review

Effects of Livestock Grazing on Stand Dynamics and Soils in Upland Forests of the Interior West

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Abstract: *Many ponderosa pine and mixed-conifer forests of the western, interior United States have undergone substantial structural and compositional changes since settlement of the West by Euro-Americans. Historically, these forests consisted of widely spaced, fire-tolerant trees underlain by dense grass swards. Over the last 100 years they have developed into dense stands consisting of more fire-sensitive and disease-susceptible species. These changes, sometimes referred to as a decline in "forest health," have been attributed primarily to two factors: active suppression of low-intensity fires (which formerly reduced tree recruitment, especially of fire-sensitive, shade-tolerant species), and selective logging of larger, more fire-tolerant trees. A third factor, livestock grazing, is seldom discussed, although it may be as important as the other two factors. Livestock alter forest dynamics by (1) reducing the biomass and density of understory grasses and sedges, which otherwise outcompete conifer seedlings and prevent dense tree recruitment, and (2) reducing the abundance of fine fuels, which formerly carried low-intensity fires through forests. Grazing by domestic livestock has thereby contributed to increasingly dense western forests and to changes in tree species composition. In addition, exclosure studies have shown that livestock alter ecosystem processes by reducing the cover of herbaceous plants and litter, disturbing and compacting soils, reducing water infiltration rates, and increasing soil erosion.*

Efectos del Pastoreo sobre la Dinámica de Árboles y Suelos en Bosques en el Altiplano del Occidente Interior

Resumen: *Muchos bosques de pino ponderosa y de coníferas mixtas en el occidente interior de Estados Unidos han tenido cambios sustanciales en su estructura y composición desde la colonización del Oeste por euro-americanos. Históricamente, estos bosques consistían de árboles tolerantes al fuego ampliamente espaciados y de densos manchones de pasto. En los últimos 100 años se han desarrollado en densos bosques que consisten de especies sensibles al fuego y susceptibles a enfermedades. Estos cambios, conocidos como una declinación en la "salud del bosque, han sido atribuidos a dos factores principales: la supresión activa de fuegos de baja intensidad que anteriormente reducían el reclutamiento de árboles, especialmente de especies sensibles al fuego y tolerantes a la sombra; y la tala selectiva de árboles más grandes y tolerantes al fuego. Un tercer factor, el pastoreo de ganado, es discutido raramente, aunque puede ser tan importante como los otros dos. El ganado altera la dinámica del bosque (1) reduciendo la biomasa y densidad de pastos del sotobosque, los cuales compiten con plántulas de coníferas y previenen el reclutamiento denso de árboles, (2) reduciendo la abundancia de combustibles pequeños, que anteriormente favorecían la expansión de fuegos de baja intensidad. Por lo tanto, el pastoreo de ganado doméstico ha contribuido a que los bosques occidentales sean cada vez más densos y a cambios en la composición de especies arbóreas. Además estudios de exclusión muestran que el ganado altera procesos de los ecosistemas al reducir la cobertura de plantas herbáceas y de humus, al perturbar y compactar suelos, al reducir las tasas de infiltración de agua y al incrementar la erosión del suelo.*

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Introduction

Management of forests throughout the mountainous interior of the western United States has recently received wide attention from both government agencies and the general public. Much of this attention has concentrated on what federal land-management agencies and the press call the "forest health emergency," which is generally described as the conversion of low-density, fire-tolerant ponderosa pine and mixed conifer forests into dense, fire-prone, diseased "thickets" that contribute to "catastrophic forest mortality" (Wickman 1992; Mutch et al. 1993). This widespread perception, which may not be supported by the evidence (Smith 1994; AFSEEE 1995), has been promoted by the timber industry, some western congressmen, and the U.S. Forest Service to justify widespread thinning and salvage logging of forests of the Interior West (DellaSala et al. 1995).

Recent publications and state and federal assessments (e.g., Gast et al. 1991; Mutch et al. 1993; O'Laughlin et al. 1993; Everett 1994) on structural and compositional changes in western forests have concentrated primarily on the effects of logging, silvicultural practices, fire suppression, disease, and road construction on forest stability and sustainable timber production. The effects of livestock grazing on these forested ecosystems have received little attention. However, an extensive scientific literature, beginning as early as the 1920s (e.g., Pearson 1923; Leopold 1924), suggests that livestock played a major role in altering these forests.

Domestic livestock currently graze approximately 115 million ha, or 91%, of all federal lands in the 11 contiguous western states (U.S. General Accounting Office 1988; Armour et al. 1991). The impacts of grazing on western ecosystems in terms of species losses, soil erosion, and degradation of wildlife habitat have been both widespread and severe (Flather et al. 1994; Fleischner 1994). Several excellent reviews have documented effects of grazing in a variety of ecosystems, primarily in western rangelands, arid woodlands, and riparian zones (Kauffman & Krueger 1984; Skovlin 1984; Thurow 1991; Archer 1994; Fleischner 1994). However, none is specific to the more arid low and mid-elevation forests of the western, interior United States, which include forests from Washington south to New Mexico and from the Rocky Mountains west to the eastern Cascade–Sierra Nevada Range. Specifically, we review the effects of livestock grazing on low- and mid-elevation forested ecosystems of the Interior West and discuss evidence suggesting that livestock have had a profound influence on the stand dynamics, species composition, soils, and stability of these forests.

Effects of Livestock Grazing on Forest Dynamics

Over the last 100 years, the structure, composition, and dynamics of semi-arid western, interior forests have changed dramatically. These forests, dominated at low elevations by ponderosa pine (*Pinus ponderosa*) and at middle elevations by Douglas fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), and western larch (*Larix occidentalis*), were once commonly described as open woodlands of widely spaced, majestic trees, underlain by dense grass swards (Fig. 1a) (Cooper 1960; Peet 1988; Habeck 1990; Covington & Moore 1994). Over the last century, most of these forests have been clearcut, roaded, and fragmented so that only a small fraction of the original forests remains. In Oregon, for example, only 2–8% of the original late-seral ponderosa pine forests still exist, and in Montana's Kootenai National Forest only 10% of its original late-seral forests remain (Henjum et al. 1994; DellaSala et al. 1995). Of those forests not extensively logged, many have experienced great increases in tree density (Fig. 1b) and changes in species composition, often forming dense stands of fire- and disease-sensitive trees. These changes were initiated by land-use changes by early Euro-American settlers and exacerbated by more recent management decisions (Weaver 1943; Cooper 1960; Peet 1988; Morgan 1994).

Presettlement Ponderosa-Pine and Mixed-Conifer Forests

Open, park-like forests were once common throughout the interior forests of British Columbia (Tisdale 1950), Washington (Weaver 1947; Oliver et al. 1994), Montana (Habeck 1990), Oregon (Hall 1976), Idaho (Zimmerman & Neuenschwander 1984), California (Laudenslayer et al. 1989; Morgan 1994), Utah (Madany & West 1983), Colorado (Smith 1967), Arizona (Cooper 1960; Clary 1975; Covington & Moore 1994), and New Mexico (Savage & Swetnam 1990). Forest overstories were composed of widely spaced trees growing in even-aged (Weaver 1943; Cooper 1960) and uneven-aged (White 1985) patches, and understories were composed of grasses, forbs, and low shrubs. Densities of large-diameter trees were on the order of 12–70 trees/ha (Laudenslayer et al. 1989; Habeck 1990; Covington & Moore 1994).

In xeric sites, at low elevations, and on south-facing slopes forests were dominated by widely dispersed ponderosa pine, which formed one of the most extensive forest types of the western United States (Peet 1988; Olson 1992). In wetter sites, at mid elevations, and on north-facing slopes late-successional forests were dominated by Douglas fir, western larch, and true firs such as grand fir and white fir (*Abies concolor*). These more mesic mixed-conifer forests had closed canopies and sparse understories, but after intense fire they were replaced by early-successional ponderosa pine and western larch stands, which often persisted for long periods as frequent, low-intensity fires eliminated the more fire-sensitive true fir seedlings. The fires, therefore, opened up the early successional pine and later successional Douglas fir stands and maintained them at low densities. At high elevations closed forests were dominated by subal-

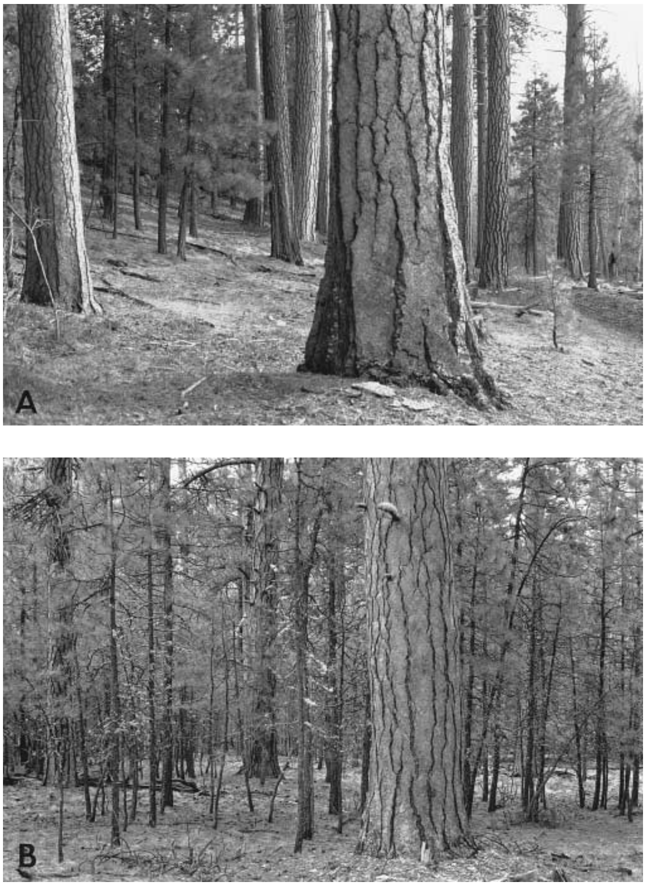

Figure 1. An open, park-like stand of ponderosa pine in eastern Oregon, which resembles low-elevation western, interior forests prior to settlement by Euro-Americans (A), and a ponderosa pine stand with a dense understory of pine saplings, which resulted from years of livestock grazing and fire suppression (B). Both stands are in the Deschutes National Forest in eastern Oregon. (Photos by Sandy Lonsdale.)

pine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga heterophylla*).

Forest floors were dominated by grasses such as mountain muhly (*Muhlenbergia montana*) in the Southwest, blue grama (*Bouteloua gracilis*) and Arizona fescue (*Festuca arizonica*) in the central Rockies, and Idaho fescue (*Festuca idahoensis*), bluebunch wheatgrass (*Pseudoregneria spicata*), pinegrass (*Calamagrostis rubescens*), and elk sedge (*Carex geyeri*) in the Northwest (Currie 1987; Laudenslayer et al. 1989; Archer & Smeins 1991). In some forests shrubs such as ninebark (*Physocarpus malvaceus*), snowbrush ceanothus (*Ceanothus velutinus*), and bitterbrush (*Purshia tridentata*) were important constituents (Franklin & Dyrness 1973; Zimmerman & Neuenschwander 1984).

Prior to extensive Euro-American settlement, circa 1820–1890, two natural phenomena maintained the trees at low densities: (1) competitive exclusion of tree seedlings by dense understory grasses and (2) frequent thinning of understory trees by low-intensity surface fires. The vigorous graminoid understory was particularly important in maintaining low tree densities because established grasses with their extensive root systems are able to outcompete tree seedlings for soil moisture and nutrients (Rummell 1951; Larson & Schubert 1969; Miller 1988; Karl & Doescher 1993). Recruitment of tree seedlings into larger size-classes was, therefore, low. Nevertheless, healthy grass swards did not totally prevent tree regeneration. The occurrence of uneven-aged stands of ponderosa pine suggests that tree seedlings occasionally survived, most probably in sites disturbed by animals, tree falls, and locally severe fires (Franklin & Dyrness 1973; White 1985).

Low-intensity surface fire was the second factor reducing tree density in presettlement ponderosa pine and mixed-conifer forests (Weaver 1943, 1947, 1950; Cooper 1960). These fires, ignited by lightning and Native Americans (Cooper 1960; Arno 1980), were fueled by grasses, shrubs, and dry pine needles (Morgan 1994). Typically, they were cool and slow burning and were non-lethal to large-diameter fire-tolerant trees (Morgan 1994). Because ponderosa pine, western larch, and Douglas fir evolved with frequent fire, they possess numerous traits, including self-pruning and thick, heat-resistant bark, that increase their tolerance of fire (Franklin & Dyrness 1973; Saveland & Bunting 1988). Douglas fir is less fire-tolerant than the other two species because it develops a thickened bark layer at a later stage (Habeck 1990). Nevertheless, saplings of ponderosa pine (stem diameter <5 cm) (Hall 1976) and saplings and trees of other species suffer heavy mortality during low-intensity surface fires (Weaver 1950; Cooper 1960; Peet 1988).

Fire-scar studies have shown that low-intensity fires occurred frequently in ponderosa pine forests of presettlement times, with an average return interval of 5–12 years throughout the West (Peet 1988). The mean fire interval was 4–5 years in some parts of the Southwest (Dieterich 1980; Savage & Swetnam 1990), 10 years in southern California (McBride & Laven 1976), and 5–38 years in the Northwest (Weaver 1947; Hall 1976; Habeck 1990; Agee 1994). Arno (1980) reported that in the northern Rockies the average fire-free interval was 5–20 years in ponderosa pine stands and 15–30 years in mixed-conifer stands.

Intense, stand-replacing fires were less frequent (Morgan 1994). In such fires most, but not all, large-diameter trees and understory grasses were killed, resulting in reduced competition, exposed mineral soils, and improved conditions for seed germination and seedling growth (White 1985). Several authors (e.g., Weaver 1947; Cooper 1960; White 1985; Savage & Swetnam 1990) have speculated that the conditions necessary for ponderosa pine regeneration are (1) an adequate seed crop, (2) reduced herbaceous competition, (3) high rainfall in the spring and early summer following germination, and (4) avoidance of mortality from fire, predation, and frost heaving. Following seedling establishment, periodic surface fires reduce the densities of the regenerating stands (Weaver 1943).

Recent Changes in Forest Dynamics

Forest composition, structure, and dynamics began to change as Euro-Americans settled the West and altered natural ecosystem processes. Sharp increases in tree density have led to less productive and aesthetically pleasing forests and to reduced nutrient cycling (Morgan 1994; Covington & Moore 1994). More importantly, they have led to widespread insect infestations, greater tree mortality, increased fuel buildup, and increased fire intensity (Mutch et al. 1993; Filip 1994; Hessburg et al. 1994). These changes have recently been attributed almost entirely to fire exclusion, which prevents the natural thinning of young trees, and to high-grading, a form of selective logging that targets commercially valuable, but also fire- and disease-resistant, species such as ponderosa pine and western larch (Arno 1980; Filip 1994; Agee 1994; Oliver et al. 1994). Changes in climatic conditions (Cooper 1960; White 1985; Neilson 1986; Savage & Swetnam 1990), reduction of genetic diversity by the planting of "improved" tree stocks, and use of herbicides and fertilizers (L. Hardesty, personal communication) have also been suggested as factors increasing the vulnerability of western, interior forests to disease and fire.

Livestock grazing is occasionally mentioned as contributing to "forest health" problems (e.g., Laudenslayer et al. 1989; Irwin et al. 1994; Oliver et al. 1994), but it is simply noted as one of many factors reducing the frequency of surface fire. Most of the recent publications on forest health issues, including U.S. Forest Service brochures (e.g., U.S. Department of Agriculture 1992, 1993), popular articles in U.S. Forest Service publications (Hall 1994; Finneran 1994), and scientific publications (Mutch et al. 1993; Filip 1994), have completely ignored livestock grazing.

Nevertheless, a large number of authors have suggested that fire began to decline in frequency and forests began to increase in density soon after livestock were first introduced into the Interior West (Leopold 1924; Weaver 1950; Cooper 1960; Madany & West 1983; Peet 1988). Livestock were brought to the Southwest in the 1700s (Savage & Swetnam 1990) and the Northwest in the mid-1800s (Harris 1991). By the early 1800s in the Southwest and the late 1800s in the Northwest, virtually all plant communities that supported grass and sedge production, including ponderosa pine and mixed-conifer forests, were heavily stocked with cattle and sheep (Savage & Swetnam 1990; Oliver et al. 1994). After clearcutting and seeding with grasses, even previously dense forests provided "transitory" range for livestock.

As the number of livestock increased the biomass and vigor of the grasses and sedges they grazed declined (Painter & Belsky 1993), thus reducing the competitive dominance of the herbaceous layer. Consequently, more tree seedlings became established (Rummell 1951; Larson & Schubert 1969; Miller 1988; Karl & Doescher 1993), and dense stands of saplings and pole-sized trees developed (Fig. 2). Livestock also reduced the frequency of surface fire by consuming the herbaceous vegetation, which otherwise would have dried into the fine fuels necessary to carry the fire (Weaver 1947; Cooper 1960; Covington & Moore 1994). Until recently this fire prevention was valued by forest managers, reflecting their strong desire to prevent forest fire.

The trend toward denser forests with smaller trees was accelerated during the early part of the twentieth century as federal agencies began implementing policies of fire prevention (i.e., Smokey Bear), containment using a network of roads and firebreaks, and active fire suppression. Densities of ponderosa pine in central Arizona, for example, increased from approximately 50 trees/ha in presettlement forests to 2000 trees/ha today (Covington & Moore 1994), and ponderosa pine stands in western Montana increased from pre-1900 levels of 93 and 172 trees/ha (on south and north slopes, respectively) to about 2300 and 1900 trees/ha today (Habeck 1990).

As forests grew denser they became shadier (Zimmerman & Neuenschwander 1984; Wickman 1992), encouraging establishment of more shade-tolerant, but also fire-sensitive, species such as Douglas fir, grand fir, and white fir. Consequently, seral forest stands shifted from dominance by fire-resistant ponderosa pine and western larch to dominance by fire-sensitive species (Habeck 1990; Morgan 1994).

Increased densities of saplings and pole-sized trees set in motion the next phase in the alteration of low and mid-elevation forests. The densely spaced young trees, as well as larger-diameter trees, become water-stressed during dry seasons and drought, causing reductions in tree vigor and productivity (Skovlin 1991; Agee 1994; Hall 1994) (Fig. 2). As growth is suppressed some tree species become increasingly vulnerable to attack by insects such as Douglas fir tussock moth (*Orgyia pseudotsugata*) and bark beetles (*Dendroctonus* spp.) (Weaver 1950; Wickman 1992; Hessburg et al. 1994; Morgan 1994). Trees also become more susceptible to pathogens such as annosum root disease (*Heterobasidion annosum*), armillaria root disease (*Armillaria ostoyae*), and Indian paint fungus (*Echinodontium tinctorium*). Because the increasingly dominant grand fir and Douglas fir are also favored hosts of Douglas fir tussock moth and western spruce budworm (*Choristoneura occidentalis*), increasing numbers of trees become infested. Higher tree densities in western forests have therefore led to more frequent and widespread disease outbreaks (Wickman 1992; Hessburg et al. 1994).

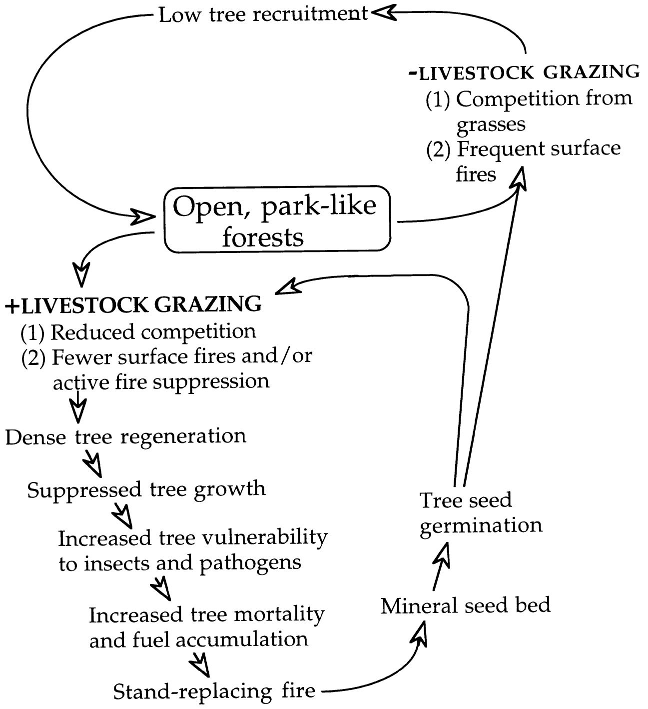

Figure 2. Effects of livestock grazing on stand dynamics of western, interior forests of the United States.

As shade, drought, water stress, and pests kill small and large trees alike, fuel loads increase. Examples are forests of the Blue Mountains of Oregon, where fuel loads have increased by a factor of 10 over the last 25 years (Hall 1994), and central Arizona, where fuel loads have increased by a factor of 9 over the last 100 years (Covington & Moore 1994). These woody fuels cause what otherwise might be low-intensity surface fires to develop into intense conflagrations, resulting in high tree mortality. Not only is there currently more woody fuel on forest floors than in presettlement times, but standing dead and dying sapling- and pole-sized trees are more likely to transport fire to forest canopies (Agee 1994), causing destructive crown fires (Morgan 1994).

Case Studies of the Effects of Livestock Grazing

Although there seems to be little debate about the mechanisms by which livestock grazing has contributed to the dense and fire-prone conditions occurring in many forests of the interior West, few have been tested experimentally. They have, however, been examined through comparisons of grazed and nearby ungrazed forest stands and through correlations of vegetational changes with historical occurrences. Although not all of the individual studies have true replication, their results are similar throughout the West, suggesting that the authors' conclusions are relatively robust. We present a few of these comparisons to illustrate the effects of grazing on a range of forested ecosystems in the Interior West.

CASE STUDY 1

Rummell (1951) compared Meeks Table, an isolated plateau in central Washington, which had never been grazed by livestock, to nearby Devils Table, which had been grazed continuously for 40 years prior to the study. The two plateaus were similar in elevation, geologic origin, climate, forest type, and fire history. Neither table had been logged.

At the time of the study forests on the ungrazed Meeks Table were covered with open, park-like ponderosa pine and mixed-conifer stands, and "luxuriantly thick" grasses, and had low tree regeneration. Conversely, forests on the grazed Devils Table had only a sparse herbaceous layer but had approximately 8000 ponderosa pine, Douglas fir, and western larch seedlings and saplings per hectare.

Rummell (1951:606) wrote that "the large number of small trees on Devils Table appeared to have been fostered by heavy livestock grazing rather than [lack of] fire" because neither table had burned in 125 years. Many of the young trees on Devils Table became established between 1903 and 1909, following heavy livestock grazing, good seed years (1903 and 1909), and above-average precipitation (1903, 1904, and 1909). He went on to conclude that "continued heavy grazing held the range vegetation [i.e., grasses and sedges] at lowered densities and permitted the seedling trees to grow without severe grass competition."

CASE STUDY 2

Zimmerman and Neuenschwander (1984) compared grazed and ungrazed ponderosa pine and Douglas fir forests in forested foothills of the Bitterroot Mountains in Idaho. The forests were selectively logged in 1925 and heavily grazed from the turn of the century through the 1960s. In 1941 a large exclosure (approximately 600 ha) was constructed in a heavily grazed stand to exclude cattle, but not deer and elk (Neuenschwander, personal communication).

Zimmerman and Neuenschwander (1984) found that grazed ponderosa pine stands outside the exclosure had twice as many trees in the smaller size classes (<5 cm diameter at breast height) as ungrazed stands inside the exclosure. The ages of these small trees indicated they had been established after the exclosure had been erected. Grazed Douglas fir stands also had a greater density of young trees than ungrazed stands; however, the differences were not as great. The authors concluded that "livestock grazing was probably the principal factor in creating and maintaining conditions that favored increased tree regeneration" (p. 106).

The study also discussed the cascade of effects initiated by livestock. As the grazed stands grew denser, they became shadier, benefiting the more shade-tolerant Douglas fir. Species composition began to shift from fire-tolerant ponderosa pine to the more fire-sensitive and disease-prone Douglas fir. The denser stands also produced more litter from shaded branches and dying trees, accumulated more woody fuel, and became more vulnerable to intense fire. The authors predicted that, if the grazed stands in the study didn't burn soon, they might "stagnate, causing reductions in growth rates and increased susceptibility to damage from insects and disease" (p. 109).

The stands that were protected from livestock later recovered much of their herbaceous cover. Conifer regeneration began to decline and low-intensity fires once again reduced fuel levels on the forest floor without damaging the larger trees. The protected stands currently have a mean fire frequency of approximately 25 years, similar to that of a century earlier (Neuenschwander, personal communication).

CASE STUDY 3

Madany and West (1983) compared ponderosa pine forests on Horse Pasture Plateau (HPP), Utah, which had been grazed by livestock since the late 1880s, to compositionally similar forests on Church and Greatheart Mesas, which had been protected from grazing livestock and fire by steep cliffs. Because neither the mesas nor HPP had burned between 1892 and 1964, livestock grazing was the only environmental variable distinguishing the sites.

Madany and West (1983) found that during the 100 years prior to their study, tree recruitment on the grazed HPP had increased by a factor of 10 or more, whereas recruitment on the nearly ungrazed mesas was unchanged. The mature-to-young tree ratio at HPP was 1:598, whereas on the two ungrazed mesas, the ratio was 1:0.8. Most tree establishment at HPP occurred between 1890 and 1940 (Fig. 3), years of high livestock densities (primarily sheep), and began to decline after a reduction in animal numbers in 1940. When livestock were permanently removed in 1960, tree establishment rates returned to the low rates of the previous century (Fig. 3).

Because Church Mesa had not burned, its low tree density cannot be attributed to recurrent fire (tree density on Greatheart Mesa was not determined). Madany and West (1983) concluded that the vigorous understory vegetation inhibited tree recruitment on the ungrazed mesas, whereas grazing and the concomitant reduction in fire frequency had favored establishment of dense stands on HPP. Active fire suppression was not a factor in tree recruitment because the decline in fire frequency on HPP occurred "45 years before the National Park Service began any sort of fire suppression" (p. 665).

CASE STUDY 4

Savage and Swetnam (1990) reconstructed the fire history of a ponderosa pine forest on the Arizona–New Mexico border by establishing fire dates from scars on tree stumps. The mean fire interval was 4.2 years between 1700 and 1830, the period when sheep herds were first building in the area; after 1830, when sheep numbers were high, only two fires were recorded. These differences in fire interval suggest that livestock were instrumental in reducing fire frequency after 1830 because the precipitous decline in fire frequency occurred 100 years before effective fire suppression was instituted. The authors concluded that "grazing may have been the most important factor in the ending of episodic fire regimes in ponderosa pine forests" (p. 2377).

Livestock grazing in the late 1800s did not immediately stimulate abundant pine regeneration. Many of the dense pine stands now found throughout the Southwest appear to have been established in the early 1900s, coinciding with a period of relatively high rainfall (e.g., Neilson 1986). Savage and Swetnam (1990) suggest that the higher ponderosa pine densities from that period resulted from a combination of livestock grazing, reduced fire frequency, abundant seed crops, and warm, wet conditions.

Effects of Livestock Grazing on Herbaceous Understory

By grazing and trampling herbaceous species livestock affect understory species composition directly; this dif-

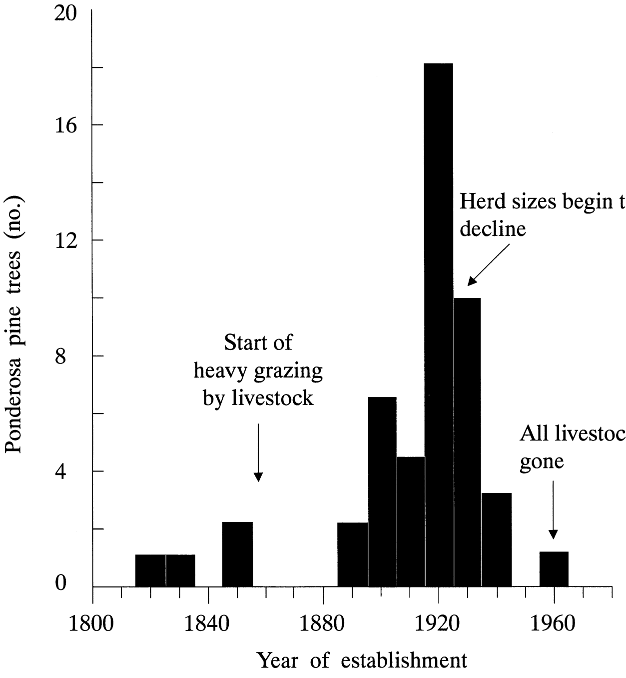

Figure 3. Effects of livestock grazing on tree recruitment in a ponderosa pine forest in Utah (after Madany & West 1983 and Archer & Smeins 1991). Dates of establishment determined by coring fire-scarred trees.

fers from the more indirect effects they have on overstory trees. Impacts vary with animal density and distribution: the more evenly grazers are distributed, the lower their impact on any given area (Gillen et al. 1984). Unfortunately, cattle show strong preferences for certain environments, leading to high use in some areas and little or no use in others. This is particularly true in western, interior forests, where steep slopes and increasingly dense forests make much of the landscape unattractive (Clary 1975; Roath & Krueger 1982).

The most thoroughly studied irregularity in livestock distribution is the heavy use by cattle of riparian areas (e.g., Bryant 1982; Roath & Krueger 1982; Gillen et al. 1984). Gillen et al. (1984), for example, found that forage utilization by livestock was 7.5 times higher in riparian meadows than in adjacent uplands, and Roath and Krueger (1982) found that a riparian zone in a forested watershed in Oregon comprised 1.9% of the allotment but produced 21% of available forage and 81% of forage consumed. Cattle distribution is also distinctly irregular on uplands, where animals tend to concentrate in open forests, clearcuts, and open meadows (Smith 1967; Bryant 1982; Roath & Krueger 1982).

Understory Cover and Composition

Exclosure studies in forested ecosystems of the Interior West have consistently found that livestock substantially reduce vegetative cover (Table 1), especially that of perennial bunchgrasses (Arnold 1950; Rummell 1951; Smith 1967). In the Bitterroot Mountains, for example, grazing has been found to reduce the productivity, frequency, and cover of Idaho fescue, bluebunch wheatgrass, and Colombia brome (*Bromus vulgaris*) by 50–100% (Zimmerman & Neuenschwander 1984). Annual grasses and perennial weeds often expand following the decline of bunchgrasses; however, this increase is typically not enough to make up for the reductions in perennial grass cover (Arnold 1950; Smith 1967). In uplands grazing has fewer effects on shrubs than on grasses (Skovlin et al. 1976; Zimmerman & Neuenschwander 1984); in riparian areas, however, grazing dramatically reduces the number and total biomass of shrubs and trees (Marcuson 1977; Schulz & Leininger 1990), which are critical for shading streams, stabilizing stream banks, and providing wildlife habitat (Kauffman & Krueger 1984).

Livestock also alter understory plant composition as animals select more palatable species, leaving the less palatable ones to increase in dominance (Smith 1967; Hall 1976; Skovlin et al. 1976). The effects of livestock grazing on understory composition and biomass are sometimes difficult to distinguish from the effects of tree canopy closure (Smith 1967), which creates shadier, cooler, and moister conditions. However, when Arnold (1950) separated the effects of livestock grazing from those of tree canopy closure, he found that grazing alone was sufficient to reduce the cover of most native bunchgrass species.

Domestic livestock, as well as agriculture, logging, road construction, and other practices that disturb soils, have been instrumental in the establishment of alien weedy species in western forests (Franklin & Dyrness 1973; Johnson et al. 1994). Livestock act as vectors for seeds, disturb the soil, and reduce the competitive and reproductive capacities of native species. Exotic weeds have been able to displace native species, in part, because native grasses of the Intermountain West and Great Basin are not adapted to frequent and close grazing (Stebbins 1981; Mack & Thompson 1982). Consequently, populations of native species have been severely depleted by livestock, allowing more grazing-tolerant weedy species to invade. It is possible that in some areas aggressive alien weeds such as cheatgrass (*Bromus tectorum*) and Kentucky bluegrass (*Poa pratensis*) have permanently replaced native herbaceous species (Smith 1967; Laudenslayer et al. 1989).

Effects of Livestock Grazing on Forest Soils

Plant Litter

By consuming aboveground plant biomass, domestic livestock also reduce the amount of biomass available to be converted into litter and, therefore, increase the proportion of bare ground (Table 1). Schulz and Leininger (1990) found, for example, that grazed areas of a riparian meadow had 50% lower litter cover and 400% more bare ground than ungrazed areas. Johnson (1956) reported that litter biomass in a ponderosa pine/bunchgrass ecosystem was reduced 40% and 60% by moderate and heavy livestock grazing, respectively. Such reductions in litter may have severe consequences on forested ecosystems because litter is critical for slowing overland flow, promoting water infiltration, serving as a source of soil nutrients and organic matter, and protecting the soil from freezing and the erosive force of raindrops (Thurow 1991; Facelli & Pickett 1991).

Compaction and Infiltration

The rate at which water penetrates the soil surface governs the amount of water entering the ground and the amount running off. Livestock alter these rates by reducing vegetative and litter cover and by compacting the soil (Lull 1959) (Table 2). As a result livestock grazing is usually associated with decreased water storage and increased runoff. Lower soil moisture contents in turn reduce plant productivity and vegetative cover, creating negative feedback loops that further degrade both the plant community and soil structure (Fig. 4). These changes in soil structure may also lead to increased water stress

Table 1. Effects of livestock grazing on herbaceous vegetation and litter in western interior forests of the United States.

Ecosystem type	*Location*	*Elevation (m)*	*Type of study*	*Livestock exclusion (years)*	*Duration of grazing prior to exclusion (years)*	*Grazing intensity*	*Results*	*Reference*
Herbaceous cover								
Alpine shrub/grassland	Manti National Forest, Utah	3000	exclosure	5	>35		grazing reduced cover by 60%	Forsling 1931
Ponderosa pine/bunchgrass	Coconino Plateau, Arizona	2000–2500	exclosure	29			grazing reduced total cover, especially of perennial bunchgrasses	Arnold 1950
Ponderosa pine/bunchgrass	Meeks and Devils Tables, Washington	1400	comparison of grazed and ungrazed areas		40		grazing reduced density of understory vegetation by 45–61%	Rummel 1951
Ponderosa pine/bunchgrass	Manitou Experimental Forest, Colorado		exclosure	10		variable: 10–20%, 30–40%, and >50% utilization	grazing reduced herbage yield by 50%; reduced vigor of perennial bunchgrasses	Johnson 1956
Ponderosa pine/bunchgrass	Manitou Experimental Forest, Colorado		exclosure	18	29	variable: 10–20%, 30–40%, and >50% utilization	grazing reduced total cover; magnitude of reduction was proportional to grazing intensity	Smith 1967
Ponderosa pine/bunchgrass	Blue Mountains, Oregon	1200–1500	exclosure	11	>40	variable: 40, 30, or 20 acres/cow-calf unit/4 months	total cover increased with increasing grazing intensity for 3 years, then declined for 8 years	Skovlin et al. 1976
Riparian/floodplain	Rock Creek, Montana		exclosure	10	>28		grazing reduced shrub cover by 92%	Marcuson 1977
Douglas fir/ninebark	Bitterroot Mountains, Idaho	900–1000	exclosure	37	>75	85% utilization	grazing reduced shrub cover	Zimmerman & Neuenschwander 1984
Riparian meadow	Roosevelt National Forest, Colorado	2500	exclosure	30	>90		grazing reduced herb, shrub, and total cover	Schulz & Leininger 1990
Litter								
Ponderosa pine/bunchgrass	Manitou Experimental Forest, Colorado		exclosure	10		variable: 10–20%, 30–40%, and >50% utilization	grazing reduced litter cover; reduction was proportional to grazing intensity	Johnson 1956
Ponderosa pine/bunchgrass	Blue Mountains, Oregon	1200–1500	exclosure	11	>40	variable: 40, 30, or 20 acres/cow-calf unit/4 months	grazing reduced litter cover and increased bare ground	Skovlin et al. 1976
Riparian meadow	Rock Creek, Montana		exclosure	10	>28		grazing reduced litter cover and increased bare ground	Marcuson 1977
Riparian meadow	Roosevelt National Forest, Colorado	2500	exclosure	30	>90		grazing reduced litter cover by 50% and increased bare ground by 400%	Schulz & Leininger 1990

Table 2. Effects of livestock grazing on forest soils in western interior forests of the United States.

Ecosystem type	*Location*	*Elevation (m)*	*Type of study*	*Livestock exclusion (years)*	*Duration of grazing prior to exclusion (years)*	*Grazing intensity**	*Results*	*Reference*
Soil compaction								
Ponderosa pine/bunchgrass	Coconino Plateau, Arizona	2000–2500	exclosure	29			grazing compacted the soil and reduced soil organic matter	Arnold 1950
Riparian meadow	Black Hills, South Dakota		exclosure	5–17			grazing reduced large pore space and increased bulk density	Orr 1960
Riparian meadow	Black Hills, South Dakota		exclosure	0–4			grazing reduced large pore space and increased soil infiltration rates	Orr 1975
Riparian meadow	Blue Mountains, Oregon	1100–1400	exclosure	5		3.2ha/AUM	grazing had no effect	Bohn & Buckhouse 1985
Soil infiltration rate								
Ponderosa pine/bunchgrass	Manitou Experimental Forest, Colorado		exclosure	10		variable: 10–20%, 30–40%, and >50% utilization	grazing reduced soil moisture by 30%; reduction in soil moisture was independent of grazing intensity	Johnson 1956
Ponderosa pine/bunchgrass	Manitou Experimental Forest, Colorado		exclosure	18	29	variable: 10–20%, 30–40%, and >50% utilization	grazing reduced infiltration rates; reduction in infiltration rates was independent of grazing intensity	Smith 1967
Riparian meadow	Black Hills, South Dakota		exclosure	0–4			grazing reduced infiltration rates, which were correlated with macro-pore volume	Orr 1975
Artificial bunchgrass and sodgrass plots	North Logan, Utah	1400	simulated trampling				trampling and loss of vegetative cover reduced infiltration and increased erosion	Dadkhah & Gifford 1981
Riparian meadow	Blue Mountains, Oregon	1100–1400	exclosure	5		3.2 ha/AUM	grazing reduced infiltration rates	Bohn & Buckhouse 1985
Varied	Blue Mountains, Oregon		compared different ecosystems				Infiltration declined with decreasing range condition and productivity	Gaither & Buckhouse 1983
Runoff and erosion								
Alpine shrub/grassland	Manti National Forest, Utah	3000	exclosure	5	>35		grazing doubled runoff and erosion	Forsling 1931
Ponderosa pine/bunchgrass	Manitou National Forest, Colorado	2300	artificial clipping and litter removal			variable: 1–1.6 ha/AUM	clipping and removal of litter increased runoff and erosion	Dunford 1954
Ponderosa pine/bunchgrass	Manitou Experimental Forest, Colorado		exclosure	18	29	variable; 10–20%, 30–40%, and >50% utilization	grazing increased sediment production by factors of 3 to 10	Smith 1967
Riparian meadow	Black Hills, South Dakota		exclosure	0–4			grazing increased summer storm runoff which increased erosion	Orr 1975
Ponderosa pine/bunchgrass	Manitou National Forest, Colorado	2400	exclosure	35			grazing did not alter soil surface elevation	Currie & Gary 1978
Riparian meadow	Blue Mountains, Oregon	1100–1400	exclosure	1 and 5		3.2 ha/AUM	grazing increased sediment production	Bohn & Buckhouse 1985
Varied	Blue Mountains, Oregon	1200–1300	exclosure	0–6	100	"low to moderate"	grazing had no effect on runoff	Tiedemann & Higgins 1989

**AUM = animal unit month (potential forage intake by one cow and its calf [or the equivalent] in one month).*

and tree mortality during dry periods, exacerbating the water stress resulting from the higher tree densities. Therefore, disturbance and compaction of forest soils by cattle and sheep may contribute to the increased incidence of water-stress, tree mortality, and fire in western forests.

The negative effects of livestock on water infiltration are illustrated by a livestock removal study in Manitou Experimental Forest, Colorado (Table 2) (Smith 1967). Five years after the exclusion of livestock infiltration rates had increased 60%, whereas infiltration rates on nearby grazed areas had declined, irrespective of grazing intensity. Although both the loss of vegetative cover and trampling contributed to the reduced infiltration rates in this study, trampling alone has been found to be sufficient to reduce infiltration. In fact, Dadkhah and Gifford (1981) concluded that severe trampling negates the beneficial effects of high vegetative cover.

Runoff and Erosion

As livestock reduce plant cover and compact the soil, the volume of overland water flow increases (Table 2). Livestock grazing in an unforested valley in the Black Hills National Forest increased summer storm runoff by as much as 60% (Orr 1975). With increasing runoff, soil erosion also increases (Dunford 1954). Smith (1967), for example, found that grazed pastures in a ponderosa pine/bunchgrass range lost 3–10 times more sediment than ungrazed pastures. The strong relationship between runoff and erosion was also demonstrated by Forsling (1931), who found that summer rainstorms on grazed subalpine hillsides accounted for 53–85% of annual sediment loss. Following elimination of livestock from the watershed, vegetative cover increased 150% whereas the proportion of annual runoff from summer rainstorms dropped 72%, causing a corresponding 50% drop in sediment loss (Forsling 1931).

Conclusion

The studies cited above strongly suggest that livestock, as well as fire suppression, logging, and other anthropogenic activities, have contributed to altered ponderosa pine and mixed conifer forests throughout the Interior West. Not only have cattle and sheep helped convert the original park-like forests into dense stands of less fire-tolerant tree species, but they have changed the physical environment by reducing fire frequencies, compacting soils, reducing water infiltration rates, and increasing erosion. As a result, many contemporary ponderosa pine and mixed conifer forests differ from those of presettlement times in density, composition, structure, and critical soil properties. These forests also appear to be less resilient to natural disturbances such as fire and disease, and will probably be less resistant to future changes that are expected to result from expanding human populations and global climate change.

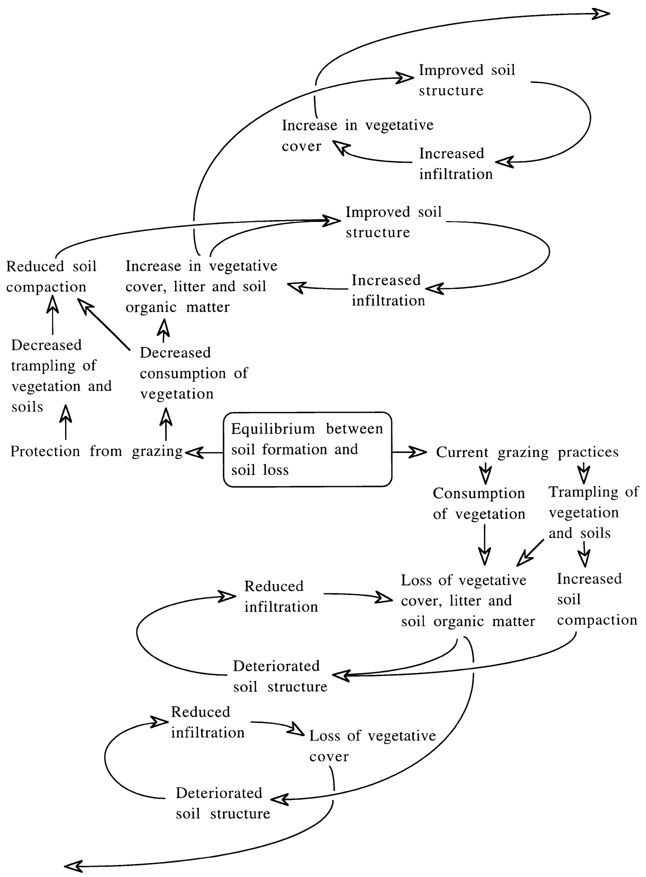

Figure 4. Effects of livestock grazing on soils (after Thurow 1991).

The effects of livestock grazing and trampling are, of course, not homogeneous across the western landscape. Effects vary with rainfall, slope, soil stability, and vegetation type, as well as with animal density, season of use, duration of use, and animal distribution. Nonetheless, the similarities of the changes occurring in grazed low- and mid-elevation forests throughout the Interior West suggest that livestock grazing has had profound effects over a wide range of conditions.

Disturbances such as periodic high- and low-intensity fires, insects, and disease have long been natural parts of western forest ecosystems (Wickman 1992; Hessburg et al. 1994; DellaSala et al. 1995). But these forests appear less able to tolerate human disturbances such as livestock grazing, logging, and fire exclusion. The studies we have discussed here suggest that livestock have actively participated in the destabilization of ponderosa pine and mixed coniferous forests. The hot fires that swept through forests of central and eastern Washington and Oregon during the summers of 1994 and 1996 may have been, partially, a result of a century of livestock grazing. The integrity and sustainability of interior western forest ecosystems rely on scientists and managers recognizing this fact.

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