CONTRA COSTA
WATER DISTRICT

USING LIVESTOCK GRAZING AS A RESOURCE MANAGEMENT TOOL IN CALIFORNIA

Numerous scientific and non-scientific papers and articles have been written about grazing and its effects on vegetation and other natural resources. This paper is based on a synthesis of many of these papers and articles and substantial experience in California using controlled livestock grazing to meet natural and cultural resource management objectives. Robert C. Nuzum – Manager, Watershed and Lands Department, Contra Costa Water District, Concord, California, July 2005.

DOMESTIC GRAZING HISTORY

Grazing Lands in the United States and Livestock Commodity Values

Grazing lands are the most widely distributed lands in the United States, including more than 840 million acres (USDA-NRCS 1997a) out of the total land area of 2.3 billion acres. The 840 million acres includes 396 million acres of non-federal rangeland, 118 million acres of non-federal pastureland and 60 million acres of non-federal grazed forestland. The ‘public’ component of non-federal lands includes lands that are privately owned and lands owned by states, counties and special districts. The federally owned grazing lands include 262 million acres, with the great majority occurring in the states west of the 98th Meridian. The livestock and forage production on these 840 million acres is the foundation for an agricultural industry that generates $42 billion in annual income from 95 million cattle and calves, 6.1 million sheep and lambs and 1.0 million goats and kids (USDA-NASS 2001, 2004; USDA-CASS 2004).

California Grazing Lands and Livestock Commodity Values

California, the third largest state in the union and the state with the greatest population (in excess of 35 million people), leads the nation in annual agricultural production with over $27 billion in value from 250 commodities. California’s grazing lands provided forage for cattle and calves, sheep and lambs and goats valued at $1.6 billion in 2004. This value was based on 5.2 million cattle and calves, 680,000 sheep and lambs and 100,000 goats and kids (USDA-CASS 2004; Canada 2004).

Estimated Acreage of Grazing Lands and Croplands in California

In 1997 the University of California, Davis estimated California’s total agricultural production acreage at 43.2 million acres. From this assessment California’s grazing lands were found to occupy about 31.5 million acres of the 99.8 million total acres statewide and cropland occupied another 11.7 million acres. Of the 31.5 million acres, 15 million acres are privately owned and 16.5 million acres are public lands owned by the federal government. The publicly owned federal grazing lands included 8.8 million acres administered by the U.S. Forest Service, 6.4 million acres administered by the Bureau of Land Management and 1.3 million acres administered by the National Park Service. Most of the forested grazing lands include lands with tree and brush cover, steep slopes, rocky patches and creek beds that do not produce usable grass. It is estimated that only 30% to 50% of the forested grazing lands were actually grazed by livestock in any one year.

Federal Ownership in California and Other Regions of the United States

Please note that the 16.5 million acres indicated for federally administered grazing lands does not reflect the total acreage of land owned by the Federal Government in California. The Federal Government owns 46,806,200 acres (GSA 2004) of land in California and the State of California owns 2,243,600 acres. Federal and state ownership is therefore 49.1% of the total land acreage in California. These ownership amounts vary over time due to property exchanges, acquisitions and sales. In the last 10 years the Federal ownership in California has decreased 3% and the state ownership is approximately the same. The GSA report of Federal ownership in 2004 indicates a total ownership of 29.6% (672 million acres) of all land in the United States. A majority of this ownership is within the 12 Western States (Fifty-five percent or 370 million acres). Unlike the Western region, Federal ownership in the other geographical regions of the United States is exceptionally low with private ownership totaling 97%-98% or more.

Agency Use of Grazing to Manage Vegetation in Bay Area Counties

In the San Francisco Bay Area, public land owned by state and local governmental agencies and special district's is far more significant than Federal land ownership. In Alameda and Contra Costa counties, east of San Francisco Bay, there are eighteen different public entities that use grazing to manage vegetation levels to meet resource objectives on their lands. These public entities include the U.S. Fish and Wildlife Service, U.S. Department of Defense, U.S. Bureau of Reclamation, California Department of Parks and Recreation, California Department of Fish and Game, California Department of Water Resources, Contra Costa County Public Works, Iron Horse Sanitary District, Alameda County Waste Management Authority, East Bay Regional Park District, East Bay Municipal Utility District, San Francisco Public Utility Commission, Contra Costa Water District, Town of Moraga, City of San Ramon Public Works, City of Walnut Creek Open Space, City of Fremont and the Livermore Area Park and Recreation District (Personal Communication – Barry 2005).

Managing Year-Around Herds Using High and Low Elevation Grazing Units

California's private and public grazing lands are often listed and discussed separately but they are frequently interdependent with one another. For example, ranchers who have high-elevation private land or public grazing allotments/leases are dependent on having low-elevation private land or public grazing allotments/leases to move to when the first major snowfall takes place in the high country during the fall. To meet the herd's forage requirements in the late fall and through the winter these low-elevation grazing lands must have high levels of forage to graze. And, likewise in the spring after the snowmelt, the herd would be removed from the lands at low-elevation and taken back to the high-elevation grazing areas. Taking the herd off of the low elevation grazing lands early allows the pasture forage to grow and mature with only minimal forage utilization. Therefore, any substantial change in the management of either of these grazing areas would have a profound effect on the other. There are also ranchers who have enough low elevation private property owned or leased to keep their herd at low elevations all year long. However, having 12-months of grazing utilization on only the low-elevation acreage requires much more grazing land, compared to the rancher who has both high and low elevation rangeland available (Sulak and Huntsinger 2002; Personal communication -- Stewart 2005).

Interdependence of Grazing Lands in the San Francisco Bay Area

The relationship between private and public grazing lands in the Bay Area is also interdependent but not with regard to high and low elevation grasslands as previously described. In the Bay Area, ranchers who may have a headquarter ranch on private land are often dependent on public lands to provide a critical mass of land to maintain a viable ranching operation. Liffmann et al (2000) found that in Alameda and Contra Costa counties about 30% of the ranchers use some public owned rangeland to augment their ranching operation. They may only be able to use the public land seasonally but they depend on it to make their operation on private land viable.

CALIFORNIA CLIMATES AND THE GRASSLAND ECOSYSTEM

(Primarily from Burcham's classic work on California's Range Land, 1957)

Within the boundary of California can be found nearly every combination and every contrasting extreme of topography, climate, soils and natural resources existing elsewhere in the United States, as well as some that are peculiar to this state. This diversification of resources influences the distribution and composition of plant cover.

- 57% of California (89,870 square miles or 57 million acres) is dominated by a climatic type known as Mediterranean, characterized by a high percentage of sunshine in all seasons; by dry, warm-to-hot summers; and, by mild rainy winters.

- The grassland elements of the California ecosystem occur on gently undulating open plains and low terraces of the valley floors. They extend upward onto moderately rolling to hilly topography bordering the valleys. They also occupy much of the more level lands within the woodlands. Woodland portions are characteristically on more rolling to hilly terrain. In elevation, the grasslands lie mainly between sea level and about 3,000 feet but fingers extend upward to about 5,000 feet in southern California and on warm slopes in the north.

- The middle and outer North Coast Ranges, from San Francisco Bay northward, have a mesothermal marine climate characterized by a mild winter and cool summers. The prevailing westerly winds bring increased precipitation to this area that includes 10,000 square miles or 6.4 million acres. This is especially true of the windward side of the outer North Coast Range.

Major climatic controls in California are exerted by latitude, the influence of the Pacific Ocean and especially by the orientation and extreme ranges in elevation (the latter control is by far the most important). The effect of latitude, usually the key factor in determining temperature differences in other states, is minor in California and is subordinated to that of topography and elevation.

> For example, grasslands of California have an exceptionally long growing season if moisture is available ranging from 6-months (northern portions at higher elevations) to the entire year (in the south). The Central Valley averages about 300 growing days whereas the mountains above 6,000 feet average about 100 days. The growing season tends to decrease roughly two weeks with each 1,000-foot increase in elevation. The frost-free period has a huge range from 175 to 365 days and the average annual precipitation (almost all during the winter) ranges from 6-inches (in the south) to more than 75-inches (along the north coast). The Sierra

> Nevada means “snowy mountain range” in Spanish. In fact the Sierra Nevada has been found to be one of the snowiest places in North America. In this mountain range almost all precipitation falls as rain below 2,000 feet in elevation. Above 6,000 in elevation, virtually all precipitation occurs as snow. The first snows of the season usually occur between mid-September and November, with snow usually persisting on the ground after mid-November. The snow-pack at the higher elevations increases in depth during the winter months, generally reaching its maximum depth in March. After mid-March, the winter storm regime tapers off, and spring thaw commences. The thaw proceeds from lower to higher elevations, working its way upslope from mid-March to mid-July. The statewide long-term precipitation means are as follows: thirty-four percent of the state receives 10 inches or less, 31% receives 10 inches to 20 inches, 22% receives 20 inches to 50 inches and 13% receives 50 inches or more. However, departures from these long-term means in precipitation are common, resulting in either exceptionally wet or dry periods that can last several years.

`

A key climatic factor for vegetation is fog, which increases with latitude and with altitude (up to 2,000-3,000 feet) and is most frequent in coastal and neighboring foothill regions in California.

Herbaceous annual plants are the dominant vegetation of the grassland ecosystem in California; made up of brome grasses (Bromus), fescues (Festuca), wild oats (Avena), and a long list of others. Associated with the grasses are a host of forbs, the most common and widespread being filaree (Erodium); a variety of legumes--bur clovers and true clovers (Medicago and Trifolium), lupines (Lupinus), trefoils and deervetches (Lotus); and tarweeds (Hemizonia and Madia) and similar late summer annuals.

The most ubiquitous and abundant grassland plant in California is soft chess (Bromus mollis) followed by the filarees and then by the annual fescues.

The fact that California's summer drought is followed by a winter season of comparatively high precipitation with moderate temperatures has an important bearing on the responses of range forage. Plants growing in the Mediterranean climate must be adapted to an extreme range in conditions, especially with regard to heat and moisture. Annual grasses are ideally adapted to summer drought by maturing seed at the beginning of the dry season and dying in June; perennial plants experience some annual die back of the top vegetation (25-30%) and root (20-50%) but the plant remains alive and enters a dormant period, relying upon food reserves stored in the remaining root.

European Annuals Dominate California Grasslands

Although perennial grassland advocates continue to promote restoration of perennial grasslands in California, the European annual grasses are dominant (98+%) and will undoubtedly remain so under current soil, climate and land use conditions. European annual grasses provide optimum protection against soil erosion, are hardy, exceptionally well adapted to California’s soils, temperature and climate and they provide an abundance of plant and wildlife diversity. Emeritus California Range Professor Harold Heady realized 25-years ago that European annuals had been naturalized and were here to stay, even if they were alien species. Lee Burcham (1957) documented that some of the European annuals were already in California and well established when the Spaniards arrived in San Diego in 1769. California’s native grassland probably consisted of a rich mixture of annual and perennial grasses and forbs (Clements 1934; Weaver and Clements 1938; Beetle 1947; Oosting 1956;

Burcham 1957; Munz and Keck 1959; Bartolome 1981; Wright and Bailey 1982). Heady (1977) noted evidence that some grasslands in California were already dominated by Avena before heavy grazing by domestic livestock occurred. Several range scientists (Robbins 1940; Burcham 1956, 1957; Heady 1977) found that the major replacement of native perennials by European annuals probably occurred in several stages beginning before the 1850's with Avena and Lolium. The second stage of this replacement, during the 1870's, documented population increases of several species of Bromus, Erodium and Hordeum leporinum. The third stage, prior to 1900, involved increases in species such as Bromus rubens and Hordeum hystrix. These phased changes in composition over time strongly indicates that the reduction in native perennials and the increase in dominance by European annuals was the result of a complex series of factors including climatic fluctuations, droughts, floods, fires, over-grazing, insect plagues and rodent activity (White 1967; Wright and Bailey 1982; Pickett and White 1985; Hobbs 1991).

NATIVE AMERICAN INFLUENCES ON CALIFORNIA

A written historical record of Native American influences on California prior to the arrival of Spanish colonists in 1769 does not exist. Historical Analyst Gerald Williams (U.S. Forest Service) indicates there is a growing body of literature (ethnobotany) about Native Americans using native plants for food, medicine and ceremonial uses, as well as using many plants, shrubs and trees for food, clothing, shelter and tools (Williams 1997). Some tribes changed water flow (canals), practiced farming, grazing (horses, sheep and cattle since the 1600's in the southwest), using vegetation, wood and bone for decorative arts and trade goods, minerals for many tribal uses and for trading, building structures of wood and rock and building seaworthy boats. Daniel Botkin (1990) said there was ample evidence that Native American's greatly changed the character of the landscape with fire, and that they had major effects on the abundance of some wildlife species through their hunting. American Indians were skilled in the use of fire; kept animals; selected, transported and planted seeds for annual and perennial crops; and, transplanted trees and shrubs (Blackburn and Anderson 1993). In most areas Native Californians relied on tree crops for much of their sustenance, primarily the oaks, mesquites and pines (Meyer 1984; Nabhan 1985; Bainbridge 1986, 1987; Bainbridge et al 1990; Ortiz 1991). Henry Lewis (1973) concluded that American Indians used fire to burn vegetation for at least 70 different reasons. The major reasons were for hunting, crop management, improving growth or yield, insect collection, pest management, warfare and signaling, economic extortion, clearing areas for travel, felling trees and clearing riparian areas. Steve Pyne (1995) noted that use of fire by native peoples to change ecosystems or portions thereof is almost universal. The use of fire by Native Americans had a general consequence of replacing forested land with grassland or savanna and that conversely wherever the European went, forests followed. Pyne (1982) stated that the Great American Forest might be more a product of settlement than a victim of it.

The archeological record indicates that Native American people were here for centuries, learning how to live within their environment and moving when necessary. We do know that fire was an essential and important tool of the Native Californian and that selected areas were burned regularly at different seasons and frequencies to improve hunting, to facilitate harvesting and to produce desired materials. These practices were pervasive and lasted until long after the Spanish missions were established. The settlers in California, who failed to understand the use of fire were tormented by these burns, and edicts from the Spanish Governor were periodically issued to stop them – beginning in 1793. The elimination of periodic burning (often on a 2 to 4 year return frequency) contributed to dramatic changes in plant communities. In Ponderosa forests in the Southwest for example, stem counts increased from 23 to more than 800 trees per acre in some areas (Covington and Moore 1992). Coastal California was once much more grassland and oak-savannas and has now been invaded by brush species. In addition to fire effects Native Californians planted tree seeds (Oak, pinyon, mesquite, walnut, etc.), took cuttings (willows, palms, etc.) and transplanting was common but often unrecognized by biologists and botanists. These skills were well developed and common (Bean and Saubel 1972; Nabhan 1982, 1985; Nabhan et al 1982; Bainbridge 1985 a, b, 1987; Shipek 1989; Anderson and Nabhan 1991; Blackburn and Anderson 1993). These crops provided food, medicine, building materials, craft materials, and fertilizer (Felger and Moser 1974; Nabhan 1982; Nabhan 1985; Ebeling 1986; Anderson and Nabhan 1991).

Native people traveled extensively and moved plant material over large areas. Studies of relatively intact cultures in the Amazon have found that Native peoples were shaping the forests to provide better living conditions and to improve resource availability (Posey 1985; Balee 1987). These primitive forest dwellers were found to be selecting, transporting, planting and managing plant materials from an area as large as Western Europe. It is likely that California was no different, and that plant resources were selected, planted and gathered from an equally large area.

EARLY EUROPEAN INFLUENCES ON CALIFORNIA

The first cattle in California were Spanish cattle that were driven to the San Diego Mission from Lower California in the spring of 1770. The herd included 165 head that were then divided and taken to four other missions in the next two years. Historians indicate that by 1773 there were 204 head of cattle at ranchos near five missions that were used primarily for milk and meat. Missions trained American Indians as herders for the cattle although there was little care given to them. Spanish law made it mandatory to register brands and there were annual rodeos in May and June to round up cattle for slaughter and to assign taxes for each animal slaughtered. By 1790 the herds were growing and no further increase was desired by Spain. Prices were reduced and additional laws enacted to limit each rancho herd to 50 head. However, outside trade was illegal and the herds continued to increase. Records indicate that by 1800 there were 75,000 head of cattle in California and two-thirds of them were on the mission ranchos. Records further indicate that by 1807 many cattle had been turned loose or had strayed and gone wild. Some of these cattle were killed when they were found but others were caught and smuggled to foreign ships trading off the California coast.

Mexico won her independence from Spain in 1822 and during the period of Mexican Rule in California (1834 to 1846) Mexico granted 800 liberal patents of land to private individuals as an incentive to engage in ranching and agriculture. Unlike Spain, Mexico opened trade with other nations, especially the United States, and the livestock industry shifted from raising commodities for local use to raising cattle to export their hides and tallow. The vast majority of the meat was discarded where the animal was killed due to the lack of refrigeration. Hides and tallow were much sought after in world commerce (non-perishable and compact with a high value per unit of weight). In 1841 Mexican exports from California averaged about 150,000 hides and five million pounds of tallow (Wilkes 1845). According to Wilkes the value of hides in 1841 was $2.00 each, while tallow was 6 cents per pound. American sailing vessels from Atlantic seaports commonly traded along the California coast during the nineteenth century. Ships brought a great variety of articles to trade for California hides and tallow, including cloth, cutlery, tools, window glass, beds, tables and dishes.

Trade rooms were established on many of these ships to exhibit their wares for the ranchero's (ranch owner's) selection. The ranchero would exchange hides that had been dried, scraped, beaten and salted at his rancho. Using hides as a medium of exchange popularized use of the term "leather dollars" or "California dollars". One competent authority estimated that from 1800 to 1845 five million hides were exported (Dobie 1939).

By 1830 there were 47 newly established Mexican ranchos, many in southern California. Branding laws were enacted by Mexico in 1827, mandating that any rancher with more than 150 head must brand his cattle and those with less had to earmark them. Wild cattle were gathered in weekly rodeos. Following secularization of the missions the mission herds were redistributed. Half of the mission cattle were supposed to be divided amongst the American Indian families associated with the missions and the other half were claimed by the Mexican government. Many of the American Indians chose to sell their cows to the local ranchero and the government officials freely helped themselves to those remaining. By 1840 almost all the cattle in the San Diego area, for example, were owned by 17 large ranchos and it was said that the herds ran wild on open range, being a hardy and tough breed.

Under Mexican rule the number of sheep increased and the quality of the breeds improved greatly. These changes substantially increased the size of sheep and improved the quality of the wool produced. (Spain had forbidden the missions to breed quality flocks to keep California wool from competing with Spanish wool on the European market.) But, by 1850 wool joined hides and tallow as a key California export commodity. The wool clip was recorded as 175,000 pounds in 1854; by 1860 it had risen to 2,000,000 pounds and by 1865 it was 6,500,000 pounds. The chief market place for wool was San Francisco with the price dependent on the variety of sheep. For example, the price ranged from 12 cents/pound for wool clipped from a low quality sheep to 28 cents/pound for wool clipped from a high quality Merino sheep.

At the time of James Marshall's discovery of gold in Coloma in January 1848 there were only about 14,000 non-Indians in California. Following this discovery the non-Indian population grew to 20,000 by the end of 1848, to 100,000 by the end of 1849 and in September 1850 California became the 31st State in the Union. Granting statehood was said to be due to the exponential increase in population and the huge value of riches being found. By the end of 1852 the population had expanded to 223,000 and in 1860 it reached 380,000.

> San Francisco, for example, grew from a small village of about 800 in 1848 to a thriving port city of 36,150 two years later when the 1850 census was taken. The 1850 census also listed 40,000 inhabitants in El Dorado County and it listed Calaveras (included Amador County's land area at that time), Yuba and Nevada Counties as each having nearly 20,000 inhabitants. This period of population growth and prosperity was confined primarily to Northern California and the mining regions of the Sierra-Nevada. Southern California's huge Los Angeles County (including present day San Bernardino, Riverside, Orange and Los Angeles Counties) contained 35,000 square miles of land but only had 3,530 non-Indian inhabitants in 1850, with half of these living in the City of Los Angeles. The Los Angeles Basin had a million acres of rangeland with 100,000 animals grazing in 1850 compared to 2,648 acres under cultivation and a total crop value of only $9,000 (Cleland 1941).

California's Mission ranches and a horde of wildlife hunters and trappers did their best to supply local demands for animal products for several years after the Gold Rush began. However, the rapidly expanding population brought an unprecedented demand for meat that greatly exceeded the limited local supply and greatly diminished wildlife populations. This situation led to major movements of cattle, sheep, horses and mules into California from Oregon, Texas, Mexico and the Middle West. It also led to an enormous shift of California livestock from the Los Angeles Basin and Santa Barbara and Monterey Counties to the Sacramento and San Joaquin Valley's. These conditions fostered intensive speculation, especially in the cattle industry. In 1850 the census indicated 253,588 head of cattle, 17,574 sheep and 23,385 horses and mules were in California and 80% of these animals were in the Los Angeles Basin and in Santa Barbara and Monterey Counties. In 1860 the census documented enormous increases in livestock with cattle increasing to 999,836 head, sheep increasing to 1,099,002 head and horses and mules increasing to 170,187. During this decade cross-country sheep drives became common and might take 10-14 months and could include as many as 12,000 head, although 1,200 to 2,000 head was the average. In the years just prior to the Civil War, approximately 100,000 "woolies" took the long walk to California. Records indicate that they came from as far away as Michigan, Illinois and Ohio and most of the drives ended in Los Angeles, San Diego or Sacramento counties (Elkins 1992). Forty percent of these animals in 1860 were located in the San Joaquin and Sacramento Valley.

Alternating periods of severe drought and high rainfall periods in the 1850's and 1860's wrought havoc with the growing livestock industry. In 1862 California had about 3.0 million head of livestock and during the winter of 1862 some areas of the state received twice their annual rainfall average. Historians relate that it began raining on December 24, 1861 and it rained for almost 4 weeks. San Francisco recorded a monthly rainfall in January of 24.36 inches and it was said that a vast sea developed in the Sacramento Valley. This great flooding event resulted in steam ships being able to operate 14 miles from their usual river channels carrying people, animals and property to higher ground. Hundreds of thousands of animals drowned when the uncontained floodwaters inundated the City of Sacramento to a depth of 20-feet and stretched east to the foothills of the Sierra, west to Benicia, south past Fresno and north to the Marysville Buttes. One news account listed this inland sea as being 200 miles long and 20 miles wide. Accounts of travelers marooned by this event said it took several months for the floodwaters to recede. Then during the next two years (1863-64) possibly a million head died from drought (Sacramento's precipitation in 1863 was 11.6 inches and in 1864 it was only 7.8 inches, compared to the long-term average of 19.6 inches). Half of all the cattle being raised in the Los Angeles Basin to supply northern mining communities died during these two years, Santa Barbara County (another top producer) lost 85,000 head of cattle and the other key livestock growing and shipping county, Monterey, lost almost all of its cattle.

The 1870 census showed the number of cattle in California had dropped from 999,836 (1860) to 479,349 head, thus ending the speculative stocking of cattle on California's open rangelands. However, the 1870 census found that sheep numbers had more than doubled since the last census (from 1,099,002 to 2,768,187 head). These animals were found primarily in the Sierra Foothill counties and the coastal counties north of San Francisco. This unusual growth in sheep numbers was due in great part to the disruption of the southern cotton trade by the Civil War and the huge demand for wool products. And, the 1870 census found that the numbers of horses and mules had increased to 228,928 (from 170,187 in 1860), primarily to support transportation, freight and hard-rock mining industries that were flourishing.

Laws were subsequently passed prohibiting the free use of lands owned by others for grazing. The laws first affected sheep grazing and then in 1870 the "Open Range" prohibitions were expanded to cover all livestock. These laws promoted barbed wire fencing of private lands and cultivation of the more productive valley lands for crops. This was the beginning of the end for the Ranchos and most were broken up into small tracts ranging in size from 15-20 acres to a few hundred acres and sold for "farms". Most of these parcels were subsequently farmed for wheat, barley and oats and the 1860 to 1870 period came to be known as the "Decade of Wheat" in California. The pastoral cattle industry shifted to the upper margins of the grasslands and the woodland ranges of the foothills, and to the plateau and mountain portions of the state where it remains today.

UTILIZING LIVESTOCK TO MANAGE NATURAL RESOURCES

Health of Western Rangelands

It is generally accepted that widespread overstocking and periods of severe drought during the late nineteenth and early twentieth centuries deteriorated the health of western rangelands and grazed forests. Beginning in the early 1900's, agricultural experiment stations were established by the federal government in strategic locations throughout the United States to assist livestock owners in learning how to utilize grazing lands in a sustainable manner. Improved land management practices over many decades led range scientists Box and Malechek (1987) to assert that, "United States grazing lands are in the best condition they have been in since the late nineteenth century and are continuing to improve".

The Bureau of Land Management (BLM) manages more land in the 12 Western states than any other Federal agency (261 million acres). This agency along with the U.S. Forest Service have a multiple-use mission that includes sustaining the health and productivity of the public lands for the use and enjoyment of present and future generations. BLM made improvements to their grazing regulations in August 1995 to improve rangeland health and have recently completed a final environmental impact study on grazing regulations. BLM has announced that additional changes in their grazing regulations will be published in the Federal Register in July 2005. BLM's Director Kathleen Clarke characterized the results of the environmental impact study as indicating that grazing management under the new regulations will produce long-term rangeland health benefits, including increased vegetation along stream banks, reduced soil erosion and more habitats for wildlife. Rebecca Watson, Assistant Secretary of the Interior Department for Land and Minerals stated that a key focus of the revisions will be to "improve BLM's management of public lands ranching, an activity that not only supports rural economies but also preserves open space and wildlife habitat in the rapidly growing West."

Land Use Regulations and Best Management Practices

Since passage of the Clean Water Act and Endangered Species Act more than three decades ago a vast complex of land-use regulations and Best Management Practices (BMP's) are now in place across the United States to monitor land use and to ensure compliance with regulations to protect water quality and endangered and threatened species and their critical habitat.

California's Geographic and Biological Diversity is Unparalled in the United States

California's geographic and biological diversity is unparalleled by any other state. Its water resources include 1,100 miles of coastline, 4,955 lakes and reservoirs, 103 major streams and 74 major rivers. Its landscape is vast and varied, including three of the four North American desert habitats, some of the highest peaks in North America, and the most productive farmland in the world. Across this landscape and along the coast live more than 935 vertebrate and 100,000 invertebrate species, more than 7,000 vascular plant species and more than 350 threatened and endangered species (California Resources Agency 2005).

Grazing Improves Habitat for Protected Animal and Plant Species

Habitats for a number of California's protected and rare species are being improved through controlled use of livestock. For example, the Contra Costa Water District in Contra Costa County uses cattle grazing on the Los Vaqueros Watershed to improve habitat for protected and candidate species such as the red-legged frog, tiger salamander, California kit fox, western burrowing owl and western pond turtle. Sheep are used exclusively in areas rich with cultural history and on very steep and rugged terrain to enhance habitat for the Alameda striped racer and to reduce vegetation in critical high fire risk areas. And, cattle and sheep are used to manage wetlands and riparian buffers to promote biodiversity and protect water quality. The U.S. Fish and Wildlife Service (USFWS) recently reintroduced grazing to the National Wildlife Refuge, Warm-Springs Seasonal Wetland Unit in Alameda County to enhance habitat for California tiger salamanders, vernal pool tadpole shrimp, Contra Costa goldfields, and western burrowing owl. The USFWS found that grazing had been excluded from the property for approximately 10-years and habitat for these species had become degraded. The Muir Heritage Land Trust in Contra Costa County reintroduced cattle grazing to manage a Contra Costa goldfield population when they saw a significant decline in plant numbers following the exclusion of cattle. At the Bouverie Preserve, part of Adobe Canyon Ranch in Sonoma County, biologists use grazing to maintain diversity and help native wildflowers such as meadowfoam and mule-eared sunflowers prosper. And, at Sea Ranch along the Sonoma County coast, sheep and goats are used to control noxious weeds, to reduce the incidence and intensity of wildfires, to improve wildlife habitat and to enhance biodiversity within the 4,000-acre residential community. (Barry 2005).

Managing California's Vegetation Using Controlled Grazing

The most effective tool for managing vegetation levels on California rangelands in a positive environmental manner is through the controlled use of domestic livestock. It is clear to resource managers that adverse environmental impacts associated with uncontrolled grazing or heavy continuous grazing can be significant. However, these impacts can be prevented, minimized, or ameliorated by control of when, where, how long and how intensively livestock are allowed to graze. Effective management of grazing pressure can achieve desirable plant community structure, decrease fuel loads to reduce wildfire risks, increase the capacity to sequester carbon, increase and regulate nutrient cycling in the ecosystem, increase wildlife habitat and enhance biodiversity. The key to sustainable and productive rangelands is to manage vegetative cover, desirable species and plant diversity, not only to provide feed for grazing livestock but also to hold soil in place, to filter water and to recycle nutrients (Council for Agricultural Science and Technology 2002).

Using Residual Dry Matter (RDM) as a BMP for Meeting Multiple Resource Management Objectives

The Los Vaqueros Watershed (19,400 acres in the San Francisco Bay Area) is owned and managed by the Contra Costa Water District (CCWD). Of this acreage approximately 14,100 acres (12,000 AUM's) are grazed and 3,800 acres are left as un-grazed buffer areas (not counting the 1,500 acre water supply storage reservoir). Lease areas are appraised on an Animal Unit basis to establish realistic stocking rates that will result in a moderate to high level of residual dry matter per acre (RDM) at the end of the grazing season in October and avoid overgrazing effects to the extent practical. An Animal Unit is defined as a 1,000-pound beef cow with or without a nursing calf with a daily requirement of 26 pounds of dry-matter forage. Therefore an Animal Unit Month (AUM) is equal to 780 pounds of dry-matter forage to sustain a cow or cow and calf for 30-days. Other livestock are compared to this 1.0 AUM standard for a cow or cow and calf by weight and forage intake, i.e. 1.25 AUM for a bull, 0.50 AUM for a 500-pound heifer or steer and 0.20 AUM for a sheep. The amount of range forage produced each year depends on the climate and in the Bay Area it is highly variable from year-to-year and decade-to-decade. In addition, the Bay Area goes through periods of dryer than normal years and wetter than normal years. To account for the annual variation in forage production the CCWD watershed manager has absolute control over stocking rate increases and decreases in accord with resource management objectives. On the Los Vaqueros Watershed beef cattle graze on approximately 10,100 acres, including one 5,400 acre lease with 400 cow-calf pairs and another lease with 4,700 acres and 750 heifers and steers. In addition, approximately 3,000 sheep and their lambs graze 4,000 acres on a seasonal (winter-spring) basis to meet special resource management objectives. The annual production of beef for market is about 800,000 pounds and for lamb it is about 450,000 pounds. The numbers and types of grazing animals varies annually in accord with the forage production year to leave an RDM that ranges from 800 lbs/acre to 1,200 lbs/acre at the end of the annual grazing season in October, depending on the slope and resource protection measures. This range of RDM was designed to minimize erosion and ensure protection of water quality, to reduce light flashy fuels to protect important resource values and to enhance wildlife habitat for protected species (Stechman et al 1996). This range of RDM at the end of October correlates closely with a total plant (live/dead biomass) cover density greater than 70% and an average plant height of 2 to 4 inches.

Four Factors Control Forage Productivity and Species Composition

Four factors, including precipitation, temperature, soil characteristics and plant residue or litter (RDM), largely control forage productivity and seasonal species composition of California's annual grassland. Management of plant residue is the factor that can be most readily controlled by a rangeland manager. Rangeland managers desire an optimum level of RDM at the end of October to provide for soil protection from rain splash erosion, improved forage productivity and increased plant diversity. On most sites, an RDM of 800 to 1,200 pounds per acre provides this optimum protection level. Ideally for plant species diversity this level provides for a patchy appearance where some spots have less RDM and some have more. The previous year's RDM impacts the current years species composition. For example, a diversity of low-stature plants such as spring-maturing forbs like filaree and summer annuals like turkey mullein will be favored in the areas with lower RDM levels. Tall stature grass such as wild oats will be favored in areas with more RDM. Ranchers and watershed managers, who recognize the influence of RDM on species composition may choose to feed off an area to a lower RDM to favor filaree or some other early high quality feed in an area (George et al 2001).

Levels of Residual Dry Matter and the Grazing Intensity Rating

The 800 to 1,200 pounds per acre RDM management objective establishes this level of grazing intensity as "moderate". Reducing the RDM level to a range of 400 to 800 pounds per acre would be considered "heavy" grazing intensity and increasing the RDM level to over 1,200 pounds per acre would be considered "light" grazing intensity. An extreme level of grazing intensity would result in an RDM level of 300 pounds per acre or less. However, if animals congregate in one place too long, spot overgrazing inevitably occurs, even when the overall assessment would indicate "light" or "moderate" grazing intensity for the overall pasture. In this case the effects of "over-grazing" are primarily related to grazing intensity and not to timing. Best Management Practices are designed to control grazing intensity to minimize these over-utilized "spots" (Nuzum 2005).

However, it should be noted in regards to perennial plants, like purple needlegrass, that overgrazing is a function of time. Overgrazing of a perennial plant is grazing the plant before it has recovered from the previous grazing. It can occur in two ways: leaving livestock in a pasture too long or bringing them back too soon. Timing is also an important consideration for managing species composition, particularly for controlling undesirable species. For example, pest species such as yellow star thistle and medusahead can both be controlled by grazing at the right time and intensity, but can rapidly be spread by grazing and/or excluding grazing animals at the wrong time. Although many range sites in the San Francisco Bay Area are very productive, producing 2,000 to 3,000 pounds per acre or more, there are some sites, often with shallow soils, that are less productive, producing less than 500 pounds per acre per year. The site's potential productivity and the resource management objectives for the site must be evaluated before establishing RDM standards. For example, an RDM standard of 400 pounds per acre may be desirable for a site with serpentine soils where the objective is to promote native vegetation. But, care must be exercised to not overgraze poor productivity sites that may not produce 400 pounds per acre even with optimum rainfall and temperature (Barry 2005).

Livestock Influences Have Been Inadequately Characterized by Authors

In 1998 a distinguished group of range specialists (Larsen et al) evaluated more than 1,500 published articles about livestock influences. Their findings emphasized that ecosystems were highly variable in space and time and that evaluations of vegetation structure and how ungulates interact with the system should be the foundation of any practical grazing management strategy or restoration effort. They concluded that a high percentage of these articles were not statistically or experimentally adequate and that a great deal of personal opinion and commentary was interspersed with a little scientifically valid experimentation. Only 248 articles reviewed contained original data and a large number of these were classified as "experimental". In addition, many of these articles were found to lack an adequate description of grazing management practices and intensities.

Grazing Animals are an Integral Component of Grassland Ecosystems

Grazing animals are a natural and integral component of most grassland ecosystems (Frank, McNaughton and Tracy 1998). Since the eighteenth century, cattle have been the dominant grazing animals in the United States (Holechek, Pieper and Herbel 1989; Maly and Wilcox 2000). Grazing animals depend on plants such as grasses, forbs (broadleaf herbs) and shrubs for sources of energy and nutrients. Large wildlife grazers can range from moose, elk and deer to small herbivores such as rabbits, squirrels, mice, grasshoppers and aphids. Certain domestic grazers (cattle, horses, sheep and goats) have replaced many of the large wildlife grazers and humans have assumed the role of land and forage managers, deciding which grazer should use the forage and to what extent vegetation should be grazed.

Grazing Effects on Plants

In many ecosystems, more grazing occurs below the soil surface than above it (Evans and Seastedt 1995). These subterranean grazers include soil insects, earthworms, nematodes and other organisms that may graze roots or simply suck juices from root cells (Byers and Barker 2000). This is not to imply that subterranean grazers are an ecological problem but simply to report that grazing effects on plants occur above ground and below ground and often they occur simultaneously. These effects range from the almost imperceptible to the quite severe and the effect depends on the frequency, intensity and season of use of the plants being grazed. Plant defoliation studies reveal that a perennial plant can give up to 50% of its leaves to grazers without affecting the plant physiologically and the plant will continue to be healthy and growing (Griffith 2002). Annual plants dominating California's grasslands can withstand severe defoliation. Severe defoliation may prevent a particular annual plant from going to seed in a given year but other plants nearby will provide the seeds necessary for replacement. The key with annuals is to retain enough of the plant material after it dies in June to insure soil protection from precipitation in the fall after the grazing season ends and before the new crop of annual plants has developed.

Grazing Effects on Water and Runoff

Grazing influences water, nutrient cycles and energy flow in the ecosystem. Grazing can have a negative impact or a neutral or positive benefit depending on the ecosystem, the environmental conditions and the grazing season and intensity selected by the watershed manager. For example, uncontrolled treading in one area by large herbivores may increase soil compaction and decrease water infiltration. But, if grazing is well managed the negative effects of compaction will be minimized and increases in water infiltration and soil organic matter will be greater than in ungrazed areas (Franzleubbers, Stuedemann and Wilkinson 2001). The largest sources of erosion on California grazing lands are related to unpaved roadways and trails and pond spillway failures. A number of practical construction and maintenance measures have been developed to minimize or avoid these risks.

Grazing Effects on the Distribution of Nutrients

Grazing increases the rate of nutrient cycling by speeding up the breakdown of organic matter into smaller particles in the system, making it more readily available for soil microorganisms such as soil bacteria and fungi. These microorganisms use the organic matter as an energy source and release nutrients back into the soil for plant uptake. Please refer to the Nutrient Cycle on page 21.

Animals grazing in one area and watering or resting in another area where they deposit urine and manure effects the soil fertility of both areas, resulting in a net transfer of nutrients from the grazing area to the resting and watering area. The behavior of the animal must be considered when developing watering and mineral supplementation areas to maintain the nutrients on the grazing areas where they were created.

Grazing Effects on Carbon Sequestration

Productive, sustainable grazing lands provide high-quality vegetation and soils, which lead to high rates of carbon sequestration and low levels of carbon dioxide emissions. The total soil carbon sequestration potential for grazing lands in the United States is approximately 70 million metric tons of carbon per year. This store of carbon is about 1.6 times the size of the carbon dioxide emission from all other agricultural activities in the United States (Lal et al 1998) and about 4.4 times the carbon dioxide emission for all grazing land agriculture.

In 1998 Patricia Richardson and Dick Richardson of the University of Texas, Austin told the attendees at the Society for Ecological Restoration Conference that dung beetles were the carbon conveyor between ungulates and earthworms. They were referring to the remarkable capacity of these scarab beetles to enhance carbon and nutrients in the soil by burying large amounts of manure. They related that dung beetle communities had been observed to bury a ton of manure per acre per day, some of it as deep as 30-inches. Please refer to Dung Beetles on page 27.

Grazing Effects on Soil Quality

Several soil functions, including soil respiration, infiltration, bulk density and aggregate stability, are directly or indirectly affected by livestock activities, especially the level and frequency of forage plant defoliation. Grazing management to achieve “moderate” and sustainable levels of defoliation (domestic and wild herbivore consumption, clipping and trampling) is necessarily site specific and depends on climate, soil, water, annual and perennial plants, nutrients and many other considerations. Grasses beneficially affect soil structure by increasing soil aggregation, which enhances water percolation, soil aeration and soil carbon sequestration. Grasses also enhance subsurface cohesion, which is critical in decreasing soil erosion (Eviner and Chapin 2001).

Grazing Effects on Compaction

Soil compaction results in an increase in specific gravity or bulk density by decreasing the pore space in the soil. Maximum compaction occurs when soil moisture levels reach 20% to 30% of the moisture-holding capacity of a particular soil type in combination with high livestock stocking densities. Excessive soil compaction can decrease plant growth (Heady and Child 1994). However, natural processes such as soil wetting and drying cycles and the use of moderate livestock stocking rates can quickly restore the physical properties of the soil.

Grazing Effects on Erosion

Grazing management practices that decrease surface runoff will decrease erosion, conserve soil moisture and nutrients for vegetation growth and restore underground water supplies (Thurow 1991).

Low gradient winding streams tend to move laterally, with or without livestock on their banks. As stream banks move laterally on outside curves the stream bank walls will be undercut, resulting in very steep walls that will slough into the stream and be washed downstream. This natural erosion process creates an encroaching front of repetitive undercutting, the creation of shear walls and sloughing. In addition to this natural consequence of stream bank meandering, having heavy livestock with sharp hooves with ready access to the top of these banks will exacerbate this erosion process (Vallentine 1990). Sloughing adds suspended sediments to the stream and increased nutrients that may be responsible for downstream algae blooms and the growth of aquatic plants.

Out-fencing the riparian corridor to eliminate domestic grazers creates a “buffer” area that will have reduced levels of bacterial, viral and protozoan pathogens that were previously associated with domestic grazing animals that had access to the riparian area. Specific stream bank erosion and resulting sedimentation related to previous livestock access will be eliminated. Over time plant diversity will increase and increased tree and shrub growth will result. Wildlife abundance and diversity will increase in response to the increase in plant diversity and the increased vertical and horizontal structure of the vegetation. Over a number of years following the establishment of the buffer area, willows, cottonwoods and other trees and shrubs will utilize more ground water and the above ground stream flow may be reduced. And, as woody plants mature within the buffer area an increase in soil stability will take place due to large, stable root systems. However, a reduction in the overall habitat values for aquatic and terrestrial wildlife may result from this dynamic, long-term process. To maintain a balance of the desired resources within the buffer area the watershed manager may have to utilize periodic short-term and high-intensity grazing pressure and potentially some amount of pruning (Nuzum 2005).

Sheet erosion is caused by the impact of raindrops on bare soil. The force of the rain dislodges soil particles and keeps the finer particles suspended in a thin sheet of runoff water when the soil surface seals over (Stallings 1957). Rill erosion occurs when water becomes concentrated into small parallel flow paths created by irregularities in the soil surface. Sheet and rill erosion on grazing lands can be minimized or prevented by maintaining a vegetative cover of at least 75% (Borst, McCall and Bell 1945). Even a low level of RDM would meet the 75% protection cover to avoid sheet and rill erosion.

Gullies can also form on deeply trenched trailing paths created by livestock and wildlife. Trailing paths are created by domestic animals and wildlife going to and from widely separated watering areas. Increasing the number and distribution of watering facilities has been found to ameliorate trailing on grazing lands.

Why terracettes form on some steeper hill slopes is a controversial issue. Obviously cattle use these terracettes while grazing across the hill slope. But, while animal use may accentuate the definition of terracettes, cattle may not be responsible for their formation. Other natural soil processes have been suggested as being responsible for the formation of terracettes (Buckhouse and Krueger 1981). Perhaps the controversy began with Odom in 1922 when he noted that terracettes could be attributed to a whole succession of very small rotational slips along the slope. Since that time many range land researchers have concluded that cattle create terracettes. However, others have found it rare to find terracettes on south or west exposures and have found most of them on north exposures with the same grazing intensity. Still others have identified terracettes on hill slopes that have not been grazed by domestic stock or where grazing has been excluded for many decades. It is informative to note that some hill slopes that have been continuously grazed do not have terracettes and other grazed hill slopes that appear to have comparable soils and slope have areas with and without terracettes. Geotechnical engineers indicate that a multitude of internal forces in addition to soil properties are responsible for holding the structure of soil intact. These forces provide strength to soil layers and maintain slope configuration. When the balance of these forces is jeopardized or the soil properties are changed the strength of the soil system fails. Small uniform failures on steeper slopes create shallow sloughing and terracettes are formed. The spacing, orientation and size of terracettes are well correlated to soil properties including soil type, porosity, moisture content, etc. (Davison and Springman 2000; Alexander 2005).

Terracettes are prone to landslips where soils slide along shear planes. These slips can be in the form of shallow, uniform soil creep and in some instances catastrophic landslides. These failures will occur irrespective of grazing pressure.

Grazing Effects on Water Quality

Water quality degradation that can occur on grazing lands is characterized as “nonpoint source” pollution. This type of pollution occurs over a wide area and usually is associated with land-use activities but it can also result from natural events such as large rainstorms (Brooks et al 1997). Except where prolonged heavy grazing occurs, moderate grazing has been found to have little effect on surface water quality (Owens, Edwards and Van Keuren 1989).

Best Management Practices adopted to protect water quality values include the establishment of fences on either side of key watercourses to create buffer areas that eliminate livestock from routine access to the watercourse. However, the useful and beneficial aspects of the buffer area will be lost without controlled high intensity and short duration grazing by livestock. Excluding livestock will quickly eliminate the beneficial aspects of the buffer areas surrounding creeks. The width of these “buffer” areas may need to vary from one area of the watershed to another in accord with vegetation management and wildlife habitat objectives. Buffer areas are also established around the perimeter of domestic drinking water reservoirs as a BMP. In this special case standard barbed wire fences are constructed 50-100 feet above the reservoirs’ spill elevation and livestock are permanently excluded from these areas. Buffer areas are effective in protecting water quality parameters. For example, a buffer that extends 100 feet out from the centerline of a key watercourse can reduce sediment by 97%, nitrogen by 80% and phosphorus by 77% (Lowrance et al 1995). And, buffer widths of only ten-meters (32.8 feet) from watercourses have been demonstrated to reduce manure based pathogens by 99.9%. Most bacterial and protozoan (giardia and cryptosporidian oocyte) pathogens are desiccated and killed quickly by temperature and those that are not killed will move less than 1-foot from the fecal pat even with high rainfall levels of long duration (3-hours). Viruses were found to move more freely with infiltrating water and for the same high rainfall and long duration events the viruses were found to move up to 10-meters (Davies et al 2005).

Soil nutrient distribution on grazing lands can be highly variable. Grazing animals return ingested nutrients to the land in highly concentrated patches through the natural processes of defecation and urination. And, as a result, livestock concentration in resting areas near shade, watering areas and mineral stations can enrich the soil in those locations and within a 30-meter area (Franzluebbers, Stuedemann and Schomberg 2000). Grazing management practices designed to evenly distribute an adequate number of resting, watering or mineral (salting) sites away from permanent water-courses have been found to substantially reduce or eliminate these potential problem areas.

Riparian and wetland systems are biologically diverse and hydrologically important features of watersheds. Management of grazing in or adjacent to these areas must include consideration of the interdependence between hydrologic and vegetative processes operating both on uplands and in adjacent in-stream channels (Heady and Child 1994). Alteration of riparian and wetland vegetation by grazing animals can have a significant beneficial or negative impact on aquatic life, riparian plants, edge effect, water yield and wildlife diversity which demands careful scheduling and control of the grazing pressure, intensity, period of entry and duration (Nuzum 2005).

Wetlands store precipitation and surface water and then slowly release water into associated surface water, ground water and the atmosphere. Groundwater occurs in saturated zones beneath the soils surface and is generally of higher quality then surface water (Brooks et al 1997). Wetlands also provide biogeochemical cycling and storage capacity that benefits water quality and wetlands filter sediment, pathogens and organic matter. Mitsch (1992) found that created in-stream wetlands controlled 63% to 96% of the phosphorus and 88% to 98% of the sediment. Periodic removal and relocation of dredged spoils during pond and wetland maintenance activities eliminates accumulated nutrients and sediment from the watercourse. Beaver impoundments or created in-stream wetlands can be extremely useful as they can retain up to 1,000 times more nitrogen than streams that are not impounded (Whigham et al 1988). Wetlands are among the most productive ecosystems in the world and they play an integral role in the ecology of the watershed (Mitsch and Gosseling 1993).

Wetland plants provide breeding and nursery sites for wildlife, resting areas for migratory species, and refuge from predators (Crance 1988). Decomposed plant matter (detritus) released into the water is an important food for many invertebrates and fish, both in the wetland and in associated aquatic systems. Wetlands provide community structure and wildlife support to many mammals (beavers, muskrats), amphibians (frogs and salamanders), reptiles (lizards, snakes and turtles), waterfowl, birds and insects. Wetland size and shape can also affect the wildlife community and the wetland's function as a suitable habitat (Brinson 1993; Kent 1994).

Grazing and Invasive Pest Plant Species

Invasive pest plant species threaten the productivity, stability and ecological functioning of many grazing lands in the western United States (Council for Agricultural Science and Technology 2000). Most of these invasive pests originated in Europe and Asia and were introduced accidentally during the nineteenth century. These plants include cheatgrass, medusahead, barbed goatgrass, several species of thistle (Carduus and Cirsium spp.), the knapweed complex (Centaurea spp.) leafy spurge, rush skeleton weed, sulfur cinquefoil, perennial white-top and hoary cress.

Some plant species that are desirable forage in some areas of the United States are considered invasive plant pests in other areas. For example, some beneficial forage species, like Kentucky bluegrass, are found growing on grazing lands of the eastern United States and irrigated pastures in the western states. And, certain introduced plants including common Bermuda grass, Johnson grass, and quack grass have become invasive weeds on croplands and other non-grazed areas. Proper grazing management contributes to the persistence of desired forages whereas poor management (heavy grazing and poor timing) hastens the demise of preferred forages and promotes their replacement by invasive species (Archer and Smeins 1991).

Locally significant pest plant species include giant reed, medusahead, tree-of-heaven, purple star thistle, wild artichoke thistle, yellow star thistle, pepperweed, pampas grass and bamboo. In addition to the key concern of a pest plant spreading is the ability of some pest plants, like medusahead, to lower the nitrogen availability in the soil (especially during the winter). This nutrient reduction adversely affects the productivity necessary for desirable grassland species and aids in enhancing the pest plant species. This effect can have a persistent impact even after eradication. The best pest management practice is to periodically inspect and eradicate pest plants quickly.

Grazing on Public Lands

Livestock grazing on public lands has become a major political issue in states with significant areas devoted to public lands management. The federal land management agencies including the U.S. Forest Service, Bureau of Land Management and National Park Service manage the vast majority of public owned lands. These agencies have different management policies regarding livestock grazing that range from exclusion to managed grazing allotments. The majority of these public owned lands are found west of the 98th Meridian. Although these lands are substantially less extensive than in the West, public grazing lands in the East face similar environmental quality concerns. The arid and semiarid grazing lands in the West have been identified as vulnerable to degradation if grazing is excessive or poorly timed. Consequently, public land managers and private ranchers have developed a high level of cooperation to sustain production on public lands.

But, even in view of these improvements in cooperation many conflicts between environmental groups, livestock Permittees and public land management agencies have taken place. Certain groups consider livestock grazing destructive and have requested that livestock be removed. And, in many cases these groups have filed suit against the land management agencies in an attempt to eliminate livestock use. Yet any use of public lands, including recreational uses, can cause resource damage. And, the elimination of grazing on some public lands has allowed open-space lands to be used for abusive, illegal and dangerous activities. Eliminating grazing from public lands in the San Francisco Bay Area has also led to the decline of some special status species. In the Coyote Valley and on the San Francisco Peninsula, populations of the Bay Checkerspot Butterfly have been extirpated due to the loss of larval host plants following the removal of livestock. It has been found that when a plant is exposed to heavy and continuous grazing pressure the results are detrimental and that when a plant is completely excluded from exposure to a grazing animal it begins a process of smothering and dying (Griffith 2002). The watershed manager insures that these two extremes are avoided and that adequate recovery time is provided to insure that plants are healthy and maintain their root systems and plant vigor.

Livestock grazing is one of the few tools available to watershed managers for vegetation manipulation and there are many benefits that can be derived from controlled use of livestock. These benefits include production of a desirable plant community structure, decreased fuel loads to reduce wildfire risks, increased carbon sequestration, regulation of beneficial nutrient cycling, control of encroaching brush species and enhancement of wildlife. Using controlled livestock grazing to manage vegetation also provides substantial revenue from the rancher, making it the most cost effective tool available when compared to the high cost per acre associated with prescribed burning, mechanical clearing, herbicide use or manual clearing. In addition to high implementation costs these vegetation management alternatives have their own set of environmental impacts that require mitigation.

Grazing and Prescribed Fire

In most grazing land areas 600 to 1,000 pounds per acre of fine fuel is needed to conduct a prescribed burn. A fuel load from 3,000 to 4,000 pounds per acre is optimal and provides the greatest flexibility for planning the burn (Wright and Bailey 1982). In areas with substantial fine fuel loads the watershed manager can utilize grazing animals to reduce the fine fuels to the “prescription” level recommended for the desired effect and then remove the animals from the area.

Grazing utilization levels can also be increased in specific areas to decrease the risk of damage from an unplanned wildfire event. Planning the grazing treatment to reduce fuel loads to 300 pounds per acre or less of fine fuel will eliminate the ability of fire to “carry” on most grazing lands (Wright and Bailey 1982).

Grazing and Water Yield

Many studies have documented the differences between high evaporation-transpiration losses associated with shrubs and trees in comparison to low evaporation-transpiration losses associated with herbaceous vegetation. Research in California over many decades documented that runoff increases on lands where the vegetation type is changed from brush to grassland. These studies also found that runoff is retarded during storms but the annual runoff is increased, indicating an extension of the runoff period or greater runoff later in the year. Many of these same studies documented that surface flows increased substantially when large areas of brush were removed and replaced with grasses. Many accounts indicate that ephemeral streams or sections of streams that were ephemeral in nature became permanent streams following clearing of brush or following large fires in chaparral or forested habitats. Since grazing can be effective in maintaining grasslands and reducing the encroachment of woody species the watershed manager needs to consider the positive effect grazing can have on maintaining a longer, slower period of runoff.

Grazing and Biological Diversity

Long-term studies on western and eastern grazing lands indicate that appropriate grazing management supports a relatively high level of plant species diversity (Milchunas, Lauenroth and Burke 1998; Tracy and Sanderson 2000; Sanderson et al 2001; Hart 2001).

Excluding grazing animals from ecosystems that evolved with grazing have been documented to decrease biodiversity through competitive exclusion of certain plant species. But where drought and uncontrolled heavy grazing have caused degradation, allowing the ecosystem to recover may increase plant species diversity (Anderson and Inouye 2001). Increased diversity is not desirable if the practice increases invasive species or decreases a key natural watershed function such as the yield of water or replenishment of a ground water aquifer.

Managing Livestock Grazing Intensity

It is clear that management is the key to preventing or ameliorating the negative effects of concentrated livestock grazing and livestock grazing is also the key to improving the sustainable health of watershed lands. Land managers make decisions daily that affect the lands’ short- and long-term ability to meet both ecological and business goals. Management requires an integration of professional resource knowledge with science as a foundation and with monitoring to provide a sound basis for proactive modification of management practices. The general principles describing how grazing affects the structure of plant and animal communities in the ecosystem have been understood for many years. But now a much greater appreciation exists for how grazing influences important processes such as the carbon cycle, water and nutrient cycles, as well as energy flow from plants to animals and from animals to soil microbes. A new century of grazing lands management has begun based on emphasizing a sustainable land ethic.

Facts : Livestock eat grass, drink water, gain weight and release nutrients.

Livestock have been found to be an invaluable resource management tool but they are not culpable for inadequate land management practices (Edwards 1992).

THE NUTRIENT CYCLE

Nutrients cycle through soil organisms, pasture plants, grazing livestock and back to the soil again as urine and manure. Application of Best Management Practices for managing watershed lands can enhance the nutrient cycle, increase soil productivity, improve wildlife habitat and reduce operation and maintenance costs (Beetz 2002).

Soil Organisms

A small sample of soil contains visible insects and earthworms and billions of microscopic organisms. An acre of soil may contain 900 pounds of earthworms, 2,400 pounds of fungi, 1,500 pounds of bacteria, 133 pounds of protozoa, 890 pounds of arthropods and algae and even small mammals. But most of these organisms are invisible much of the time and people forget that they are key components of the soil ecosystem. However, even though these can't be readily seen watershed technicians can utilize two "surrogates" that are reliable indicators of good soil health – the first is the relative number of earthworms in the soil (per square foot) and the second is the relative percentage of organic matter in the soil (per square foot).

- Soil Bacteria -- the most numerous organisms in soil – a gram of soil (28th of an ounce) may contain 3 billion bacteria. Bacteria help plants take up nutrients by releasing nutrients from organic matter and soil minerals. Certain of these bacteria can 'fix' nitrogen for use by plants and certain other species release nitrogen, sulfur, phosphorus, and trace elements from organic matter. Other species break down soil minerals and release potassium, phosphorus, magnesium, calcium and iron. And still others make and release plant growth hormones, which stimulate root activity. Bacteria also help plants by improving soil structure, fighting root diseases and detoxifying the soil.

- Actinomycetes -- thread-like bacteria that look like fungi. Like bacteria (but not as numerous) they help decompose organic material, releasing nutrients. They also produce antibiotics to fight root diseases and they are responsible for the sweet earthy smell of biologically active soil.

- Fungi – a gram of soil may contain a million fungi that can come in many sizes, shapes and colors. Some appear as thread-like colonies, while others are one-celled yeasts. Slime molds and mushrooms are also fungi. Many fungi aid plants by breaking down organic matter and by releasing nutrients from soil minerals. Some produce hormones and antibiotics to enhance root growth and provide disease suppression respectively and a few trap harmful plant-parasitic nematodes. Mycorrhizae are fungi that live on or in roots and act to extend the reach of root hairs into the soil (to increase the uptake of water and nutrients). The fungi, in turn, benefit symbiotically by taking nutrients and carbohydrates from the plant roots they live with.

- Algae – a gram of soil may contain a quarter of a million algae and unlike the other soil organisms, algae produce their own food through photosynthesis. After a rain algae produce the greenish film on the soil surface. The primary role of algae is to improve soil structure by producing sticky materials that glue soil particles together into water stable aggregates. The blue-green algae can "fix" nitrogen (converts atmospheric nitrogen to a plant usable form) that is later released to plant roots.

- Protozoa -- Free living animals that crawl or swim in the water between soil particles. These animals are predatory, eating other microbes. By eating bacteria, protozoa speed up the release of nitrogen and other nutrients through their waste products.

- Nematodes -- Very abundant in the soil and only a few species are harmful to plants. The harmless species eat decaying plant litter, bacteria, fungi, algae, protozoa and other nematodes. They speed the rate of nutrient cycling.

- Earthworms -- Very good indicators of soil health. Numerous studies have shown improved soil qualities where worms thrive. Forage production nearly doubles when worms are introduced and establish themselves. Worms enhance water filtration and aeration and they pass soil, organic matter and soil microbes through their digestive systems as they move through the soil. This process increases the soil's soluble nutrient content substantially. Worms eat plant material left on top of the ground and re-distribute it within the soil. Worms also secrete a material that stimulates plant growth and studies of parasites have found that worms reduced the transmission of some parasitic nematodes from cowpats to grass.

    - Noted forage specialist Charles Griffith (Noble Foundation, Ardmore, Oklahoma) claimed that you cannot have too many worms. His goal was 25 per square foot but other investigators in New Zealand found 40 per square foot the optimum number. Earthworms thrive where there is no tillage, which destroys their burrows, and their most active periods are during the spring and fall. They prefer a neutral pH, moist soil, and plenty of plant residue on the surface. Earthworms are very sensitive to some pesticides. Fertilizers are often beneficial but strong fertilizers like anhydrous ammonia is quickly fatal.

- Other Visible Soil Organisms -- dung beetles, sow bugs, millipedes, centipedes, slugs, snails and springtails. These primary decomposers start with raw plant residue and manure. Their by-products are eaten by other species whose wastes feed still other microbes. After moving through several species, these raw materials become soluble plant nutrients and humus. Please refer to Dung Beetles, page 27.

Organic Matter

Excepting algae the soil organisms listed all depend on organic matter in the soil for their food. Organic matter levels are critical for storing water and holding plant-available forms of a nutrient so they are not washed away. Organic matter creates an open soil structure for water, dissolved minerals and oxygen to move within the soil profile and it has the capability to disable certain plant toxins. The actual level of organic matter in any soil is relative to the climate, soil type and depth, over and under story plants, topography and the number and type of soil organisms present. The accumulation of organic matter is the first step to developing humus resulting from the final stage of organic matter decomposition.

Humus is organic matter that has been digested by soil organisms and turned into a stable form. Humus gives soils the flexibility to withstand conditions ranging from too wet to too dry. In a waterlogged condition a high humus soil wicks water downward. In a drought condition, water moves upward by capillary action through little humus particles. And, humus increases a soil's ability to hold onto nutrients without them leaching away.

> Summary of the beneficial effects of humus:
>
> a) Granulation of soil-particles into water-stable aggregates;
> b) Decreased crusting;
> c) Improved internal drainage;
> d) Better water infiltration;
> e) Fixation of atmospheric oxygen;
> f) Release of bound nutrients; and
> g) Increased water and nutrient storage capacity.

This accumulation process of building or maintaining the level of organic matter in the soil can be arrested or limited by the lack of nitrogen or oxygen, unfavorable temperature and unfavorable pH. Organic matter levels are harder to maintain in warmer, more humid climates and what constitutes a "high" or "low" level varies greatly throughout the country. The key for organic matter levels is to determine the level that currently exists and to manage the grasslands in a manner that increases the level of organic matter over time. Local Agricultural Extension offices can assist in finding a soil testing service and helping to interpret the results.

Plants Cycle Nutrients

Rhizobium bacteria live in legume (clover) root nodules and convert or "fix" atmospheric nitrogen into a form the legumes can use. The plant uses this nitrogen and it generally does not become available to nearby plants until the legume dies. Depending on the variety of legume the natural release of nitrogen into the soil will take place from 4-12 months after it has been "fixed" by the plant. In addition, some nodules are separated naturally from the legume roots during grazing activity and thus become available. And, some legumes have "leaky" nodules and share more of their fixed nitrogen then others.

> For example: A nitrogen molecule can be "fixed" by white clover in one day. If eaten by a cow and excreted in urine, it could take as little as two weeks before it's again available in plant tissue. If the plant is not eaten directly the nitrogen that was harvested from the air may become naturally available to nearby grasses in as little as four months. Nitrogen in a leaf that falls on biologically active soils can be used again in the same growing season.

Deep rooted trees and many broadleaf plants including weeds have taproots that go deep into the soil horizon below where grasses can reach. The nutrients from this deeper soil level are used by the plant and become available at the soil surface when the tree leaves fall, or the forage dies, or a tree limb falls, decomposes and releases its nutrients.

Roots constitute at least half the weight of a grass plant. And, perennial grasses may have a root system that reaches 6-feet or more into the soil. Every year 20%-50% of the root mass of a perennial and 100% of the root mass of an annual grass plant will die and becomes light organic matter that will decompose rapidly within the soil.

One of the main purposes of a plant root system is to gain access to nutrients stored in the soil. Some plants go to enormous lengths to do this. For example, Cesare Emiliani the founder of paleoceanography (1992) stated that "a single plant of winter rye, 50 cm high, was found to have a root system consisting of 143 main roots, 35,600 secondary roots, 2.3 million tertiary roots and 11.5 million quaternary roots ! The root system was found to have a total length of 600 kilometers and a total surface of about 250 square meters". Some nutrients, such as nitrogen, phosphorus and potassium are often harder for roots to find and specialized enzymes have evolved located in root membranes to seek out these scarce and needed resources. In general, the availability of nutrients (deficit or surplus availability) often controls the form of the ecosystem, determining its overall productivity, and influencing which particular set of plants come to predominate (University of Michigan, Soils Lecture 2004).

Livestock's Use of Minerals and Excretion as Urine or Manure

Domestic and wild grazing animals redistribute nutrients and speed up nutrient cycling. Livestock and wildlife use a small proportion of the minerals they ingest in forage to build bones, meat, milk, hide and hair. As much as 75% to 95% of the ingested nutrients that the grazing animals eat may be returned to the pasture as urine or manure, deposited in highly concentrated patches (Whitehead, 1995). Urine contains most of the nitrogen (N), and potassium (K) being excreted and manure contains most (97.3%) of the phosphorus (P). The nutrients in the urine are soluble and move rapidly in the soil down to the roots. These liquid forms of N and K are taken up by plants at once and are then quickly available as food for domestic stock, wildlife and insects.

Phosphorus (P) is excreted primarily in manure and it can take from 6-months to two years to break down manure to recycle the P. The speed of this cycle is dependent on the biological organisms available as well as mechanical means. For example, dung beetles harvest and bury manure with their eggs in burrows. This beneficial process puts the minerals back into the soil where plant roots can use them. However, most of the broad-spectrum anti-parasitic medications leave a long-lasting toxic residue (up to 28-weeks) in the dung that unfortunately kills dung beetles and harms the ability of the natural ecosystem to function appropriately (Kruger and Scholtz, 1997). Other invertebrates that assist in breaking up manure pats, including ants, grasshoppers, and earthworms, can also be harmed by non-target pesticides. However, before you preclude the use of broad-spectrum anti-parasitic medications a thorough evaluation is indicated. Please refer to Dung Beetles on page 28.

Livestock's Utilization of Grasslands

The key management practice for balancing domestic animal utilization of grasslands is the careful location and distribution of watering facilities. With only one or two widely separated watering sources in a large pasture livestock will usually go to water together. This herd movement results in "trailing" which can form rutted trails. Better distribution of watering sites results in cattle going to the watering facility individually and returning to the grazing area away from the source of water. In addition, when only a few watering sites are available livestock will congregate around the trough area, waiting to drink. While they wait they will graze and while they graze they will deposit urine and manure. Over time the watering area will be overgrazed and the plants that grow from the urine and dung deposition spots will be avoided.

Grazing Patterns Based on the Natural Behavior of Cattle

A recently completed 3-year study in Texas examined grazing patterns based on the natural behavior of cattle that may have important implications for managing livestock to meet resource management objectives here in California. Paul Schattenberg in a recent article entitled "Natural Grazing Study Helps Find Pasture, Range Management Opportunities" is in large part reproduced here due to its applicability to the subject of this paper (Schattenberg 2005). Mr. Schattenberg writes for Ag News of the Texas A&M University System Agricultural Program. His article summarizes a 3-year study by researchers at the Texas A&M Agricultural Research and Extension Center (Center). The researchers included Dr. William Holloway (Director of Research at the Center), Dr. Robert Warrington (a beef cattle researcher at the Center), Dr. Keith Owens (a range ecologist at the Center) and Dr. Robert Lyons (a range specialist at the Center). These researchers installed global positioning collars on different cattle to track their daily grazing activity and found that larger framed cattle (Brahman x Angus) grazed over greater distances than cattle with smaller frames. The data indicated that animals with a small frame grazed about 3-miles per day, while a large framed animal covers up to a half-mile more in a day. The researchers also found that cattle with smaller frame sizes or those not adapted to heat stay closer to water than larger framed breeds adapted to heat. Their conclusion was that one could utilize large-framed, heat-adapted cattle to help prevent overgrazing around water and that those with larger ranges and pastures may use this information to determine which cattle may get the most use from the available grazing area. This group of researchers also determined that cattle tend to graze into the wind. They surmised this may be an adaptation to protect themselves from predators and it also allows them to keep cooler while they are grazing. Their research showed cattle tended to overuse the windward portion of a pasture, so producers could potentially reduce grazing activity in that direction by making access to water in the windward area more difficult. Pasture shape was found to influence grazing behavior due to the terrain and the prevailing wind. A pasture should therefore have a 'broad-front' on the windward side to prevent cattle from being funneled in that direction. Team members also noted that, like humans, cattle tend to travel the path of least resistance using roads, pathways and trails to get from one place to another. Cattle will avoid rough terrain, so impediments such as dense brush or rock affect their overall use of range and pasture areas. The practical aspect of this is that producers with rough pastures will likely need to adjust their stocking levels to better reflect the true acreage cattle will use. These researchers also looked at cattle distribution in relation to natural vegetation distribution. There are many types of vegetation cattle won't eat, so there will be range or pasture areas they won't visit as much. These researchers found that cattle spent most of their time grazing in low areas or draws indicating that a producer just can't stock a pasture as if its all going to be used. The team also studied whether an external food source could be used to alter grazing patterns. A molasses based liquid feed was chosen as the exogenous or outside food source. The feed was limited but made available throughout the year. The result was fatter cows throughout the year, heavy weaning weights and high levels of reproduction. This feed was also portable, so lick tanks could be placed in different areas of the pasture to see what effect it had on where the cattle grazed. Researchers discovered that moving the lick tank was often effective in drawing cattle away from preferred grazing areas and water sources, as well as toward unused forage areas.

Small Mammal and Invertebrate Utilization of Grasslands

Many studies have shown that small rodents may consume and destroy upwards of ¼ of the crop of range forage each year. Left unchecked these small rodents may be a potent biotic factor in influencing the composition of the plant cover on rangelands.

Moderate infestation levels of 10-grasshoppers/square meter can consume or waste 16% to 60% of the available forage depending on the condition of the range forage. In normal weather periods grasshoppers consume about 20% of the available forage (Hewitt and Onsager 1982; Lockwood and Kemp 1987). Local outbreaks under season-long grazing on the Great Plains that generated 18 adult grasshoppers/square meter consumed 91% as much forage as cattle and 27 adult grasshoppers/square meter consumed 168% as much forage as cattle (Onsager 2000). Onsager found that the consumption levels on rotational grazing areas on the Great Plains, with the same numbers of grasshoppers/meter (18 and 27) were substantially lower, 10% and 23% respectively. His conclusion was that twice-over rotational grazing in the northern Great Plains mitigated a localized grasshopper outbreak and demonstrated the eminently practical importance of selecting a grazing regime to manage grasshopper densities.

During succeeding years of a drought grasshopper consumption can double, triple or quadruple. Grasshoppers are a source of food for ground nesting birds, burrowing owls and small mammals (Hewitt and Onsager 1982). They may also be considered litter producers in that they waste about half of what they consume.

Production and Value of Urine and Manure Deposited

Beef cattle produce 30 to 49 pounds of urine and 29 to 72 pounds of manure each day. The daily value of these minerals per 1,000-pound cow and in 2004 costs is estimated at:

a) 0.35 lb of N @ 40 cents/lb = 14 cents N
b) 0.23 lb of P @ 28 cents/lb = 6 cents P
c) 0.28 lb of K @ 15 cents/lb = 4 cents K

Total NPK = 24 cents

Ten cows @ 24 cents each = $2.40 per day or $120.00 per day for 500 cows. These values double if you add the value of organic matter and trace minerals.

Soil moisture and fertility levels are key limiting factors associated with grass production. Nitrogen and rainfall are closely related because of their mobility in the soil: as water moves through the soil for plant uptake, nitrogen moves with it. Forage production and the nutritional value increases as the nitrogen rate increases and proper soil fertility levels help to maintain desirable and more palatable forage species. Soil fertility of California rangelands is usually lacking in one of the three key minerals and the fertility of the soil across a pasture varies considerably.

Water and Energy Interact with the Nutrient Cycle

Water

Water is a raw ingredient used by plants to make carbohydrates and it is a key to nutrient cycling because plant nutrients are soluble and move with water. Soil itself moves in water, taking with it insoluble nutrients such as phosphorus.

When rainwater enters the soil easily, runoff losses are less and the increased infiltration will raise the groundwater table. A higher groundwater level enables springs and wells to be productive longer in the season or year around and potential drought related impacts would be minimized. High infiltration is usually marked by abundant ground cover (living plants and surface litter) and good soil aggregation. Higher infiltration also extends surface water flows in creeks later into the summer season or all year long.

Grasses provide optimum protection from raindrop impact. A moderate amount of thatch continually provides food for soil microbes and earthworms that generate the glue-like substances that bind aggregates into water-stable units. The dead plant material and the plants themselves shade the soil and help to maintain a cooler temperature and higher humidity at the soil surface. Conditions that reduce water infiltration and percolation are bare ground, surface crusting, compaction and soil erosion. Bare ground leads to erosion, crusting and weeds. Crusting seals the soil surface when the soil aggregates break down. Excessive trampling, for example, may be desirable for incorporating mulch that has accumulated and may be inhibiting the growth of new seedlings. It can also be used on erosion sites to incorporate mulch and stabilize steep banks before they slough off. However, excessive trampling and the impact of falling raindrops on bare soil are two common causes of crusting. It is important to move water sources (or turn them on or off) and mineral supplements (salt) throughout the pastures to avoid bare ground around these areas and crusting.

Energy

Plants convert sunlight into carbohydrates and the denser the canopy the more solar energy the plant can capture. Different leaves, from broadleaf plants and grasses, also increase energy Transfer from the sun to the plant. In addition, taller plants receive more light then short plants, even at extreme angles during sunrise and sunset and horizontal leaves capture the noon sun better than upright grass leaves. The watershed manager must consider the pasture as a three dimensional solar collector.

Energy from plants is transferred into the soil ecosystem through the death and decay of plant roots and residue. The plant roots and residue are decomposed first by soil-dwelling insects and other primary decomposers. The waste and by-products from the primary decomposers are broken down further by secondary decomposers. Finally the components of decomposition become humus. At each step of this process, energy is either being used to create the next generation of decomposer or it is lost as heat.

Livestock and wildlife convert plant material into meat, milk, fiber, bones and hair. The leftovers become urine and manure. Livestock products are sold, and the waste products again cycle through the decomposer organisms. Minimal loss of energy depends on proper stocking rates, good decisions on when animals are moved and how much rest the forage plants require.

Nutrients Imported, Generated on the Watershed and Exported

Nutrients Imported:

a) Purchased livestock;
b) Chemical fertilizers;
c) Manure brought in from other areas;
d) Supplemental livestock feed (grain, hay);
e) Wind and water (erosion); and
f) Precipitation.

Nutrients Generated on the Watershed

a) Atmospheric nitrogen “fixed”(captured) by legumes;
b) Rock minerals dissolved by microbial acids;
c) Subsoil minerals mined by deep roots of trees and other plants; and
d) Nutrients made available to plants by changes in pH.

Nutrients Exported:

a) Products sold (crops or livestock);
b) By wind and water (erosion);
c) Leaching into groundwater; and
d) Volatilized as gas

The input of nutrients by rainfall can be significant. Olness et al 1975 found that the rangeland watershed received more total inorganic nitrogen in rainfall than was lost with surface runoff. Ritter, 1986, found that both nitrogen and phosphorus contributed by rainfall was greater then rates occurring in stream flow. Menzel et al 1978 during a four-year study found that rainfall added 4-times the nitrogen compared to nitrogen discharged in runoff from seasonally grazed pastures and about equaled the amount discharged from continuously grazed pastures.

DUNG BEETLES

Dung beetles are biological control agents for horn flies and intestinal parasites. Ranchers were estimated to spend $800 million dollars per year (in 1997) in controlling these pests of livestock that complete their lifecycle in dung pats. Dung beetles will bury the dung pats, destroying the habitat for other insects and internal parasites to complete their lifecycle (Fincher 1997). Dr. George Bornemissza found that 95% fewer horn flies emerged from cowpats attacked by dung beetles, than from pats where beetles were excluded (Allen 2000).

Dung pats contain carbon and valuable soil nutrients. Dung is a food source for soil microflora (fungi, bacteria and actinomycetes), protozoa and earthworms. Dung beetles are nature's way of recycling carbon and minerals back into the soil to be further broken down into humus for plants. If dung stays on the soil surface and dries, 80% of the nitrogen is lost into the atmosphere.

Dung beetles (a beneficial member of the scarab family of beetles) are important enough in manure and nutrient recycling that they deserve special consideration by watershed managers and technicians. Under adequate moisture and warm temperatures dung beetle communities have been observed to bury a ton of fresh manure per acre per day. In Oklahoma dung beetles have been observed clearing a paddock of manure in 48 hours after cows have been removed. In addition to dung beetles, other species of beetles feed on manure, not burying it, but breaking it up into soil litter (Richardson and Richardson 1998).

Adult dung beetles are drawn to manure by detecting its odor and flying upwind in the odor plume. They will fly up to 10-miles in search of just the right dung, and can attack dung pats within seconds after they drop. Some species will even hitch a ride near the tail of animals in anticipation of a deposit. Once drawn by the odor the adults use the liquid content of the manure for their nourishment...Dr. Patricia Richardson, of the University of Texas, memorably referred to this as a "Dung Slurpie".

The best-known group of dung beetles is the 'tumble bugs' or 'rollers'. In the typical characteristic of this group a male-female pair roll a ball of dung (brood ball) away from a manure pile in order to bury it. She digs a tunnel for the ball while the male hauls the soil from the tunnel. These tunnels can be quite deep (1-3 feet). The ball is placed into the tunnel and the female lays one egg in each ball and seals the egg into the ball. The larvae dung beetle when it hatches feeds on the dung ball and then leaves the tunnel. Another group are the 'tunnelers', which bury the dung ball under the manure pat or close to the edge. Collectively the tunnelers and tumblers are classified as "nesters" because of their behavior in preparing a home for their young. The third group of beetles that use dung are the 'dwellers'. The dwellers live within the pat, engage in little to no digging and generally do not form brood balls (Thomas 2001).

Dung beetles range in size from 2 mm to 60 mm (2.5 inches). The front legs have serrated edges for powerful digging. Colors range from black to brown to red and they have a metallic appearance. Males have one or two horns. Scarab beetles have segmented and long antennae with a plate-like oval club at the end. These clubs are for detecting odors.

Dung beetles are just one small part of the pasture ecosystem, but they are an important part. Over time, the added organic manure in the soil is an extremely effective restoration feature for grazing lands. To summarize dung beetle benefits:

1. Increased plant rooting and grass yields;
2. Reduction of soil compaction;
3. Increased number of earthworms;
4. Increased food source for beneficial soil microorganisms;
5. Reduction of other insect pest populations that breed in animal feces;
6. Reduction of animal diseases by removing fecal material from pasture surfaces;
7. Return to the soil of nutrients that would otherwise be tied up in fecal deposits and unavailable to pasture grasses; and
8. Reduced nitrogen loss in livestock feces.

Using dung beetles more efficiently in agriculture, according to one USDA scientist, could save U.S. farmers up to $2 billion a year by improving grazing land, recycling the nitrogen normally lost to the atmosphere, and reducing the populations of flies around livestock (Moseley 2000).

LEASING LAND FOR LIVESTOCK GRAZING

COMMUNICATING WITH THE LIVESTOCK OWNER/OPERATOR

A major failing of some public land management agencies is their inability to communicate effectively with the livestock owner/operator. While the agency staff is usually very knowledgeable about the agency lands and their natural and cultural resources they are not well trained in livestock management practices, herd health, production standards and techniques or the livestock market. These limitations must be rectified by the agency in order to effectively oversee and manage livestock operations on agency property. The agency must be cognizant that an experienced livestock owner/operator can be expected to have an excellent land stewardship ethic. In California, for example, 60% of the ranching families have been ranching for 3-generations or more and they have production goals for their operations that need to be understood by the agency and worked into the overall lease objectives (Liffmann et al 2000). However, all too frequently the operational needs of the rancher and the agency objectives are not discussed or they are not clearly understood by both parties. An experienced livestock owner/operator will have valuable and practical ideas on how to improve a resource condition or satisfy an objective using livestock but they need to clearly understand what the environmental and cultural operational limitations are. It is also critically important for the livestock owner/operator to clearly understand that the agency objectives are a top priority and that the management objectives must be met regardless of the type of water year being experienced, grass production, available water or wildland fires. The livestock owner/operator must be flexible enough to increase or decrease his herd to meet these land management objectives within a very short window of opportunity following notification by the agency (Nuzum 2005).

LAND USE MASTER PLAN – RESOURCE MANAGEMENT OBJECTIVES

Most public land management agencies manage their watershed lands in strict accord with Land Use Master Plans that satisfied the requirements of the California Environmental Quality Act. In addition, a Conservation Easement may have been granted by the land management agency and/or Biological Opinion(s) may have been issued by a state or federal resource agency to protect a natural resource that exists on the agency property. The important provisions of the Master Plan must be incorporated into the livestock lease as management and operational requirements and thoroughly discussed with the livestock owner/operator. These management provisions would then become part of the Annual Grazing Plan for the livestock lease in question.

REINVESTMENT OF GRAZING REVENUES FOR MAJOR IMPROVEMENTS

The livestock owner/operator is responsible for all routine maintenance of leasehold facilities including watering facilities, corrals, loading chutes, weighing facilities, interior fences, etc. The livestock owner/operator is also responsible for the control of noxious animals and plants in accord with agency guidelines and Integrated Pest Management Program objectives. Performing major maintenance or replacing leasehold facilities or constructing new operational facilities on the lease area remains the prerogative of the public land management agency. These functions are often funded through a system that allows the reinvestment of a substantial proportion of the annual grazing revenue. To optimize the effectiveness of this reinvestment program the development of the restoration program and the prioritization of projects should include participation by the livestock owner/operator. This program and its implementation schedule must be carefully thought out and agreed upon between the agency and the livestock owner/operator prior to any implementation. These major maintenance or restoration projects would then be included in the Annual Grazing Plan for that lease.

LITERATURE CITED

Alexander, J. 2005. Formation of Terracettes. Personal Communication. Professional Engineer, Fugro Engineering. Oakland, California.

Allen, K. 2000. Dung Beetles – Biological control agents of horn flies. Texas Biological Control News. Winter. Texas Agricultural Extension Service. Texas A&M University System. College Station, Texas.

Anderson, M. and G. Nabhan. 1991. Gardeners in Eden. Wilderness 55(194): 27-30.

Anderson, J. and R. Inouye. 2001. Landscape-scale changes in plant species abundance and biodiversity of a sagebrush steppe over 45 years. *Ecol Monogr* 71: 531-536.

Archer, S. and F. Smeins. 1991. Ecosystem-level Processes. Pp. 109-139. In: R. Heitschmidt and J. Stuth (eds.). *Grazing Management: An Ecological Perspective.* Timber Press. Portland, Oregon.

Balee, W. 1987. Cultural forests of the Amazon. Garden. Nov/Dec, pp. 12-14 and 32.

Bainbridge, D. 1985a. Acorns as Food: History, Use, Recipes and Bibliography. Sierra Nature Prints. Scotts Valley, California. 28pp.

Bainbridge, D. 1985b. The rise of agriculture: A new perspective. Ambio 14(3): 148-151.

Bainbridge, D. 1986. Quercus: A multi-purpose tree for temperate climates. International Tree Crops Journal 4(3):289-291.

Bainbridge, D. 1987. Acorn use in California: Past, present, future. Pp. 453-458 in T.R. Plumb and N.H. Pillsbury, editors. Proceedings of the Symposium on Multiple-Use Management of California's Hardwood Resources. PSW-GTR-100. Pacific Southwest Forest and Range Experiment Station. Berkeley, California.

Bainbridge, D., R. Virginia and W. Jarrell. 1990. Honey Mesquite : A Multipurpose Tree for Arid Lands. NFT Highlights 90-07. Nitrogen Fixing Tree Association. Waimanalo, Hawaii. 2 pp.

Barry, S. 2005. Public agency land use in the San Francisco Bay Area. Personal Communication. Bay Area Natural Resources and Livestock Advisor, University of California Cooperative Extension. University of California. Davis, California.

Bartolome, J. 1981 Stipa pulchra - a survivor from the pristine past. Fremontia 9:3-6.

Beetle, A. 1947. Distribution of the native grasses of California. Hilgardia 17:309-357.

Beetz, A. 2002. A Brief Overview of Nutrient Cycling in Pastures. National Sustainable Agricultural Information Service. Fayetteville, Arkansas.

Blackburn, T. and M. Anderson, 1993. Before the Wilderness. Ballena Press. Menlo Park, California. 476 p.

Bean, L and K. Saubel.1972. Temalpakh, Cahuilla Indian knowledge and usage of plants. Malki Museum Press. Banning, California.

Borst, H., A. McCall and F. Bell. 1945. Investigations in erosion control and the reclamation of eroded land at the Northwest Appalachian Conservation Experiment Station, Zanesville, Ohio, 1934-42. USDA - Technical Bulletin No. 888. United States Department of Agriculture. Washington, D.C. Pp. 1-95.

Botkin, D. 1990. Discordant Harmonies: A New Ecology for the Twenty-First Century. Oxford University Press. New York, New York.

Box, T. and J. Malechek. 1987. Grazing on American Rangelands. *Proc West Sect Am Soc An Sci* 38:107-115.

Brinson, M. 1993. Changes in the functioning of wetlands along environmental gradients. Wetlands 13(2): 65-74.

Brooks, K., P. Ffolliott, H. Gregersen, and L. DeBano. 1977. *Hydrology and the Management of Watersheds.* 2nd Ed. Iowa State University Press. Ames, Iowa.

Buckhouse, J. and W. Krueger. 1981. What caused those terracettes ? *Rangelands* 3:72-73.

Burcham, L. 1956. Historical backgrounds of range land use in California. Journal of Range Management 9:81-86.

Burcham, L. 1957. California Range Land. Division of Forestry, Department of Natural Resources. State of California. Sacramento, California.

Byers, R. and G. Barker. 2000. Soil dwelling macro-invertebrates in intensively managed grazed dairy pastures in Pennsylvania, New York, and Vermont. *Grass Forage Science* 55:253-270.

California Resources Agency, 2005. Department of Fish and Game -- Budget Fact Book. California Department of Fish and Game. Sacramento, California.

Canada, C. 2004. Report for Congress. Farm Commodity Programs: Wool and Mohair. Congressional Research Service. Library of Congress. Washington, D.C.

Cleland, R. 1941. The Cattle on a Thousand Hills. The Huntington Library. San Marino, California.

Clements, F. 1934. The relict method in dynamic ecology. Journal of Ecology 22:39-68.

Council for Agricultural Science and Technology (CAST). 2000. *Invasive Plant Species*. Issue Paper Number 13. Council for Agricultural Science and Technology. Ames, Iowa.

Council for Agricultural Science and Technology (CAST). 2002. Environmental Impacts of Livestock on U.S. Grazing Lands. Issue Paper Number 22. Council for Agricultural Science and Technology. Ames, Iowa.

Covington, W. and M. Moore. 1992. Post settlement changes in natural fire regimes: Implications for restoration of old growth ponderosa forests. Pp. 81-99 in M. Kaufman, W. Moir and R. Bassett -- Old-Growth Forests in the Southwest and Rocky Mountain Regions. GTR RM 213. U.S. Department of Agriculture, Forest Service. Rocky Mountain Forest and Range Experiment Station. Ft. Collins, Colorado.

Crance, J. 1988. Relationships between Palustrine Wetlands of Forested Riparian Floodplains and Fishery Resources: A Review. U.S. Fisheries and Wildlife Service. Biol. Rep. 88(32). 27 pp.

Davies, C., C. Kaucner, N. Altavilla, N. Ashbolt, W. Hijnen, G. Medema, C. Ferguson and D. Deere. 2005. Fate and Transport of Surface Water Pathogens in Watersheds. American Water Works Association Research Foundation. Report #2694. Denver, Colorado.

Davison, L. and S. Springman. 2000. Shear Strength. Dr. Davison and Professor Springman are respectively with the University of the West of England (Bristol, England) and the Swiss Federal Technical Institute (Zurich, Switzerland).

Dobie, J. 1939. The first cattle in Texas and the southwest progenitors of the longhorns. The Southwestern Historical Quarterly 52:(3), pp: 171-197.

Ebeling, W. 1986. Handbook of Indian foods and fibers of arid America. University of California Press. Berkeley, California.

Edwards, S. 1992. Observations on the Prehistory and Ecology of Grazing in California. Fremontia. Vol. 20: (1) 3-11 pp.

Elkins, E. 1992. Sheep Trails to California. Fedco Reporter.

Emiliani, E. 1992. Planet Earth: Cosmology, Geology and the Evolution of Life and the Environment. Cambridge Press. Wellesley, Massachusetts.

Evans, E. and T. Seastedt. 1995. The relation of phytophagous invertebrates and rangeland plants. Pp. 580-634. In: D. Bedunah and R. Sosebee (eds.). *Wildland Plants: Physiological Ecology and Developmental Morphology.* Society for Range Management. Denver, Colorado.

Eviner, V. and F. Chapin III. 2001. Plant species provide vital ecosystem functions for sustainable agriculture, rangeland management and restoration. Pp. 54-59. California Agriculture, Volume 55, Number 6. Oakland, California.

Felger, R. and M. Moser. 1974. Seri Indian Pharmacopia. Economic Botany 28(4): 414-436.

Fincher, T. 1997. Dung Beetles. Noble Foundation Ag News and Views. Volume 15, Number 10. Noble Foundation. Ardmore, Oklahoma.

Frank, D., S. McNaughton, and B. Tracy. 1998. The ecology of the earth's grazing ecosystems. *Bioscience* 48:513-521.

Franzluebbers, A., J. Stuedemann, and H. Schomberg. 2000. Spatial distribution of soil carbon and nitrogen pools under grazed tall fescue. *Soil Sci Soc Am J* 64:635-639.

Franzluebbers, A., J. Stuedemann, and S. Wilkinson. 2001. Bermudagrass Management in the Southern Piedmont USA: I. Soil and surface residue carbon and sulfur. *Soil Sci Soc Am J* 65:834-841.

George, M., G. Nader, N. McDougald, M. Connor and B. Frost. 2001. Annual Rangeland Forage Quality. Publication 8022. California Rangelands Research and Information Center. University of California Davis. Davis, California.

George, M., J. Bartolome, N. McDougald, M. Connor, C. Vaughn and G. Markegard. 2001. Annual Range Forage Production. Publication 8018. California Rangelands - Research and Information Center. University of California, Davis. Davis, California.

Griffith, C. 2002. Sustainable Grazing for Profit. Kerr Center for Sustainable Agriculture, 2002 Proceedings. Poteau, Oklahoma. Pp. 128-130.

GSA. 2004. Land and Buildings Owned by the Federal Government. U.S. General Services Administration. California Capital Hill Bulletin, Volume 11, Bulletin 15. Washington, D.C.

Hart, R. 2001. Plant biodiversity on shortgrass steppe after 55 years of zero, light, moderate, or heavy cattle grazing. *Plant Ecol* 155:111-118.

Heady, H. 1977. Valley Grasslands, pp 491-514, In: M.G. Barbour and J. Major (Editors), Terrestrial Vegetation of California. John Wiley and Sons. New York, New York.

Heady, H. and R. Child. 1994. Rangeland Ecology and Management. Westview Press. Boulder, Colorado.

Hewitt, G. and Onsager, J. 1982. Grasshoppers: yesterday, today and forever. Rangelands 4: 207-209.

Hobbs, R. (1991). Disturbance - a precursor to weed invasion in native vegetation. Plant Protection Quarterly 6:99-104.

Holechek, J., R. Pieper and C. Herbel. 1989. Range Management: Principles and Practices. Prentice Hall, Pp. 45-64. Englewood Cliffs, New Jersey.

Kent, D. 1994. Designing Wetlands for Wildlife. Chapter 13. In: Applied Wetlands Science and Technology. CRC Press: Boca Raton, Florida.

Kruger, K. and C. Scholtz. 1997. Lethal and sub-lethal effects of Ivermectin on the dung-breeding beetles Euoniticellus intermedius and Onitis alexis (Coleoptera, Scarabaeidae). Agriculture, Ecosystems & Environment. Pp. 123-131. Volume 61, Issues 2-3.

Lal, R., J. Kimble, R. Follett, and B. Stewart (eds.). 1998. *Soil Processes and the Carbon Cycle.* CRC Press: Boca Raton, Florida.

Larson, R., W. Krueger, M. George, M. Barrington, J. Buckhouse and D. Johnson. 1998. Viewpoint: Livestock influences on riparian zones and fish habitat: Literature classification. J. Range Manage. 51: 661-664.

Lewis, H. 1973. Patterns of Indian Burning in California: Ecology and Ethnohistory. Lowell John Bean (ed.), Ballena Anthropological Papers. Vol. 1. Ramona, California: Ballena Press. Reprinted on Pp. 55-116 in Thomas C. Blackburn and Kat Anderson (eds.). Before the Wilderness: Environmental Management by Native Californians. Menlo Park, California.

Liffmann, R., L. Hunsinger and L. Forero. 2000. To ranch or not to ranch: Home on the urban range ?. Journal of Range Management 53: 362-370 pp.

Lockwood, J. and W. Kemp. 1987. Probabilities of rangeland grasshopper outbreaks in Wyoming counties. Bulletin B-896. University of Wyoming - Experiment Station. Laramie, Wyoming. 17 pp.

Lowrance, R., L. Altier, J. Newbold, R. Schnabel, P. Groffman, J. Denver, D. Correll, J. Gilliam, J. Robinson, R. Brinsfield, K. Staver, W. Lucas and A. Todd. 1995. Water Quality Functions of Riparian Forest Buffer Systems in the Chesapeake Bay Watershed. U.S. Environmental Protection Agency. Washington, D.C. EPA 903-R-95-004/CBP/TRS 134/95.

Maly, K. and B. Wilcox. 2000. A short history of cattle and range management in Hawaii. Rangelands 22: 21-23.

Menzel, R., E. Rhoades, A. Olness and S. Smith. 1978. Variability of annual nutrient and sediment discharges in runoff from Oklahoma cropland and rangeland. J. Environ Quality. 7:401-406.

Meyer, D. 1984. Processing, Utilization and Economics of Mesquite Pods. Swiss Federal Institute of Technology. Zurich, Switzerland. 159pp.

Milchunas, D., W. Lauenroth, and I. Burke. 1998. Livestock grazing: Animal and plant biodiversity of shortgrass steppe and the relationship to ecosystem function. *Oikos* 83:65-74.

Mitsch, W. 1992. Landscape design and the role of created, restored, and natural riparian wetlands in controlling nonpoint source pollution. Ecological Eng. 1:27-47.

Mitsch, W, and J. Gosselink. 1993. Wetlands. 2nd Edition. Von Nostrand Reinhold. New York, New York.

Moseley, J. 2000. The Poop on Dung Beetles. Cattleman's Newsletter. Volume 3, Number 1. Red River Valley Cattleman's Association. Powderly, Texas.

Munz, P. and D. Keck. 1959 A California Flora, 1681 pp. University of California Press. Berkeley, California.

Nabhan, G. 1982. The Desert Smells Like Rain. North Point Press. San Francisco, California. 148pp.

Nabhan, G. A. Rea, K. Reichardt, E. Melink and C. Hutchinson. 1982. Papago influence on habitat and biotic diversity: Quitovac oasis ethnoecology. Journal of Ethnoecology 2: 124-143.

Nabhan, G. 1985. Gathering in the Desert. University of Arizona Press. Tucson, Arizona. 209pp.

Nuzum, R. 2005. Outfencing streams and reservoirs; Long-term management implications; Leasing land for livestock grazing. Personal Experience -- Manager, Watershed and Lands Department. Contra Costa Water District. Concord, California.

Olness, A., S. Smith, E. Rhoades and R. Menzel. 1975. Nutrient and sediment discharge from agricultural watersheds in Oklahoma. J. Environ. Quality 4:331-336.

Onsager, J. 2000. Suppression of grasshoppers in the Great Plains through grazing management. Journal of Range Management 53(6): 592-602.

Ortiz, B. 1991. It Will Live Forever: Traditional Yosemite Indian Acorn Preparation. Heyday Books. Berkeley, California. 148pp.

Oosting, H. 1956. The study of plant communities. W.H. Freeman and Co. San Francisco, California. 440pp.

Owens, L., W. Edwards and R. Van Keuren. 1998 Budget of non-nitrogen nutrients in a high fertility pasture ecosystem. Agric. Ecosyst. Env. 70: 7-18.

Pyne, S. 1982. Fire in America: A Cultural History of Wildland and Rural Fire. Princeton University Press. Princeton, New Jersey.

Pyne, S. 1995. World of Fire: The Culture of Fire on Earth. Henry Holt and Company. New York, New York.

Pickett, S. and P. White. 1985. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press. Orland, Florida.

Posey, D. 1985. Indigenous management of tropical forest ecosystems: The case of the Kayapo Indians of the Brazilian Amazon. Agroforestry Systems 3(2): 139-158.

Richardson, P. and D. Richardson. 1998. Dung Beetles: The Carbon Conveyor between Ungulates and Earthworms. Society for Ecological Restoration International. Texas Section. Austin, Texas.

Ritter, D. 1986. Process Geomorphology. Wm. C. Brown, Publishers. Dubuque, Iowa. 579 pp.

Robbins, W. 1940. Alien plants growing in cultivation in California. Bulletin 637. University of California, College of Agriculture. Agriculture Experiment Station. Berkeley, California.

Sanderson, M., B. Tracy, R. Skinner, D. Gustine and R. Byers. 2001. Changes in the plant species composition of northeastern grazing lands during the 20th century. Pp. 365-373. In *Proceedings of the first National Conference on Grazing Lands,* 5-8 December 2000. Las Vegas, Nevada.

Shipek, F. 1989. An example of intensive plant husbandry: the Kumeyaay of southern California. Pp. 159-170. In D. Harris and G. Hillman editors. Foraging and Farming. Unwin Hyman. London, England.

Stallings, J. 1957. Soil Conservation. Prentice-Hall. Englewood Cliffs, New Jersey.

Stechman, J., Montgomery Watson and Brady and Associates, Inc. 1996. Agriculture Technical Report. Los Vaqueros Resource Management Plan. Contra Costa Water District. Concord, California.

Stewart, E. 2005. Interdependence of low and high elevation grazing systems in California. Personal Communication. Senior Watershed Resource Specialist. Los Vaqueros Watershed. Contra Costa Water District. Concord, California.

Sulak, A. and L. Huntsinger. 2002. The importance of federal grazing allotments to Central Sierran Oak-Woodland Permittees: A First Approximation. USDA Forest Service. General Technical Report PSW-GTR-184. Pacific Southwest Forest and Range Experiment Station. Berkeley, California.

Thomas, M. 2001. Dung Beetle Benefits in the Pasture Ecosystem. National Sustainable Agricultural Information Service. Fayetteville, Arkansas.

Thurow, T. 1991. Hydrology and erosion. Pp. 141-160. In R. Heitschmidt and J. Stuth (eds). *Grazing Management: An Ecological Perspective.* Timber Press: Portland, Oregon

Tracy, B. and M. Sanderson. 2000. Patterns of plant species richness in pasture lands of the northeast United States. *Plant Ecol* 149:169-180.

University of Michigan Soils Lecture. 2004. Soils, Weathering, and Nutrients. University of Michigan. Ann Arbor, Michigan.

U.S. Department of Agriculture – California Agricultural Statistical Service (USDA-CASS). 2004. California Livestock Review. Sacramento, California.

U.S. Department of Agriculture – National Agricultural Statistics Service (USDA-NASS). 2001 USDA published estimates database. National Agricultural Statistics Service, U.S. Department of Agriculture. Washington, D.C.

U.S. Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS). 1997a. National Resources Inventory. Natural Resources Conservation Service. U.S. Department of Agriculture. Washington, D.C.

Vallentine, J. 1990. *Grazing Management.* Academic Press: San Diego, California.

Weaver, J. and F. Clements. 1938. Plant Ecology, 601 pp. McGraw-Hill. New York, New York.

Whigham, D., C. Chitterling and B. Palmer. 1988. Impacts of freshwater wetlands on water quality. Environmental Management 12(5): 663-671

White, K. 1967. Native bunchgrass (Stipa pulchra) on Hastings Reservation. California Ecology 48:949-955.

Whitehead, D. 1995. Grassland Nitrogen. CAB International. Wallingford, United Kingdom

Wilkes, C. 1845. Narrative to the United States exploring expedition during the years 1838, 1839, 1840, 1841, and 1842. 5 vols. Lea and Blanchard. Philadelphia, Pennsylvania.

Williams, G. 1997. American Indian Use of Fire in Ecosystems: Thousands of Years of Managing Landscapes. Presented at the American Ecological Society annual meeting in Albuquerque, New Mexico in 1997. Revised in 1998.

Wright, H. and A. Bailey. 1982. *Fire Ecology: United States and Southern Canada.* John Wiley & Sons. New York, New York. Chapter 16.

Wright, H. and A. Bailey. 1982. Chapter 5, Grasslands. Pp. 80-137 In: Fire Ecology – United States and Canada. John Wiley. New York, New York.