Rangeland Ecology and Management

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Westview Press

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TO RUTH,
whose excitement and persistence at becoming
a range person has pushed this work to completion

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Contents

Preface

Rangeland Ecology and Management focuses on the ecology of rangeland grazing, practical management of animals, and vegetational manipulation. Part Four brings these together in the context of decision making for damaged land, riparian and water conservation, multiple-use, and modeling.

The reader will find scattered paragraphs taken from *Rangeland Management*, published in 1975, but this writing is more than a revision of that book. In 18 years, rangeland resource ecology has seen new principles in defoliation effects, added fire to its understanding, and again engaged in theoretical examination of succession, stability, and range condition. Animal numbers and their distribution continue to be cardinal principles of management. Grazing management of wild and domestic species, separately or together, gains in attention. Seasonal livestock management has bypassed rest-rotation toward short-duration systems and may finally come to rest on flexible schedules that meet the requirements of each location and manager.

Rangeland management has responded to the environmental movement with less application of machines, herbicides, fertilizers, and seeding of exotics. More prescribed burning, biocontrol measures, plant breeding, seeding of native species, and knowledgeable worldwide rangeland management have occurred. The present rangeland programs on the reclamation of damaged land, riparian healing, reducing water and air pollution, gaining user acceptance of multiple-use, and modeling were only in distant sight in 1975. The result is an increase in chapters, from 21 in 1975, to 31. Rangeland resource management may not be a third greater since 1975, but in our opinion everything in the field has changed in that time. We have attempted to review those changes, including a moderate view of controversy, for the benefit of all those interested in the rangeland resources.

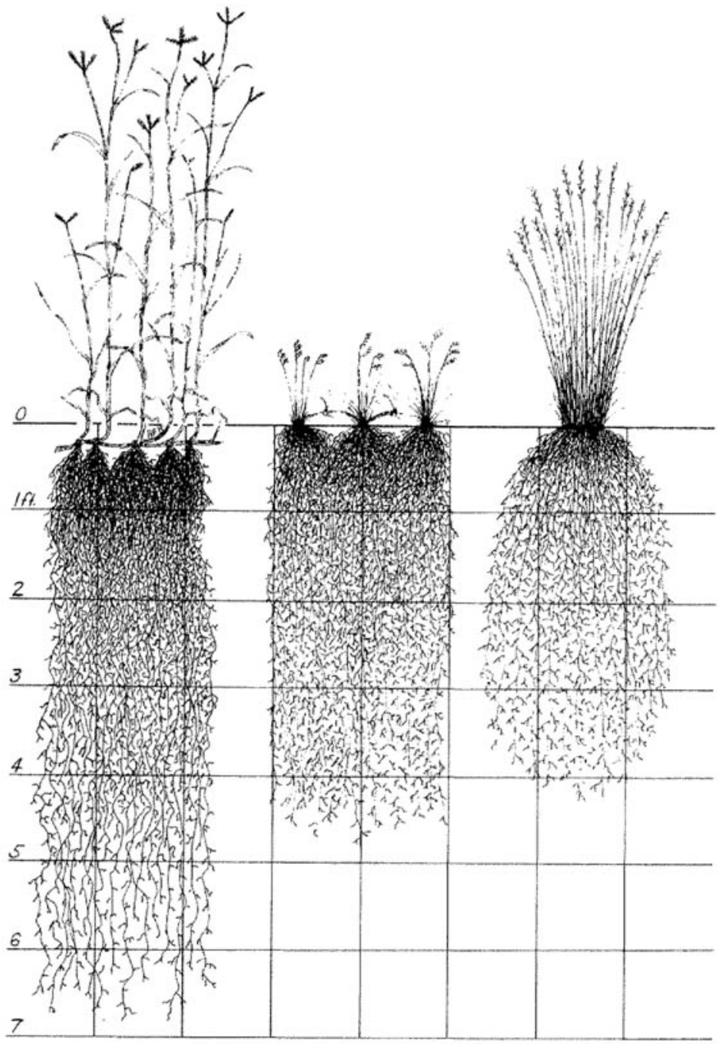
Many new names of plants and animals have appeared since 1975. These are cited as the various authors used them; therefore, the reader is referred to Appendix One and Two where common names indicate changes in scientific names.

A book of this magnitude could not have been written without many contributors. Numerous persons have helped by their willingness to discuss what they believe and show what they are doing. We gratefully acknowledge that influence and want especially to mention W. A. Laycock, J. L. Dodd, E. J. DePuit, J. A. Bartolome, Barbara Allen-Diaz, and Lynn Huntsinger. Bill Laycock offered suggestions on the whole manuscript. Ruth Heady spent many days editing, proofreading, and checking literature citations. (She disclaims responsibility for any errors.) USDA-ARS has supported the effort through approval of the use of word processing equipment and the grant of time to the second author. Our wives, Ruth and Carla, have been supportive, even through missed celebrations of birthdays and anniversaries. We thank them all.

Harold F. Heady
R. Dennis Child

PART ONE

Grazing Ecology



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Rangeland Conservation

Rangeland occupies approximately 51 percent (6.7 billion ha) of the earth's land surface (World Resources Institute 1986). One billion acres (404 million ha) of rangelands, pastures, and woodlands in the United States provide forage and habitat for some 70 million cattle, 20 million deer, 8 million sheep, half a million pronghorn, 400,000 elk, 55,000 wild horses and burros, and many other animals (Evans 1990). All areas produce water and recreational facilities. Rangeland supplies forage for herbivores; additional products such as minerals, construction materials, wildlife, medicines, chemicals, fuel; and intangible values including areas for the preservation of endangered species, anthropological sites, recreational activities, and wilderness. These land-uses as a group are often mentioned as the multiple-uses. Competition and controversy exist over their relative values and coordinated management. The choice among them for the use of public land is as often determined by social preference and judicial-political pressures, as by their economic and physical-biological attributes.

RANGELAND DEFINED

Rangeland is a type of land that supports different vegetation types including shrublands such as deserts and chaparral, grasslands, steppes, woodlands, temporarily treeless areas in forests, and wherever dry, sandy, rocky, saline, or wet soils, and steep topography preclude the growing of commercial farm and timber crops. Rangeland vegetation may be naturally stable or temporarily derived from other types of vegetation, especially following fire, timber harvest, brush clearing, or abandonment from cultivation. Weed and brush control, seeding, and fertilization of rangeland are infrequently applied practices.

The relative importance of different rangeland uses change, giving rise to a second definition that is based on kind of use, usually equated with livestock grazing. Historically, this was the accepted definition. For example, some rangeland is livestock summer range, or another area is deer winter range. Boundaries among the various uses change and many uses are made of the same rangeland. This book does not refer to **range** or **rangeland** as a kind of use.

The second definition is the one employed by those with an overriding interest in livestock grazing and by those who are derogatory of livestock grazing, especially on the public lands. Range research and professional practice have fostered this view through concentration on effects of livestock on vegetation and soil and on land treatments aimed at improving livestock production.

The dual definitions have important implications in budgeting, personnel selection and promotions, relationships among user organizations, and cost-effectiveness of land management. The second definition pits the livestock producer against other users; the first considers all the users in coordinated land-use decisions.

RANGE MANAGEMENT DEFINED

Range management is a discipline and an art that skillfully applies an organized body of knowledge accumulated by **range science and practical experience** for two purposes: (1) protection, improvement, and continued welfare of the basic resources, which in many situations include soils, vegetation, endangered plants and animals, wilderness, water, and historical sites; and (2) optimum production of goods and services in combinations needed by society (Fig.1-1). The range management profession places emphasis on ecological understanding such as that shown in Figure 1-1 and the following: (adapted from Joyce, 1989)

- Determining suitability of vegetation for multiple-uses
- Designing and implementing vegetation improvements
- Understanding social and economic effects of alternatives
- Controlling range pests and undesirable vegetation
- Determining multiple-use carrying capacities
- Eliminating soil erosion and protecting soil stability
- Reclaiming soil and vegetation on disturbed areas
- Designing and controlling livestock grazing systems
- Coordinating activities with other land resource managers
- Protecting and maintaining environmental quality
- Mediating land-use conflicts
- Furnishing information to policy makers

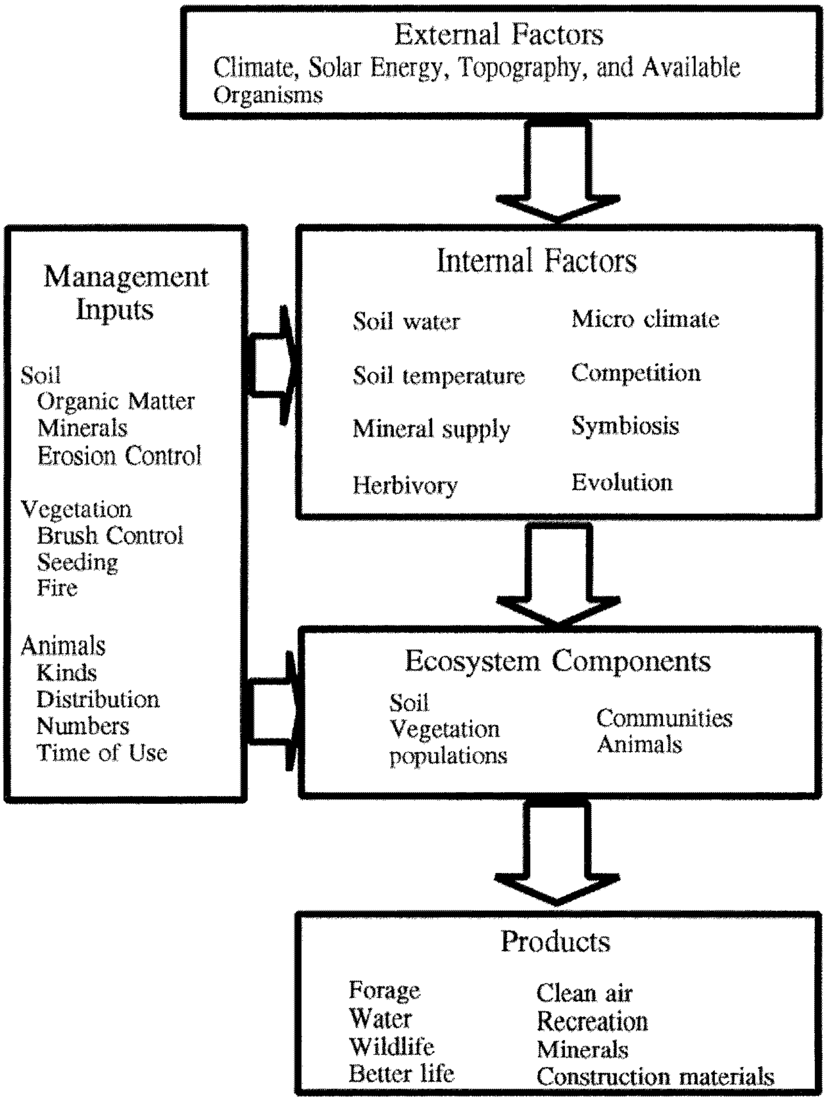

Figure 1-1 Rangeland ecosystems and management.

Management of rangeland requires selection of alternative techniques for optimum production of goods and services with no resource damage. No single set of management practices has ever been found to achieve management goals on rangeland. Ecological principles underlie most of the decisions made by the range manager because of the diversity of natural and humanly disturbed ecosystems.

The use of different management strategies is dependent upon management goals and objectives as well as the ecological potential of the rangeland in question. The planning and application of the many alternatives has come to be known as **holistic resource management** (Savory 1988). Ideal holistic management requires renewal and sustaining of natural resources, and elimination of destructive use by shortterm mining of vegetation and soil. While emphasis is often placed on effects and management of domestic animals, **the overriding goal is rangeland resource rehabilitation, protection, and management for multiple objectives including biological diversity, preservation, and sustainable development for people.**

THE RANGELAND ECOSYSTEM

Rangeland systems consist of many interacting environmental forces, local combinations of organisms, and the impacts of use by an increasing number of people. These systems remain primarily under the control of the overall environment, although use and management of rangeland ecosystems alter populations of organisms and change the rate of physical and biological inputs (Fig. 1-1).

Rangeland Development

The topmost box in Figure 1-1 depicts the interacting state factors of Jenny (1941). He suggested that soil is a function of parent material, relief, climate, and organisms. Over time, well-developed or mature soils result. Major (1951) applied Jenny's concept to vegetation and developed the thesis that vegetation depends upon the same state factors as does soil. **Primary succession is the development from pioneer to relatively stable communities of plants and animals beginning on raw parent material.** Mature soil and climax communities continue to be located at specific topographic places on particular physiographic bases and to receive an energy combination the universe provides for each spot. Jenny (1958) called the wide variation in natural ecosystems **landscapes**. Other terms that apply to the homogeneous units within landscapes on rangeland are **habitat types** (Daubenmire 1970), **range sites** (Dyksterhuis

1949), and **ecological sites** (Jacoby 1989). Landscape systems are on a complicated spatial scale because each range site or location, even a square decimeter or smaller, has its separate set of organisms, inputs, and responses. These vary continuously through space as well as time. Two examples are shown in Figure 1-2 of rangeland deterioration and improvement.

Rangeland Deterioration

The human rangeland resource user entered this system after it was well developed. Most areas had mature soils and climax vegetation, only temporarily set back because of occasional natural disturbances. The new land-users in the late 1800s and early 1900s destroyed the natural grasslands to make room for food crops, harvested timber for fuel and shelter, and replaced the large wild herbivores with domestic animals. Too many poorly managed animals overgrazed rangelands, causing deterioration of vegetation through several commonly accepted stages (Fig. 1-2). The most palatable plant species were selected first, continually grazed, and closely defoliated; this practice reduced plant vigor, lessened seed production, and eventually, caused plant death. Usually the space vacated by desirable species became the expanded home of less palatable and nutritious species. If overgrazing continued, these species gave way to annual invaders, many of which were weeds introduced from other continents. The palatable species in the pioneer successional stages became rare, and continued overgrazing reduced the invaders. Deteriorated rangelands resulted in ever-widening patches of totally bare soil, beginning where animals naturally congregated. This process of ecosystem destruction occurs worldwide and is one cause of **desertification.**

Disappearance of soil-holding mulch and plant roots permitted erosion, which further destroyed the land. Accelerated erosion is characteristic of overgrazing. Except on steep slopes and fragile soils, erosion came after considerable vegetational deterioration. In Figure 1-2, deterioration and improvement are shown for a sequence that moves regularly away from and toward stability and another that shows irregular change with various stable combinations of species.

An extensive summary of range problems in the western United States by the United States Forest Service (1936) established the fact that overgrazing had already destroyed more than half of the range forage resources and at that time deterioration was continuing on three-fourths of all rangeland. Little more than 75 years of high livestock numbers, uncontrolled grazing on public lands, and lack of knowledge or care for

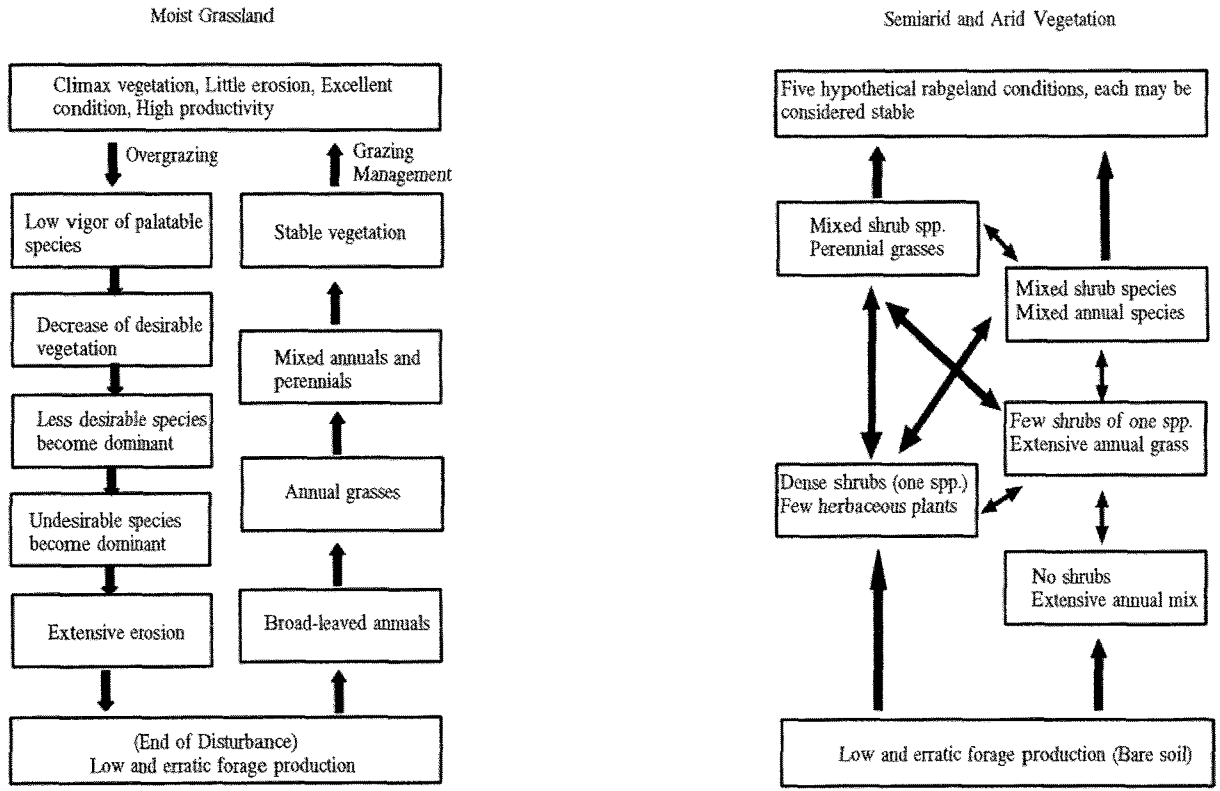

Figure 1-2 Two examples of deterioration and secondary succession or vegetative change in rangeland ecosystems.

the land mainly caused the destruction. Overuse of the land was fostered by society and approved by government; it was a benevolent and necessary policy for westward expansion of the United States. In addition, extensive droughts and drastic price fluctuations combined to cause periodic presence of surplus cattle and sheep on the western ranges. Sufficient concern by the 1930s resulted in efforts to regulate livestock grazing on western public rangelands to reduce erosion and rehabilitate the national rangeland resources.

The percentage of rangeland in poor condition decreased from 36 percent to 18 percent from 1936 to 1984 (CAST 1986). During the same period the percentage in good to excellent condition increased from 16 to 36 percent. From 1960 to 1988 numbers of pronghorn, deer, bighorn sheep, elk, and moose have shown dramatic increases on public rangelands in the presence of livestock grazing (Bureau Land Management 1989). **Perhaps as much as 60 percent of the Nation's rangeland is in stable condition. The western rangelands as a whole have a denser cover of vegetation and less erosion in 1990 than they had in 1890. Accomplishments are many but there is still improvement to be made.**

Rangeland Improvement

The range manager may begin efforts to halt destructive processes and increase yield at any stage of range condition (Fig. 1-2), because the primary ecosystem is seldom completely destroyed. Secondary plant succession often begins with broad-leaved annuals, changes to dominance of annual grasses, becomes a mixture of perennials and annuals, and finally returns to perennial vegetation. In the Mediterranean-type annual grassland, annuals dominate all stages of change. Sampson (1919) was the first to describe these stages for grazing in forest openings, and his description of secondary succession following relief from overgrazing continues to be pertinent to management of rangelands. Clements (1916) is usually given credit for the foundation statements on plant succession. Many others have described patterns of species dominance and successional stages for numerous vegetation types. Gradually stages in secondary plant succession became the foundation of range condition evaluations (Dyksterhuis 1949). His suggested procedures have been used for several decades in the large grassland region of central North America. In the western states where perennial grasses are not the recognized dominant and major climax species, argument surrounds the concepts of range site and range condition as based on plant succession and climax (more in Chapter 10).

The orderly replacements of species in secondary succession is suggested in Figure 1-2. Because of variable site conditions, types of vegetation, evaluations by technicians, and management objectives, successional stages in semiarid and arid shrublands and others are not so clearcut and vegetation appears stable. The diagrams emphasize that grazing, as an ecological factor, causes major vegetational changes.

THE GRAZING FACTORS

Grazing of both wild and domestic animals exert an influence upon the productive rangeland systems by their defoliation of plants through eating and physical damage, by their digestive processes, and by their movements. Separation of this total influence into individual factors promotes an understanding of grazing impacts and fosters informed animal or grazing management. To use the grazing animals as tools to attain vegetational production goals, the manager must know the impact of grazing upon the ecosystem. Consideration of animals only as products is not enough.

Figure 1-3 shows reciprocal relationships between land and animals as arrows from vegetation through the grazing factors (large circle) to animals and from animals to vegetation. Grazing also affects the decomposers and the soil. The range manager has two sets of manipulator tools. One aims at controlling range vegetation by altering the grazing factors, and the other applies such items as seeds and fertilizers directly to the vegetation/soil complex.

Individual Effects of Grazing

When a grazing animal eats, it selects certain plants or plant parts and removes them to a definite degree or intensity. This event occurs at a specific season in the phenological development of the plant, and it may be repeated. Thus, grazing includes four aspects of defoliation: intensity, frequency, seasonality, and selectivity. Each of these factors influences the growth and reproduction of the plants differently, and hence, the vegetation being grazed. Animals can be managed to influence vegetation by changing their impact on the four defoliation factors and on their continual spatial rearrangement of minerals, plants, and other animals. For example, accumulations of minerals where animals bed stimulate some plant species more than others, and animals move plants whose seeds attach externally to their bodies or survive passage through their digestive tracts.

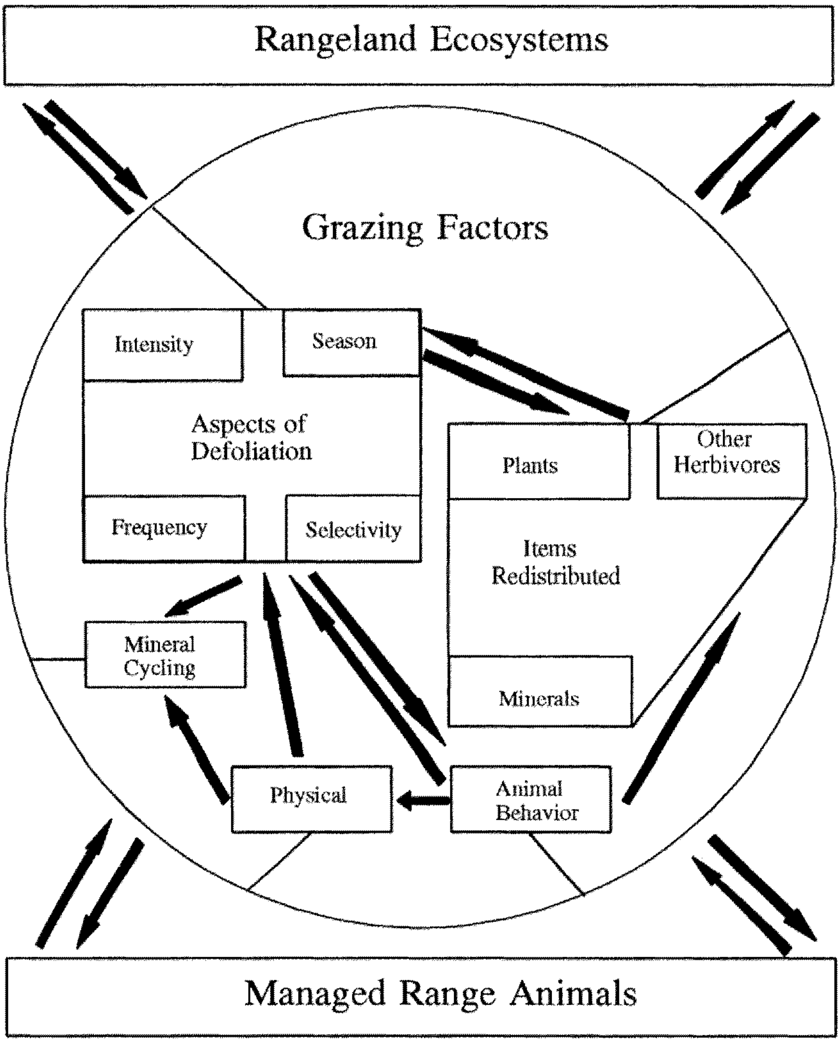

Figure 1-3 Interacting grazing factors by domestic and wild herbivores that influence rangeland ecosystems.

Each species of range herbivore has its own peculiar behavioral characteristics, some inherited--some learned, that determine part of its total impact on the habitat. Sheep often graze into the wind, many species prefer specific types of cover, some establish territories, and herding instincts are common. Sheep and cattle differ in their seasonal preference of riparian and upland sites. Animals exert a physical impact by trampling which damages plants, compacts soil, makes trails, churns soil surfaces, and covers seeds. Other physical actions by animals include the burrowing activities of rodents and the mixing of organic materials with mineral soil by invertebrates.

Slight to nearly complete decomposition of plant material in digestion by herbivores occurs rapidly and speeds mineral cycling. The reduced state of chemical bonds in dung and urine makes the minerals more quickly available for use by plants and hence by another herbivore than are minerals from slowly decomposing, ungrazed plant materials.

Effects of Grazing as a Whole

The grazing factors are shown in Figure 1-3 as a highly complex set of interacting processes. One factor of defoliation can hardly happen without the others. Cycling of minerals depends upon defoliation, but the recycled minerals influence grazing only after being returned to the soil and reabsorbed by plants.

Range managers have few data on many individual relationships in the grazing process. In general, the total grazing influence, or the large circle in Figure 1-3, has been the center of attention and the separate factor operation within the grazing process has been minimized. Studies of individual factors have concentrated on animal response. For example, data on the influence of forage selectivity on the nutrition of domestic animals can be found for more situations than can data on vegetational responses to selective grazing.

It is well to keep in mind that every animal is always a whole animal, exerting the different grazing impacts at the same time. A cow, for example, tramples plants while selectively grazing forages to a certain intensity. Thus its grazing effects are confounded. Separation of grazing factors is important because each animal species grazes and behaves differently, to which the vegetational response varies. Better understanding of these various aspects of grazing gives knowledge useful to the manager who must make decisions about kinds of animals, stocking rates, seasonal grazing, and many other range inputs.

The approach taken in Figures 1-2 and 1-3 is one of showing the importance of the separate rangeland ecosystem elements and their relationships with each other. This is an analysis procedure. Actually analysis and synthesis in rangeland management should be growing as twins. However, analysis is by far the most frequent approach. Pulling apart is far easier than putting together. Analysis is subject to greater quantification and therefore is often more scientifically respectable than synthesis. One objective in this book is to present both the accumulated facts and principles on grazing management and the synthesis of that information into managed ecosystems. The theory of holism gives emphasis to the synthesis half of the twin activities. The following chapters analyze these separate grazing factors and show how the information is useful in decision making on grazing management.

Analyzing the separate effects of grazing and suggesting the best management of grazing is only one part of range management. Other parts include the social and economic situation of the landowner, either public or private, and the tradeoffs among all the uses of the land. These change over time just as the vegetation changes. The range professional is rapidly coming to a point that requires analysis of the total system of biological production, the economics of that production, the sociological aspects of public and individual use of rangeland, and the political rules involved. The interactions and synthesis of all these factors are not yet attainable in nicely operating computer systems. Managers of rangeland operations who use systems for decision making usually do so at the subsystem level.

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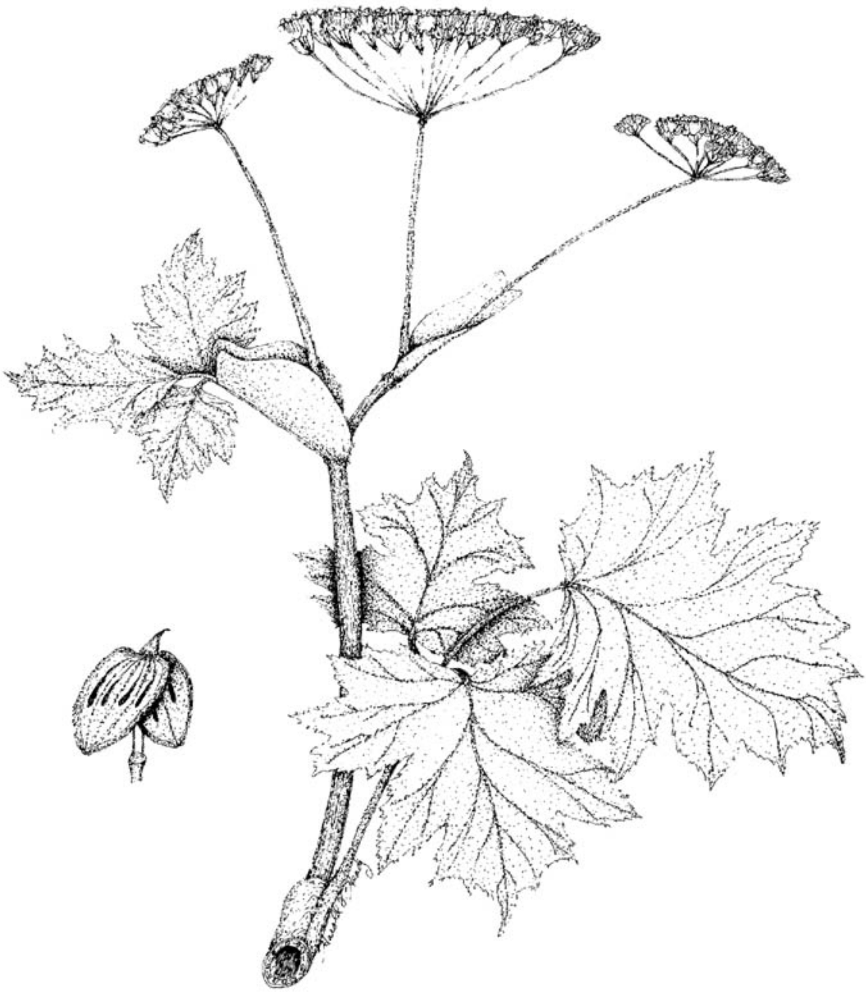

2

Defoliation

Defoliation is the removal of physiologically active material, as by herbivore eating, clipping, and trampling. A longterm and continuing question about defoliation is the proper use of rangelands; or how much and when grazing defoliation can take place without damaging the plant's physiological processes. The ultimate competitive success of the defoliated individual within the plant community is at stake. The grazing manager's purpose is to use a pattern of defoliation that maintains production levels and fosters better range conditions.

The plant requirements of proper use or defoliation have been the subject of two families of experiments extending over a century. The first combines grazing trials with variable stocking rates on range pastures that are grazed yearlong or in a vast variety of seasonal schedules. The second family is the response of plant biomass and total nonstructural carbohydrates (TNC) levels to a wide array of simulated grazings by clipping at different intensities, frequencies, and seasons.

Both types of research have their disadvantages. The grazed pastures were seldom uniform and costs have been great. Which individual plants were grazed, how severely, and how frequently were more often estimated than measured. The clipping treatments were more severe than grazing. Those that determined changes in chemical contents, emphasized the percentage content, not the quantity of plant foods that arrived or left the food storage pools. Critical levels and timeliness of food sources and transport processes within the plants became known for only a few species. Usually little attention was given to the plant's competitive ability or to the environmental factors such as water stress.

The large body of clipping and grazing data and experiences unquestionably tells us that plants, plant communities, and vegetational regions differ greatly in their ability to withstand defoliation and maintain their livelihood. Those with high grazing tolerance may have attained it through evolutionary development of physiological and morphological adaptations.

The controversial grazing optimization hypothesis states that annual net primary productivity (ANPP) increases when herbivory increases. Observations of increased tillering by grasses and shrub sprouting when they are defoliated would seem to substantiate that hypothesis. However, a light clipping when moisture and temperature are adequate for regrowth usually has little influence on annual ANPP (Savelle and Heady 1970, Williamson et al 1989).

COEVOLUTION OF PLANTS AND ANIMALS

Plants and herbivores have evolved an interdependent relationship and tolerance in which defoliation is as much a part of the system as is the need for herbage by grazing animals. Natural selection operates both to provide herbivores with food and to permit growth and survival of plants. The fact that plants palatable to one kind of animal or another dominate the world's grasslands and commonly occur in shrublands and forests suggests that adaptive processes through natural selection operate to foster both the eater and the eaten.

Most forage plants have the capacity either for rapid replacement of green tissue or for grazing avoidance. Plants have developed such deterrents to grazing as high lignin content with low nutrient values as they mature, tannins, alkaloids, essential oils, organic acids, and other compounds that do not appear to have important roles in plant metabolism (Stuart-Hill and Mentis 1982). Other seemingly protective characteristics to tolerate or escape grazing include spines, high tensile strength, low growth, abundant seed, stolons, short periods of rapid growth, rhizomes, basal meristems, and carbohydrate storage. Evolution to accumulate silica may be a defense against herbivores (O'Reagain and Mentis 1989).

Herbivorous animals have developed such characteristics as chewing of cud, a rumen or cecum with digestion by microorganisms, use of a high volume of low-nutritive forages, mobility, seasonal breeding, and special mouth and teeth arrangements. The result has been vegetation tolerant to grazing by numerous large animals of several species, as in Africa and the central United States; and fewer herbivores on less tolerant vegetation, as in New Zealand and some mountain grasslands (Heady 1968).

Grazing and defoliation can get out of balance, as illustrated by overpopulation and overgrazing by either wild or domestic animals. Usually, it does not stay in balance for very long. The stresses from defoliation, either natural or human-caused, speed evolutionary processes and may severely damage the rangeland ecosystems for the short term.

DEFINITIONS

The range manager's aim is to reduce the damage from severe defoliation by controlling the amount, the time in relation to phenological development of the plant, the frequency if defoliation occurs more than once, and the selection of the grazed species (Alcock 1964).

Intensity of Defoliation

The proportion of the current year's forage production that is consumed or destroyed by grazing animals from a single plant, a species, or the vegetation is expressed in three different terms--defoliation intensity, use, and utilization. The early range management literature and much of today's favor "utilization." The glossary of range terms (Jacoby 1989) did not recognize "intensity of defoliation" and did not define "utilization" as referring to the harvested or destroyed biomass. In clipping experiments, "intensity" rather than "use" is the term that usually expresses the proportion of the plant weight or height that has been removed. In this book the three terms have the same definition.

In clipping experiments, where the investigator harvests and weighs the removed materials, the calculation of proportion of material removed depends upon some measurement of the remaining stubble. That measurement is most accurately determined by sacrifice of the whole plant. If animals harvest the forage, direct measurement is impossible and the investigator must rely upon measurements of ungrazed plants or on dietary factors to reconstruct the portion that has been eaten.

Because of these difficulties and the fact that plant regrowth begins from the material left unharvested, the use and proper use of rangeland forage is best defined in terms of the amount or length of herbage remaining on the plant. Commonly for grasses, it is expressed as the average stubble height or weight of plant materials per land unit. For shrubs, the length or amount of uneaten twig growth that remains on the plant after grazing or treatment is of critical importance to the plants. As grazing animals depend upon the amount of material removed and the plants upon the herbage remaining, it would seem that attention to plant residue after grazing is most important to managing the vegetation and material removed to managing animals.

Frequency of Defoliation

Frequency of herbage defoliation is the number of occurrences of herbage removal in a certain interval of time. In a clipping experiment, frequency might be expressed as weekly herbage removal to a constant stubble height occurring between certain dates. In grazing situations, frequency of defoliation becomes the rotation schedule for schemes that use large numbers of animals in small areas for short grazing periods. Repetition of defoliation, hence frequency, in longterm grazing is difficult to determine. The use of **frequency** in the sense used here should not be confused with the ecological usage: the ratio of units containing a species to the total number of units.

Clipping of container plants is the common procedure for separating effects of frequency from those of intensity of defoliation. For example, repeated clipping at the same stubble height but at different time intervals would hold intensity of defoliation constant and vary the frequency. By definition, intensity of defoliation does not differ as the interval of time between defoliations changes. Some studies describe an increasing number of clippings as greater intensity of herbage removal. Undoubtedly plants clipped more than once have less photosynthetic tissue than those clipped once and in this sense are subjected to increased intensity. However, intensity effects are confounded with frequency and seasonal effects. Only by careful attention to these concepts can adequate determinations of effects due to degree and timing of defoliations be distinguished. The separate effects indicate that more frequent defoliations result in a drop of carbohydrate reserves and less vigorous plant (Teague 1989 and many others). Frequency effects are of special importance to short-duration grazing.

Season of Defoliation

Season of defoliation is the time measured along the growth curve of the plant or vegetation when defoliation occurs. Some grasses and most forbs are highly susceptible to defoliation and lose vigor when active green tissue and meristems are removed at any time during the growing period. The meristems of shrub and broadleaved herb leaves are at the outside edges. Their removal stops further growth. Some grasses with basal meristems show little effect of leaf blade removal in terms of dry weight and seed produced. Sensitivity of many grass species to defoliation is highest when the flower stalks begin to develop and decreases rapidly as the plants approach maturity.

Growth patterns determined under field conditions are subject to much variation resulting from irregularities in weather. Average growth at certain calendar dates has advantages for managing livestock, but the value of a fixed date is minimal for prediction of phenological development in another year or location. Therefore, the investigator must define the growing cycle of the plants precisely in order to relate effects of herbage removal to plant development.

DETERMINING EFFECTS OF DEFOLIATION

Investigators in hundreds of experiments have used clipping, grazing, or both treatments to study effects of defoliation. While an extensive review of methods is not intended, a brief description of experimental techniques is needed to facilitate understanding of the results. (see Forage Supply Cycle in Figure 11-1 and in Chapter 16)

Clipping Studies

Clipping has been the principal technique used in the study of defoliation. Most investigators have applied clipping to single species grown in pots under fluctuating greenhouse or lath-house conditions. Controlled environment chambers have also been used. Other pot-type studies have depended upon the natural environment, with supplementary water supplied as needed. The substrate upon which the plants were grown has varied from closely controlled nutrient solutions and untreated but uniformly mixed soil in pots to planting in cultivated field plots. Growth conditions must be controlled and measured in laboratory and field if responses are to have predictive value for other situations.

Clipping treatments differ as much as growing conditions. Treatment variables include clipping height, time of first clipping, frequency of clipping, time of last clipping, and type of material removed. These variables have been defined by calendar dates, growth stages, and occasionally both items. For example, one study stipulates that plants be clipped to a defined stubble height every two weeks while another requires clipping only when regrowth reaches a certain height.

Measurements of plant response to clipping nearly always include dry weights of material removed and a final weight of crowns and roots at the end of treatments. Pots or boxes facilitate measurement of root responses because whole plants must be harvested. A pot contains all the roots; it contains only the roots of the plants treated; and these roots can be removed easily from the container and substrate. Other measurements include length, width, and thickness of various parts; color; degree of branching; reproductive responses; ratios of various plant parts; longevity; changes in plant form; vigor; and chemical composition.

A pot experiment that includes comparisons of three species, three intensities of defoliation, and three clipping frequency regimes, replicated five times, requires 135 pots plus control pots and replacements. This experiment entails a sizable effort but includes only a small portion of the possible permutations and needed information.

Although results are available from many clipping experiments, few are comparable and seldom test the same hypothesis. The general principles that regulate plant responses to defoliation remain unclear in many instances. A suggestion for procedural improvement specifies that the growth curve for an untreated set of plants be determined in each clipping experiment as the normal from which various defoliations cause deviations. Clipping of a new replicate set of previously unharvested plants at each 2-week interval throughout the growing season gives a measure of cumulated growth. The plotted data produces the typical normal growth curve (Fig. 2-1). At plant maturity, clipping the same replicates again (at the same stubble height as earlier clippings) measures regrowth. A third clipping at ground level gives stubble weights. The sum of these three weight measurements--accumulated growth, regrowth, and stubble weight--for each treatment date provides an estimate of total response from the first clipping. The data and curves provide a basis for evaluating various other treatments of intensity, frequency, and season of defoliation against the untreated phenological growth curve of the species.

Grazing Studies

Effects of defoliation by grazing animals have been studied in many experiments using several stocking rates. Usually these experiments specify grazing with a constant number of animals for a certain period of time or until a certain degree of forage utilization has been attained. Interpretations of degrees of defoliation usually depend upon the difference between measurements taken before and after grazing or inside and outside of small areas protected from grazing by cages. A glance at Figure 1-3 suggests the complexity of using grazing animals for the study of defoliation effects. Grazing animals confound all of the grazing factors so that the investigator cannot determine the relative importance of, for example, frequency and intensity of defoliation without the influence of trampling. Grazing periods of more than a few days give relatively inaccurate measures of frequency and season of defoliation. Grazing studies give excellent overall estimates of vegetational changes.

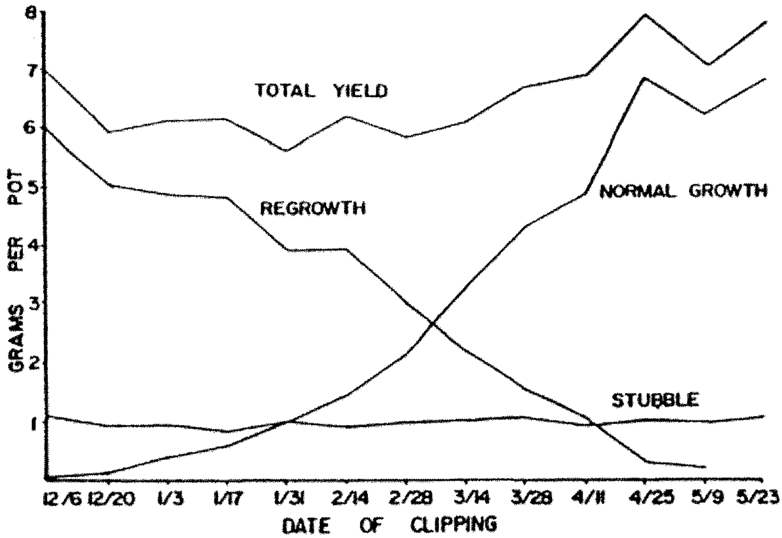

Figure 2-1 Mean oven-dry weights, in grams, of *Avena barbata* resulting from clipping a new set of replicates on each date to determine normal growth. On May 23, all plants were clipped to a 4-centimeter stubble height for measurement of regrowth and to the soil surface for stubble weights (Savelle and Heady 1970).

Effects of Clipping Versus Grazing

Several differences exist between the effects of grazing and clipping. Grazing selectively removes plant parts and individual plants in the vegetation and includes factors of pulling and nutrient cycling, while clipping tends to be uniform and severe (Hart and Balla 1982). Hand clipping did not closely approximate the effect of taking some mature stems and parts of leaves from the shrub *Acacia karroo* by goats (Teague 1988). Only with extremely heavy use by animals does an even stubble height develop. Grazing animals usually take repeated bites to harvest an individual plant, but the time interval between the bites may permit regrowth. Different animals graze by pulling, breaking, or biting at random heights whereas cutting with shears is uniform. Even with heavy continuous grazing of pastures, individual plants may escape defoliation for a time (Briske and Stuth 1982). Clipping treatments have tended to be at constant time intervals and at a uniformly severe intensity. If the amounts and kinds of foliage removed by clipping and grazing are the same, the effects of both are likely to be the same (Jameson 1963).

Responses of plants in grazing trials include the effects of competition, but many studies of clipped plants in containers do not. Therefore, clipping and grazing affect range vegetation differently; either may be the most damaging to the vegetation. Grazing animals do more than defoliate. They trample, move seeds and minerals about the landscape, and select what and where they eat. Clipping does not duplicate these effects on water and nutrient availability in the soil and decomposition of litter. Clipping should be considered as a means of studying the defoliational effects of grazing, not the whole set of grazing factors. In this context, clipping is a sensitive and valuable tool that can yield more information about defoliation alone than can a grazing trial.

EFFECTS OF DEFOLIATION ON PLANT MORPHOLOGY

Defoliation, including removal of perennial stems, alters normal structural changes that occur during the development of plants. Removal of terminal buds from young tree branches often causes several lateral buds to germinate, foliage to increase, and the tree to thicken. Hedging of browse plants by animals and development of an uneven underline of foliage on shrubs and trees attest to morphological responses by plants to herbage removal. Lawn mowing results in an increase in grass tillers, leaves, and percent of ground cover below the clipping height. New sprouts on *Chrysothamnus viscidiflorus* and *Symphoricarpos vaccinoides* were increased in number by clipping new growth at various intensities. They were shorter on the former species (Willard and McKell 1973). Tueller and Tower (1979) found that nonuse of *Purshia tridentata* resulted in an average reduction of 70 percent in annual branch and leaf growth. Grasses in the middle of improved pastures often have a short spreading form while those protected at the pasture edges are more upright.

Grass Morphogenesis

The number, locations, and activity of meristems, thus to some degree the morphology of the forage plants, are important to resprouting after grazing and fire. Tolerance to grazing is also related to the ability to reestablish foliage in the face of competition from nearby and often undefoliated plants, especially under conditions of water stress. Stress endurance and competitive effectiveness constitute critical and complex interactions that most clipping studies have not measured.

The growth unit of grasses is the phytomer. It consists of a node, the internode above, leaf sheath, leaf blade, and with or without an axillary bud and adventitious roots. There are several phytomers per tiller, and several tillers per plant (Fig. 2-2). Thus, the terminal meristems and buds are nearer the soil surface than many forbs with only terminal meristems. This suggests both avoidance and tolerance components of grass resistance to defoliation by large herbivores. The unit basis of the phytomer probably results in first choice call on photosynthates produced by that phytomer as well as contribution to the next developing phytomer on the tiller (Briske 1986).

The apical promeristem of a grass stem consists of an ever-expanding cone with cells being displaced laterally as the central plant enlarges by cell division. Organs such as leaves and spikelets arise as primordial ridges immediately below the apex. Each leaf extends vertically from a ridge to quickly enclose the shoot apex. Soon a meristematic collar separates leaf blade and sheath. Where leaf sheath and stem join, a node, and perhaps an axillary bud or adventitious roots, develop. Cell division at leaf collars and nodes ends early, and major apparent growth thereafter is by cell elongation. Of necessity, each new leaf forms above and inside the older leaves, and all remain rolled or folded together until elongation of the stem internodes separates them. Therefore, grass leaves originate in a linear sequence and expand in order by elongation (Fig. 2-3). The floral shoots may take 2 or 3 years to develop in some grasses (White 1977).

Tillering, germination of axillary buds, proliferates new vegetative and reproductive materials. For example, removal of the growing point stimulated axillary shoot growth in *Trichachne californica* when soil moisture was present (Cable 1982). Elongation of internodes elevates only fertile culms in some species, lengthens vegetative stems in others, and may do both in still different species. Height and display of foliage and inflorescence, arrangement of leaves, number of nodes, timing of the period of elongation, and perhaps size attained appear to be species characteristics (Rechenthin 1956). However, they can be altered. Defoliation by grazing and cutting changes architectural display of foliage and reproductive parts from taller, open arrangements to lower, compact, horizontal positions. Knowledge about the morphogenesis of species can be useful in designing grazing schedules. For example, *Bouteloua gracilis* has a high percentage (85 to 90) of the shoots being vegetative. Conversely *Andropogon hallii* has only 60 to 65 percent of vegetative shoots. Regrowth in *Bouteloua* comes rapidly after each bit of rain, but in the *Andropogon* regrowth was stopped with clipping in midsummer. This suggests that the former could be grazed continuously and the latter ungrazed after July (Sims et al 1973).

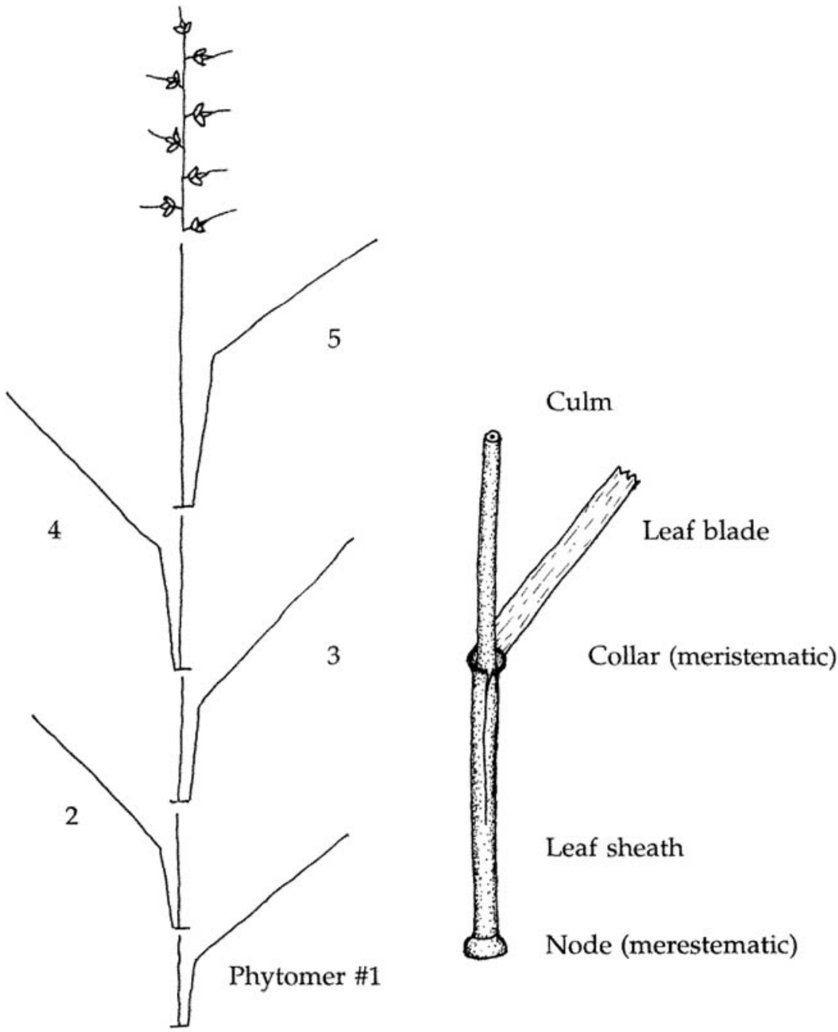

Figure 2.2 Stylized structure of a grass tiller showing five phytomers and the seed head. The parts of a phytomer are indicated on the right. (adapted from Briske 1986).

Initiation and Development of Culms

Major control of culm initiation and elongation in grasses apparently rests with the species. Branson (1953) suggested that one group of grasses maintains a high proportion of vegetative culms with growing points in or near the soil, another group has a high proportion of vegetative culms with elevated growing points early in the growth cycle, and the third group develops inflorescences on most stems. However, elevation of the fertile apices may be gradual for much of the growing period in one species or rapid in another following an early period with abundant leaf growth but little stem elongation. Examples of plants in three groups are:

Group I Infertile apices numerous and in or near the soil	**Group II Infertile apices numerous and soon above the soil**	**Group III Fertile culms more numerous than the infertile; apices elevation varied**
Andropogon gerardi	*Agropyron smithii*	*Agropyron desertorum*
Bouteloua gracilis	*Bromus inermis*	*Agropyron spicatum*
Buchloe dactyloides	*Panicum virgatum*	*Andropogon scoparius*
Hilaria belangeri	*Sorghastrum nutans*	*Bromus mollis*
Lolium perenne	*Sorghum halepense*	*Elymus canadensis*
Poa ampla	*Themeda triandra*	*Festuca octoflora*
Poa pratensis		*Hyparrhenia hirta*
Sitanion hystrix		Annual grasses
Stipa comata		
Tristachya hispida		

Defoliation effects are closely associated with removal of meristematic tissues. Frequently, growth of roots and culms has been inversely proportional to the intensity of clipping in experimental studies (Branson 1956). As intensity increases or stubble height becomes lower, the chances increase for apical meristems to be removed. However, Group I grasses and certain of the Group III species may be defoliated through much of the early growing periods without danger that the growing points will be removed. An example of the different responses that result from defoliation is given for *Agropyron desertorum* (Fig. 2-3) (Cook and Stoddart 1953).

Comparisons of three South African grasses illustrate extreme patterns in elevation of shoot apices (Booysen et al 1963). *Hyparrhenia hirta* buds initiate in the spring, and remain at low level until midsummer, when the apex becomes reproductive and the internodes elongate. Buds of

Tristachya hispida begin growth in the spring but remain close to the soil until the following spring, when the apices become reproductive. Growing points of *Themeda triandra* elevate in midsummer but do not become reproductive until the second summer. The growing points of *Themeda* are vulnerable to grazing for at least nine months, but repeated clipping or grazing tends to lower the apex height and to favor plants with self-protecting basal buds (Rethman 1971).

Clipping position	Type of subsequent growth
1 Below uppermost culm node while still in sheath	1 Only from axillary buds at culm base
2 Between seedhead and uppermost culm node	2 Culm continues to develop but is headless
3 Upper part of head removed	3 Culm continues to develop with part of an inflorescence
4 Leaves below collar; culm apex intact and enclosed in several sheaths	4 Culm and seedhead develop; leaves without blades
5 Leaves above collar; culm apex intact and enclosed in several sheaths	5 Culm and seedhead develop; leaves with stubby blades

Figure 2-3 Response to clipping position (Cook and Stoddart 1953).

When a culm enters the reproductive phase and begins to elongate, no new leaves will be produced. Removal of the apical meristem prevents further development of the culm and stimulates axillary buds at the base (Jewiss 1972). Grasses in general require a new culm if new leaves are to develop. *Andropogon scoparius* and *Bouteloua curtipendula* have 10 to 15 basal nodes with potential buds in the first 2.5 centimeters of culm, and others, for example, *Sorghastrum nutans* and *Agropyron cristatum*, as few as 2 to 4 such nodes.

Defoliation that removes the growing point and stimulates new tillers from rhizomes, stolons, and low buds on vertical stems does not necessarily result in greater biomass production. Total yield of *Avena barbata* may be little influenced by a single defoliation (Fig. 2-1).

Summer removal of the growing point may be too late in the season for regrowth of fertile culms (Sims et al 1971). Evidently late clipping and frequent clipping tend to reduce flowering and maintain plants in vegetative stages of growth. Maintenance of culmless vegetative growth by heavy grazing during the boot stage may be highly desirable for species such as *Sitanion hystrix* which have undesirable awns at maturity.

Many pasture management systems use frequent grazing and mowing to prevent flowering and resultant dormancy of the forage species. Normally, vegetative material has a higher nutritive value than has mature herbage. Many species resistant to defoliation (1) maintain vegetative buds in or close the soil surface, (2) do not elevate the apical meristems more than 2 or 3 centimeters until rapid elongation and flowering take place, (3) produce numerous fruiting stems, and (4) have the capacity to initiate abundant new culm development from basal buds.

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3

Physiological Effects of Defoliation

The good health of plants depends upon their ability to maintain normal physical and chemical processes. Many studies have measured effects of defoliation by determining changes in the percentage chemical composition of plant compounds, especially carbohydrates.

The term total nonstructural carbohydrates (TNC) refers to the group of carbohydrates commonly called food reserves that the green plants manufacture and use in growth and respiration. The compounds are soluble or readily changed to that form and are mainly dextrins, fructose, sucrose, and starch. The usual analysis procedure is by detergent analysis. TNCs are grouped because the kinds vary in proportion from one species to another and they may be converted from one kind to another between day and night and as the growing season progresses. TNC is preferred to the synonym "total available carbohydrates" (TAC) because "available" for what is not always clear. Not included are the structural carbohydrates, such as the cellulose compounds, which plants do not use in respiration, but are important in the morphological structure of plants. Herbivore nutrition depends in part upon microbial digestion of the structural carbohydrates.

THE CYCLE OF NONSTRUCTURAL CARBOHYDRATES

The concept that disappearance or persistence of grazed plants correlates with amount and percentage of TNC reserves has been propounded and reviewed many times. Overharvesting, either by cutting or grazing, generally reduces TNC in roots and perennial stem bases. However, quantities of TNC fluctuate through normal cycles in relation to growth stages of pasture species.

More or less summarizing the results of TNC analysis over many decades were the generalized seasonal cycles of TNC concentrations described for nine range species (4 shrubs, 3 forbs, 2 grasses) by Menke and Trlica (1981). **The cycles are variations on the succession of (1) gradual decline during the dormant season due to continued respiration; (2) a rapid decline with the onset of new growth, continuing until photosynthetic products become greater than immediate needs; and (3) a sharp rise during maturation and onset of dormancy.** For many species minimum amounts of stored TNC occur at initiation of growth and maximum amounts at the beginning of dormancy. In the absence of defoliation, period 2 may not be long and a second low in grasses may occur during flowering, suggesting that at those times it is important to schedule relief from grazing.

Some herbaceous species apparently store TNC during seed development while others are using reserves at that time. Storage in lower culms and roots normally occurs during maturity of the foliage and at a time when TNC in the leaves is declining. Fall regrowth reduced reserves in *Oryzopsis hymenoides, Stipa comata,* and *Sitanion hystrix* (Coyne and Cook 1970). Other variations from the general TNC cycle are related to species of plant, type of phenological cycle, part of the plant considered, site where the plant grows, and type of analysis.

TNC PRODUCTION AND PLANT GROWTH

Growth after defoliation has long been linked to pools or reserves of carbohydrates in roots, rhizomes, stem bases and other ungrazed portions of plants. Fluctuations in these concentrations have been used to explain plant responses to intensity, frequency, and season of defoliation; but these explanations do not account for the many irregularities and differences among the data. For example, both net photosynthesis and carbon allocation to synthesis of new photosynthetic tissue increased following defoliation of *Bouteloua gracilis* (Detling et al 1979). In a different study on the same species, Wilson (1984) reported in a 3-day growth test that only 13 percent of new root biomass came from stored TNC. Carbon gain and water loss rates in *Agropyron desertorum* and *Agropyron spicatum* foliage did not account for differences in grazing tolerance. Production and maintenance of photosynthetic tissue were more important (Nowak and Caldwell 1986). In other words, early physiological principles based on TNC indicating plant vigor and recovery after defoliation were oversimplifications.

Experiments with *Agropyron desertorum* and *A. spicatum* suggest that in most instances photosynthesis during growth outweighs stored carbohydrates as a source of energy for growth. The first carbohydrates produced are delivered to the critical meristems where that growth is attached (Richards 1986). Therefore it now appears that only the carbon reserves above the zones of cell division in the two grasses are immediately available to the shoot meristems. Thus, the major source of carbon for regrowth is current photosynthesis and the amount of regrowth is controlled by meristematic limitations. This is contrary to the earlier view that the potential of a plant to recover after defoliation depended upon abundant and quickly movable carbon reserves in the roots and stem bases.

The recent findings for grasses also give emphasis to location of node meristems and their germination characteristics. Those nodes morphologically nearest to the point of defoliation and to the initiation of new growth are the principal ones. Their initiation of growth in relation to apical dominance and other physiological controls are poorly understood. Effects of intensity and frequency of defoliating new growth are considerations in the designing of grazing schedules.

STIMULATION BY CLIPPING

On a basis of logic any defoliation of green tissue should reduce photosynthesis and thereby net primary production, but that is not always the result. A small degree of live herbage removal may stimulate one species to produce more tillers, leaves, branches, or seed but the same degree may severely reduce the size and growth rate in another.

Increased production at certain levels of defoliation have occurred with short grasses that have rhizomes and stolons and those that maintain growing points near the soil surface. Short grasses in Kansas produced more with light and moderate use than with no defoliation (Albertson et al 1953). Clipping of shortgrass range in Texas at 2-week intervals increased yield by 94 percent over one fall harvest (Eck et al 1975). Tainton et al (1970) found both increases and decreases in biomass production from clipping among 24 plant species in a review of 21 papers.

Removal of the terminal bud on shrub twigs often results in two or more branches and increased growth (Shepherd 1971) but less flower and fruit growth (Garrison 1953). *Coleogyne ramosissima,* when heavily browsed, increased twig production by a factor of 3.6 relative to the control plants and remained at that high production for at least 4 years (Provenza et al 1983).

Browse species in moist climates are favorably affected by moderate clipping in certain stages of growth. Lay (1965) showed that browse production increased on a number of species when 25 or 50 percent of the current year's growth was removed in either fall or winter. Garrison (1953) obtained similar results from *Purshia tridentata, Ceanothus velutinus,* *Chrysothamnus nauseosus, Holodiscus discolor,* and *Cercocarpus ledifolius.* Topping of tall *Purshia tridentata* plants to a 0.9-meter height increased yield of new growth for at least four years (Ferguson and Basile 1966).

DEFOLIATION AND COMPETITION

Most clipping studies are on plants in isolation and their immediate competitive environment is seldom considered. Highly important to rangeland use is new understanding that a defoliated plant may react as much to competition from surrounding nondefoliated individuals as to the biomass removed from it (Mueggler 1972, 1975; Archer and Detling 1984). Partial reduction of competition can offset adverse effects of heavy defoliation. **Plant recovery on rangeland must include both new plant tissue and favorable competitive position.** Shoot establishment is at least partly a result of the plant's competitive status. Competition and defoliation are confounded and their relative importance seldom measured. Species differ in response to each factor and the interaction between them (Caldwell and Richards 1986).

DEFOLIATION AND OVERGRAZING

Excessive and frequent defoliations in container and grazing studies have resulted in nearly complete exhaustion of stored TNC in roots and stem bases, resulting in loss of plant vigor and plant death. Defoliation approaching the time of normal late growing season accumulation magnified the effects. Generally, early clipping had little effect on food reserves at plant maturity. Therefore, severe continuous overgrazing is more likely the cause of vegetational deterioration than early growing season defoliations alone.

Moderate grazing and rotations of nongrazing periods increased the need to know how many days plants needed to recover during the growing season. Reestablishment of TNC reserves in roots and lower stem bases did not answer the question. Donart and Cook (1970) claimed that normal TNC levels of several species on mountainous summer range often were restored by the time regrowth had reached 20 percent of the expected total growth or within three weeks during the rapid growth period.

Recent studies have shortened the time that new growth depends upon or even uses food reserves. Replenishment begins when new leaves are still very small in the southern African shrub, *Acacia karroo* (Teague 1988). By using Carbon-14, Steinke (1975) determined that close clipping caused *Eragrostis curvula* to draw on reserves for initial regrowth but new growth after light clipping did not use reserves of carbon. In *Paspalum notatum* the normal growth of a new leaf depended upon stored TNC for only two or three days (Sampaio et al 1976). White (1973) in a review paper stated that apparently stored TNC affects regrowth for the first 2 to 7 days. **The regrowth from reserves is now thought to be only for a day or two until photosynthesis from new growth becomes independent of reserves (Caldwell et al 1981, Caldwell 1986).** The TNC pool in the above-ground parts of *Ceratoides lanata* was shown to be the equivalent of one day of photosynthetic carbon gain in favorable conditions (Caldwell 1984).

OTHER NUTRITIVE COMPONENTS

Defoliation influences other nutritive components of plants in addition to TNC. Herbaceous and woody species tend to lose crude protein, phosphorus, and other minerals but to gain in structural carbohydrates as the growing season progresses. Stimulation of new growth by clipping and grazing tends to retard maturity and to decrease the proportion of structural materials. Therefore, percentages of crude protein, phosphorus, and potassium, as well as TNC, tend to increase as intensity and frequency of defoliation increase. Clipping of *Agropyron spicatum* in the spring lowered fiber content and increased crude protein and phosphorus in fall growth (Pitt 1986). Harvesting of *Schizachyrium stoloniferum* in the fall gave highest yield but poorest quality feed. Spring and summer grazing year after year reduced vigor but gave higher quality forage (Kalmbacher et al 1986). Total amounts of these components on an area basis will be lower if biomass decreases more than the compensation resulting from their percentage increases.

YIELD AND VIGOR EFFECTS OF DEFOLIATION DURING GROWTH

Foliage removal has more influence on yield at certain seasons than at others. Low heights of grasses and short twig length in shrubs indicate that intensity of defoliation may have been high. Also indicated is low production of herbage. For example, Canfield (1939) reported the 10-year average yield of *Bouteloua eriopoda* as 9.8 grams per square meter when clipped at two-week intervals to the 2.5-centimeter height and 19.5 grams per square meter at the 5-centimenter height. One end-of-season clipping did not change the results at the 2.5-centimeter height but the yield nearly doubled when the clipping height was doubled. Other examples establish the severe effects of defoliation that removes a large portion of current growth too late for it to be replaced.

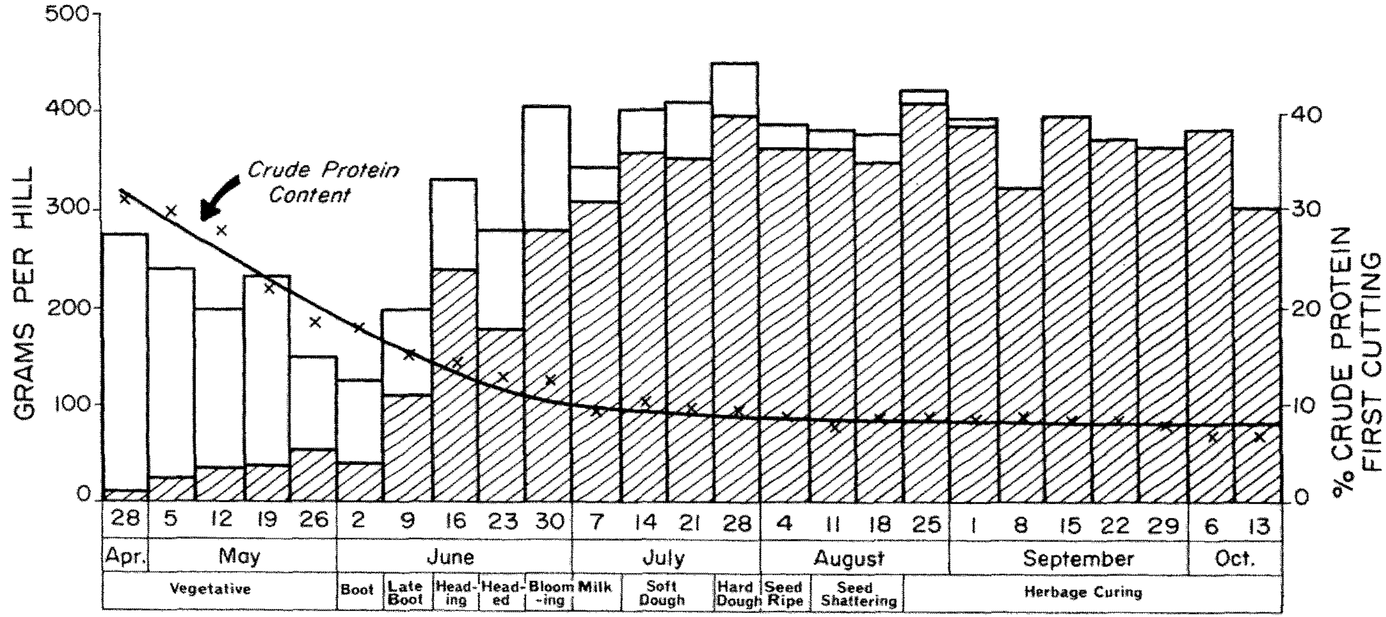

Figure 3-1 Yield at time of a single clipping (hatched bars), regrowth yield at plant maturity (plain bars), and crude protein content of *Elymus cinereus* in 1966 at bridger, Montana (Krall et al 1971).

Removal of 90 percent of the current growth from desert shrubs killed many of them. Even 50 percent removal in late spring and summer for three years caused significantly lower yield than that from unclipped plants. After seven years of no clipping, recovery in most species was proportional to degree of vigor deterioration during the three years of clipping (Cook 1971).

Defoliation effects on *Elymus cinereus* gradually became more severe with advancing growth until the late boot stage, after which time the combined yield of growth and regrowth increased to a high at flowering (Fig. 3-1). Single clippings that removed three-quarters of the foliage at boot stage also resulted in reduced yield the following year. Krall et al (1971) suggested that *Elymus cinereus* can be grazed prior to the boot stage if no more than 50 percent of the herbage is removed. Clipping at the boot stage was too late for new culms to complete the normal growth cycle. This was clearly the most critical time to defoliate the species. In another study, *Elymus cinereus* showed greater response to clipping height and frequency than to time of foliage removal (Perry and Chapman 1975, 1976).

Removal of 65 percent of the leaf area of *Muhlenbergia porteri* reduced plant vigor regardless of the growing season. Late and continuous defoliation had a greater effect than during early growth (Miller and Donart 1981). In *Lolium perenne*, TNC reserves were down in winter and early spring but up during and after seed formation. Yearly rest from grazing by sheep made no difference than grazing at any season. There was no advantage for deferment in spring, summer, or fall as long as 650 kilograms of herbage remained available per animal (Hassan and Krueger 1980). Clipping of *Agropyron spicatum* at early bloom reduced its yield to 15 percent of controls (Blaisdell and Pechanec 1949) and greatly reduced flowering the next year (Heady 1950). Repeated heavy defoliation at the boot stage may eliminate this species from the vegetation within three years (Wilson et al 1966).

Perennial grasses vary in sensitivity to herbage removal, but a majority of them sustain little damage if early defoliation ceases in time for them to complete seed maturation. From early boot stage in some species to late flowering in others appears to be the most sensitive time for defoliation. Several are listed below:

Agropyron desertorum (Cook et al 1958)
Agropyron spicatum (Stoddart 1946, McLean and Wikeem 1985a)
Atriplex canescens (Menke and Trlica 1983)
Balsamorhiza sagittata (Blaisdell and Pechanec 1949)
Bouteloua eriopoda (Miller and Donart 1979)

Calamagrostis rubescens (Stout et al 1980)
Elymus cinereus (Perry and Chapman 1975)
Elymus junceus (Svejcar and Rittenhouse 1982)
Eragrostis trichodes (Moser and Perry 1983)
Festuca scabrella (McLean and Wikeem 1985b)
Mertensia arizonica var. *leonardi* (Laycock and Conrad 1969)
Panicum virgatum (Haferkamp and Copeland 1984)
Purshia tridentata (Menke and Trlica 1983)
Sporobolus flexuosus (Miller and Donart 1979)
Sporobolus wrightii (Haferkamp 1982)
Stipa thurberiana (Ganskopp 1988)

DEFOLIATION EFFECTS AFTER PLANT MATURITY

Defoliation after plants have ceased growth is generally believed to do no harm to the plants. However, Anderson (1960) found that removing herbage of prairie vegetation in September decreased yields the next year from 3,900 to 2,650 kilograms per hectare. Delaying removal of aftermath from middle September to late October increased the next year's yield by 38 percent (Conrad 1954). Curtis and Partch (1950) obtained a sixfold flowering stalk increase in *Andropogon gerardi* and 60 percent more height growth by removing old growth mid-March. Removal of all mulch and standing dead litter in late winter resulted in no negative effect on forage yield in the fescue prairie but may have stimulated tillering. In the mixed prairie the removal of plant residue decreased yields (Willms et al 1986).

Standing dead material can have no direct physiological link to perennial materials at the ground surface and below. However, the effects of standing dead, litter, and mulch on the soil surface are real. They are indirect effects that operate through changed environment rather than direct stimuli from clipping.

EVALUATION OF DEFOLIATION PRACTICES

Many studies relating to intensity, frequency, and timing of defoliation confound the treatments and even confuse the terminology. Increased frequency of defoliation may be called increased intensity and time of cutting may refer to calendar dates or days since planting, all without reference to the phenological sequence of growth stages. The separate effects of intensity, frequency, and season of defoliation seldom have received separate attention. However, defoliation studies with individual plants and plant communities have contributed to an understanding of grazing effects. Although contradictory results make every generalization risky, a number of solid conclusions can be stated:

- Removal of living tissue will cause varied responses according to amount removed or intensity, frequency of removal, and phenology of the plants at the time. Any one of these three factors or any combination of them can cause plant deterioration, no obvious effects, or stimulation, depending upon level or timing of application. Plant responses to severe treatments have shown **decreased** (1) above-ground biomass, (2) culms or woody branches, (3) seed, (4) height of leaves and culms, (5) length of twigs, (6) quantity of nutrients per land unit, (7) root biomass, (8) root length, (9) TNC storage, and (10) vigor of plant. Overdefoliation causes winter killing, injury during drought, and undesirable changes in botanical composition of range vegetation. All these results vary by species and site. Any one or combination of them in the extreme constitute the signs of rangeland overuse. Light and moderate use does not cause significant change in these parameters.
- Senescence and decreased nutritive quality of lower leaves in a thick grass stand due to abundant, tall, flowering stems may be remedied by cutting or grazing. New growth is more leafy and higher in proportion of nitrogen than is old growth so defoliation usually improves quality of forage for livestock. This tradeoff with losses from overdefoliation requires careful synchronization of grazing pressure with pasture growth. Manipulating animal grazing with the aim of developing nutritive feeds requires small pastures, long growing seasons, and species that tiller easily or branch profusely. Extensive areas and short growing seasons effectively reduce application of such a management restraint on rangeland.
- Major susceptibility to defoliation seems to be from flowering into maturation. Reasons for this may be (1) that leaf tissue is at a maximum, (2) most culms are reproductive and few are vegetative, (3) apex removal is abundant without time for tiller reproduction and leaf regeneration, (4) stores of TNC may be minimal, and (5) factors such as shortening days and little soil moisture may prevent tiller replacement which requires bud release and allocation of assimilates (Branson 1956, Caldwell et al 1981, Mueller and Richards 1986, Marshall 1987).
- **Resilience to defoliation in a species may be attributed to factors other than TNC pool size and translocation. For example, species may have high photosynthetic capacity, long foliage longevity, protected meristems, rapid shoot and leaf replacement, a low degree**

of apical dominance, a high ratio of leaf area to leaf weight, high allocation of TNC and nitrogen to shoot growth, and be well adapted to water stress and competition in the plant community. An understanding of the defoliation effects and the importance of plant adaptations to any type of defoliation is fundamental for the professional rangeland manager.

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4

Palatability, Preference, and Selective Defoliation

Each herbivorous species or individual, wild or domestic, large or small, selects a daily ration from the forages available within a chosen place, a niche, a plant community, a territory, its habitat. All grazing includes elements of choice ranging from obligatory grazing on, or choice restricted to, a part of a single plant to display of little forage preference. The plants preferred are said to be **palatable**. As used here, **preference** refers to animal reactions and palatability to plant characteristics. Separation of these two concepts aids analysis and understanding of the grazing process, although their combined process is **selective defoliation**. Forage selectivity results from a highly complex interaction among three sets of variables operating over time: the animals doing the grazing, the plants being eaten, and the environment of both.

Each animal lives, grows, and reproduces on the food it eats so animal responses to selective feeding constitute a large and important study discipline. Digestibility trials; chemical analysis of feeds; and determinations of intake, nutritional requirements, nutritional imbalances, growth rates, reproductive rates, and many other animal responses belong to interdisciplinary understanding between the interests of rangeland and those of animals. When an animal takes food for nutritional needs, it exerts an influence upon further production of food and on the evolution of the forages. For example, Detling et al (1986) found that *Agropyron smithii* had more, shorter, and more prostrate tillers in areas grazed by prairie dogs than in areas free of prairie dogs. The hypothesis is that longterm grazing changes the genetic makeup of the species.

Diet information is useful for forage allocation among animal species, selecting type of animal most compatible with the range resource, selecting the plant species to monitor or seed, determining suitability of habitats for introducing exotic animals, and predicting outcome of forage utilization. However, tabulation of diets alone does not compare what is eaten with that which is available to be eaten, explain reasons for diet differences, nor give evidence of competition for foods (Hanley 1982).

EXPRESSIONS OF SELECTIVITY

Selectivity of herbage expresses the degree to which animals harvest plants or plant parts in different proportion than in the herbage available to them. It is not "to the exclusion of others" as defined in the Range Glossary (Jacoby 1989). A principal dietary item may or may not be a selected item as here defined. **Selectivity ratios** between the proportion of any species, plant part, or group of plants in the diet and the proportion of that item in the herbage available to the animal were used by Van Dyne and Heady (1965) as expressions of relative preference on an index scale (Fig. 4-1). The two numbers used to calculate the ratio should be determined by the same procedure; for example, the point system on both fistula material and clipped vegetation from the same pasture. Selectivity ratios effectively show differences in food habits (Table 4-1).

Methods of determining selectivity ratios have been studied. Krueger (1972) and Krueger et al (1974) used frequency in the diet and on the range as well as percent of diets and range composition. Vavra et al (1977) divided a measure of consumed by consumed plus unconsumed. Tucker et al (1976) calculated linear regression as a measure of association or selectivity. Rank correlations may also indicate degree of association between consumed and available forage. After field testing, Loehle and Rittenhouse (1982) concluded that a need for further investigations existed because of sampling problems and inadequacies of selectivity indexes.

Caution must prevail with these indexes because as degree of forage utilization approaches 100 percent the relative selectivity ratio will approach 1.0, which indicates that all herbage is eaten without selection. As availability declines selectivity is reduced. A small percentage of forage utilization in a pasture would yield the widest selectivity ratios.

Most statements about selectivity have been based on measurements, ocular estimates, or general observations of the amount or percentage of material removed from a pasture. This percentage is referred to as **actual use** or **utilization** in the older range literature and **degree of use** in Jacoby (1989). **Proper use or proper utilization indicates that the removal of forage is estimated to be the correct amount to maintain or improve the productivity of the site.** When the rangeland is used

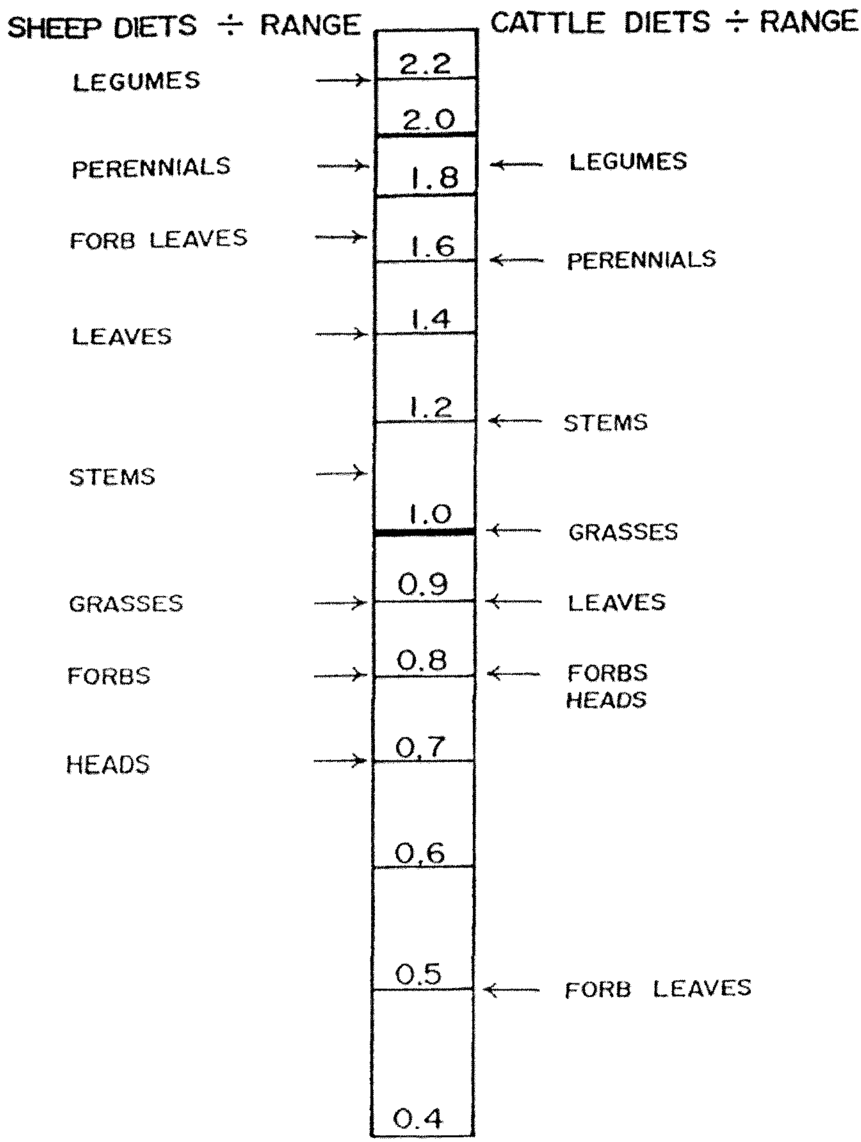

Figure 4-1 Selectivity ratios exhibited by sheep and cattle for plant groups. Ratios shown on the central axis express dietary composition in proportion to range composition. Those parts of the diet near the top of the scale were highly selected while those near the bottom were rejected (Van Dyne and Heady 1965).

Table 4-1 Selectivity ratios exhibited by several animal species for numerous dietary items. (Ratios were calculated from data given in the sources cited.)

Animal	Plant species or group	Selectivity ratio	Season	Location	Source
Cattle	*Sporobolus airoides* *Bouteloua barbata* *Bouteloua eriopoda* *Salsola kali* *Gutierrezia sarothrae* *Scleropogon brevifolius*	7.1 6.4 1.7 1.3 0.2 0.2	Yearlong	New Mexico	Herbel and Nelson (1966)
Cattle	*Phalaris tuberosa* *Stipa pulchra* *Trifolium spp.* *Bromus spp. (annual)* *Avena barbata* *Aira caryophyllea*	2.6 2.2 1.9 1.0 0.6 0.5	Summer	California	Van Dyne and Heady (1965)
Sheep	*Phalaris tuberosa* *Stipa pulchra* *Trifolium spp.* *Bromus spp. (annual)* *Aira caryophyllea* *Avena barbata*	10.0 3.1 1.8 0.9 0.4 0.3	Summer	California	Van Dyne and Heady (1965)
Sheep	Grasses Forbs Browse	1.5 1.7 0.5	Summer	Utah	Smith and Julander (1953)
Angora Goats	Grasses Forbs Browse	0.7 - 1.6	Winter	Texas	Malechek and Leinweber (1972)
Angora Goats	Grasses Forbs Browse	0.7 8.3 1.0	Spring	Texas	Malechek and Leinweber (1972)
Angora Goats	Grasses Forbs Browse	1.1 8.0 0.7	Summer	Texas	Malechek and Leinweber (1972)
Angora Goats	Grasses Forbs Browse	1.0 4.0 0.8	Fall	Texas	Malechek and Leinweber (1972)
Mule Deer	*Quercus spp.* *Cercocarpus breviflorus* *Garrya wrightii*	1.7 1.3 0.3	Yearlong	New Mexico	Boecker et al (1972)
Mule Deer	Grasses Forbs Browse	0.3 3.3 0.4	Summer	Utah	Smith and Julander (1953)
Mule Deer	Grasses Forbs Browse	5.9 2.4 0.3	Spring	Utah	Smith and Julander (1953)

Pronghorn	Grasses Forbs Browse	0.2 2.8 10.9	Yearlong	Alberta	Mitchell and Smoliak (1971)
Pronghorn	*Artemisia tridentata* *Artemisia tridentata* *Artemisia tridentata*	4.1 3.6 2.9	January February March	Montana	Bayless (1969)
Bighorn Sheep	*Lupinus spp.* *Agropyron spicatum* *Chrysothamnus viscidiflorus* *Artemisia frigida* *Astragalus spp.*	24.8 2.2 2.3 1.1 0.2	Winter	Wyoming	Oldemyer et al (1971)
Rocky Mountain Goat	Grasses Forbs Browse	1.6 0.6 0.1	Summer	Montana	Saunders (1955)

properly, one species may have 60 percent of current growth removed but a less preferred species only 40 percent. These are expressions of forage utilization for the whole range, rather than of selectivity as defined above.

METHODS OF STUDYING SELECTIVITY

Paired Grazing Studies

Degree of use on each species in a stand as a measure of selectivity has been determined by comparison of herbage weights per unit area from paired grazed and ungrazed conditions. Commonly, determination of the degree of herbage utilization constitutes the principal aim of studies using ungrazed plots, and measurement of selectivity or some aspect of forage preference is secondary.

Observing Grazing Animals

Another approach to gathering data on food selectivity centers on observation of grazing animals. The observer records the time an animal grazes on a species or the number of bites it takes to obtain a frequency of use for each species or for certain vegetational types. Tamed whitetailed deer, mule deer, red deer, and pronghorn permit exceptionally close observation of grazing. The aim of most observational studies of this type is to characterize food habits and animal behavior as much as to quantify selectivity.

Controlled Feeding

Feeding two foods at a time to penned animals quickly shows which is preferred and permits ranking the foods. Pairing a third food species first with one and then with the other allows ranking of three species. In cafeteria fashion, Murray (1984) rated fourteen grass accessions, grown in a uniform nursery, according to their palatability to sheep.

Retrieval of Eaten Material

Retrieval of any kind of eaten material for measurement was practically impossible before the surgical establishment of fistulas became successful. The installment of esophageal fistulas in sheep permitted the collection of relatively unchewed but animal-selected and -eaten material with apparently minor influence on the animal's natural grazing habits (Heady and Torell 1959). Point sampling, using a crosshair in a binocular microscope of about 15 power, provided frequency data and percentage composition of species and parts of plants in each fistula-collected sample. Fistulation procedures require tame animals and frequent care.

Sampling and analysis of stomach contents of killed animals have given abundant information on the food habits of wild animals. These partially digested materials have been separated into their various components by estimations, hand picking and weighing, point sampling, screening, and flotation procedures. Major criticism of stomach sampling stems from biased high estimates for indigestible material, small numbers of animals sampled, and sacrifice of animals.

Plant Cells in Fecal Material

The frequency, size, and pattern of different indigestible cuticle and plant cell walls such as epidermal, guard, cork, and silica cells varies by plant species. Microscopic analysis of these fragments in fecal material is a low cost method for determining preference and food habits. This situation permits determinations of diets on a qualitative basis by ranking species according to abundance in the fecal material (Vavra et al 1978). The method does not indicate the quantity of the separate species eaten by an animal, nor the amount available to the animal. A library of cuticle and cell patterns aids in accurate identification of plants eaten.

By using the plant cell technique, Hansen and Reid (1975) found that the overlap in diets between deer and elk ranged from 3 percent in winter to 48 percent in summer; 12 to 38 percent for deer and cattle in summer; and 30 to 51 percent for elk and cattle in summer. McInnis et al (1983) claim that the esophageal method of determining diet composition is more accurate than visual observations and analysis of either stomach contents or fecal material. Regardless, the fecal analysis technique has gained wide use in the determination of food habits because of its low cost by not requiring tame and fistulated animals.

PALATABILITY FACTORS

Palatability factors are those attributes of plants which alter their acceptability by grazing animals. They may stimulate a selective response by animals or they may prevent the plant from being grazed (Heady 1964). Factors involved are not completely understood; for example, nutritive and chemical contents correlate with palatability in many instances but in others they do not. Acceptance by animals of a given plant species changes, sometimes for unknown reasons, but probably because of changing plant characteristics that an animal can recognize by its senses of touch, taste, and smell. Palatability cannot be based on one factor alone.

Chemical Composition

Many studies correlate palatability with various plant chemical components. It is commonly accepted that forage high in crude protein is highly accepted by cattle and sheep (Cook 1959, Blaser et al 1960, and many more). Forages high in sugars or with sugars added and high fat content usually correlate with high palatability. Livestock accepted the grass cultivars highest in phosphorus and potassium before those with low contents of these minerals (Leigh 1961). Percentages of lignin and crude fiber increase when crude protein, the simple carbohydrates, and fats decrease; therefore, negative relationships between palatability and content of lignin and crude fiber are as common as positive relationships with other compounds.

Plice (1952) found that manure-affected plants in a pasture were not grazed by cattle, but were grazed by sheep, although they were higher than unaffected plants in crude protein, calcium, potassium, iron, fat, nitrates, and vitamins. The unaffected contained more silica, aluminum, phosphorus, tannin, chloride, and sugars. Any type of added artificial sweetener, such as sugar, saccharin, or sodium cyclohexyl sulfamate, increased the palatability of the manure-affected plants. These results suggest that the taste of sweetness and not the presence of sugar itself determines palatability. Molasses sprayed on dry grass improves acceptance by cattle and furnishes them an energy supplement as well (Wagnon and Goss 1961). Sheep will graze the affected areas.

Volatile Oils and Palatability

Efforts to explain why numerous unpalatable species contain as much as, or more, nutrients than those readily grazed suggested analyses for other plant compounds. In 1964, Nagy et al demonstrated that essential oils of *Artemisia tridentata* reduced rumen bacteria, fermentation, and appetite in deer and cattle. However, volatile fatty acids supply a major source of energy to ruminants, so not all essential oils can be antagonistic to rumen functions. Chromatography indicated that the oxygenated monoterpenes might be the cause of rumen disorders (Hanks et al 1971). Undoubtedly proper functioning of the rumen and other parts of the digestive tract influence selectivity of feeds.

Some terpenoids may be attractants and others toxic (Personius et al 1987). Utilization by sheep varied from none to 98 percent of current growth for 21 accessions in three subspecies of *Artemisia tridentata* (Welch et al 1987). Not only were the terpenoids different among plant varieties and collections; they may be lost by exposure and by mastication (White et al 1982, Cluff et al 1982). In addition to the terpenoids, the astringent properties of tannins and toxic compounds in poisonous plants are known to affect palatability.

Many conflicting results from proximate analysis have been reported in studies aimed at explaining palatability according to differences in chemical contents. For sheep and cattle it is usually indicated by high crude protein, phosphorus, gross energy, and by low crude fiber (Arnold 1964a). Perhaps the best positive indicator is crude protein.

Proportions of Plant Parts

Grass and forb leaves contain greater proportions of fats, crude protein, and simple carbohydrates but less lignin and crude fiber than do stems. Fruits and seeds vary among species, but they usually have a relatively high content of crude protein, fats, and carbohydrates. Although chemical contents may not be the reason for differences, leaves, flowers, and seeds are generally more palatable than stems. In the dry season, when stems may be the principal material available, sheep and cattle continue to show preference for other plant parts (Van Dyne and Heady 1965) as follows:

Percentage of diet in late dry season			
Class of Animal	Stems	Leaves	Inflorescence
Cattle	77	8	15
Sheep	70	19	11

Most grazing animals select leaf over stem and green material over dry. The proportions of plant parts influence the palatability of forages. For example, plants of a species that are short because of poor site, drought, and defoliation will have a higher leaf/stem ratio than tall plants of the same species. This translates into higher palatability and nutritive value for the shorter plants, although forage components may be less per unit area.

Growth Stage and Palatability

As herbaceous plant materials mature, they generally decrease in palatability and in nutritive value. Succulence decreases and soft leaves become harsh. For example, leaf harshness in phenotypes of *Agropyron* was negatively correlated with preference by sheep (Shewmaker et al 1989). O'Reagain and Mentis (1989b) on the basis of comparisons of nine native species claimed that increased acceptability occurred with increasing leaf percent as well as leaf crude protein. Typically, the whole plant becomes higher in fiber, and the leaf/stem/fruit ratio changes toward a higher proportion of stems as it matures. Systems of management that prevent accumulations of mature plant materials tend to maintain grasses in a higher palatable condition than those of the same species that are mostly stems.

The position and extent of lignification in each grass species characterizes advancing maturity, curing qualities, and palatability. The patterns may be different according to variety or cultivar; a situation useful in selecting the best varieties for propagation (Goodenough et al 1988).

Palatability of a few species gain as the growing season progresses. The selectivity ratio for *Medicago hispida* from new growth to maturity illustrates increasing palatability of this species as it becomes older (Heady and Torell 1959):

Date	Palatability
February 1	0.15
March 5	0.82
April 1	1.08
May 2	2.25
July 9	2.45

Arnold (1964a) showed the same trend in several legumes for increasing palatability as growth stage advances and attributed it to changing odor.

Animals alter their preferences to meet changes in feed supply. For example, juvenile sage grouse maintain a diet of succulent forbs by selecting one species after another paralleling the development of the plant species (Klebenow and Gray 1968).

External Plant Form

Palatability usually is reduced by the presence of awns, spines, excessive hairs, stickiness, coarseness of texture, and unfavorable odor from external glands on the plant. Glabrousness and succulence tend to enhance palatability. Height, growth habit, and position of the various plant parts affect accessibility and palatability. One study found that small plants of *Agropyron cristatum* tended to be avoided (Hacker et al 1988).

Kind of Plant

Although a few species of plants dominate each range type, many occur within the distance traveled daily by large herbivores. Only a few will constitute the diet at any one feeding. During a longer time period, all available species are likely to be grazed to some extent, as was found in the southern New Mexico desert grassland (Allison et al 1977) and in the California annual grassland (Van Dyne and Heady 1965). The less abundant species can add substantially to animal diet but may go unnoticed in analyses of available forage. For example, the lichen *Ramalina reticulata* may be missed as an important component of the forage because it grows on trees and is consumed immediately after falling.

In a test of 16 species, Hansen et al (1985) found that *Labops hesperius* (black grassbug) preferred *Agropyron cristatum* and *Elytrigia intermedia* and the least preferred were *Dactylis glomerata* and *Phalaris arundinacea*. Greatest variation was found in the hybrid, *Elytrigia repens x Elytrigia spicata* indicating possibilities for selection of cultivars resistant to the bug.

Availability of Associated Feed Elements

The availability or proportional botanical composition of a species in the vegetation influences its acceptability. Plants with low palatability were selected to a greater degree when they compose a small rather than a large proportion of the stand (Tomanek et al 1958). In contrast, Cook (1962) found that increases in the proportion of a palatable desert plant led to increased use of it but increases in the proportion of unpalatable species resulted in less use of them. Associated feeds and species availability alter the palatability of any other food item in the diet.

On mountain ranges in Wyoming, Hurd and Pond (1958) showed that preference for *Stipa columbiana* was greater and for *Danthonia intermedia* less in a grass/shrub cover, than in a grass/forb cover. Annual species on one habitat showed different acceptances by sheep when the species occurred together in different proportions (Heady and Torell 1959). Such relationships are common with many species.

Where forage is abundant in relation to the grazing pressure, animals express their preferences freely. As feed become less available, the more palatable portions disappear first, then animals must eat less desirable forages (Arnold 1964a, Van Dyne and Heady 1965). Domestic livestock and most other large herbivores are opportunistic grazers so their diets vary greatly from place to place, time to time, and among individuals and species.

PREFERENCE FACTORS

Animal reactions that regulate food acceptance have been classified into three interrelated systems (Young 1948). One of these systems includes stimuli within the animal's body which bring on desires for eating, some of them learned. The second system conditions the animals through evolutionary development of feeding habits on a long time scale and through learning on a short time scale. The third system affecting food preference comprises the animal's environment. These three systems operate a chain of events that includes recognition of food, movement toward the food, appraisal, eating, and leaving the food source.

Preference for a food may be exhibited at any point in this series (O'Reagain and Mentis 1989a).

The understanding of plant chemical defenses to herbivory has progressed beyond the traditional concentrations of alkaloids, phenolics, resins, tannins, and terpenoids. Animal selectivity is related to these and many more specific chemical substances. Additionally, other studies have given importance to learning from postingestive consequences, from mother, and dietary training of livestock (Bryant et al 1991).

Internal Animal Factors

Animal preferences for foods are stimulated by the senses of sight, smell, taste, touch, and perhaps hearing in special instances. In a series of experiments with sheep on pastures Arnold (1966) and Krueger et al (1974) impaired the sheep's sight, smell, taste, and touch separately and in combinations. Blinkering changed their behavior but did not alter their preference for certain forage species. Sight allowed them to recognize food items and to orient themselves with their surroundings while smell, taste, and lip-touch were each important in determining the acceptability of some forage species but not others. Apparently each plant stimulates these three senses differently.

Longhurst et al (1968) showed that deer use smell to make their initial selection of forage. If they like the smell, they taste. If they like the taste, they feed upon the plant. Once the plant is learned, feeding proceeds without initial testing. Hearing is used when fruits are falling but, like sight, has little importance in determining preference. Overall, taste appears to be the principal sense used in selecting forages.

A very small amount of data exists on the influence of physiological state of an animal on preference for foods. Changing conditions of breeding, pregnancy, lactation, fear, excitement, fullness of the intestinal tract, and hunger influence animal behavior, grazing time, and amount of forage intake by animals (Arnold 1964b). Consequent changes in food preferences would be expected, but whether they exist and how they operate have not been fully explained.

Learned and Evolved Behavior

Delphinium barbeyi, tall larkspur, with toxic diterpenoid alkaloids is the most important plant poisonous to cattle and sheep grazing on mountain rangeland in the western United States. Provenza and his team (Provenza and Balph 1988, 1987, Lane et al 1990) were able to condition heifers to avoid eating the plant by intraruminal infusion of lithium chloride whenever they consumed the larkspur in pen feeding. The aversion lasted into the second summer and was broken when the treated animals were allowed to graze with untreated animals. Successes with conditioning animals for food selectivity are encouraging, but many questions remain. What is the strength of social interactions, the optimum age for conditioning, the best procedure?

Previous grazing experience influences the selectivity of foods. Sheep reared on range and pasture were compared as to their preferences for forages after a 3-week pen-feeding equalizing period for stabilization of rumen organisms. The sheep reared on irrigated pasture ranked *Medicago sativa* first in preference, but those raised without *Medicago* selected their previous diets. These differences soon disappeared. Differences between preferences for generally unpalatable species lasted longer (Arnold 1964a).

If the motivation in selective grazing is adequate nutrition, animals should consume highly nutritious but unpalatable feeds before less nutritious but palatable materials. Little evidence exists that grazing animals have nutritional wisdom enabling them to select the best available diet (Arnold 1964a). Precise rectification of salt deficiency seems to be an exception. Several experiments have demonstrated, however, that forages actually eaten contain a higher nutritive content than the average of the pasture from which they were selected (Weir and Torell 1959).

Restricted food habits, such as that of the walkingstick (*Diapheromera velii*), which feeds only on *Psoralea tenuiflora* (Ueckert and Hansen 1972) may have evolved through coadaptation; the grazier becoming more and more specific for food and the producer withstanding the pressure or even evolving a symbiotic need for the consumer. The grazing animal must have an instinct or a hereditary nutritional wisdom to select the foods it can use. This selection process would seem to be a self-regulating mechanism, whereby materials not accepted readily along the digestive tract are not accepted by its mouth. Perhaps the animal accepts undesirable material only to avoid extreme hunger or death.

Many native grazing animals have little ability to search for food beyond routes learned as juveniles. They usually spend most of their lives in a restricted territory even when the food supply in that area diminishes.

Grazing herbivores differ markedly in their food habits; each animal species shows preference for certain plant species, individual plants, parts of plants, plants in certain growth stages, areas of previous use, successional stages, range sites, and range types. Animals often continue to graze these preferred elements although their availability becomes low and associated but less desirable elements more abundant. Animals show variation in food preferences among locations, among seasons of the year, over a period of a few days, within the same day, and among individuals (Van Dyne and Heady 1965).

Food habits are not exhaustively catalogued here, but reference is made to a few of them (Table 4-2). In Chapter 14, further reference is made to diets in conjunction with the management of mixed animal species.

Environmental Influences

Climate, topography, and soil affect palatability of plants and preference for foods by animals. A plant species on different sites will vary in chemical composition, succulence, proportion of leaf, and harshness of the foliage. These differences may be fixed genetically as indicated when plants from different areas are grown together. Animals prefer different sites, and the site affects their selection of foods. Hooper (1962) found that deer browsed the same species to different degrees when it occurred on different soil types. Degree of forage use on different sites and selectivity of area for grazing correlated positively with nitrogen, phosphorus, and potassium contents in plants and soils (Vandermark et al 1971).

Two management practices, fertilization and burning, change palatability of plants as well as feed quantity and nutritional quality. Burning affects availability of new growth by removing standing dead, shrubs, and cactus spines. Grazing animals prefer fertilized and burned areas.

Grazing animals change their behavior, hence their food preferences, with differences in temperature and rainfall and with wetness of foliage. When other and more palatable plants are covered with snow, mule deer will browse on less desirable species such as *Juniperus osteosperma* and *Pinus edulis*. Areas of heavy clay soils tend to be avoided by plains game animals in Africa during wet weather, thus weather influences their selectivity of foods.

VEGETATIONAL RESPONSES TO SELECTIVE GRAZING

In an attempt to study selective grazing alone as a factor causing vegetational changes single sheep were placed in small, uniform pastures of *Phalaris tuberosa* and *Trifolium subterraneum*. Marked differences in botanical composition resulted after five months. Presumably, each animal selected a different diet, but the animals also ate different amounts, and the conclusion was reached that intensity of grazing influenced pasture changes more than did selectivity (Arnold 1964c).

After five years of sheep grazing in south central Canada, *Euphorbia esula* was reduced by 95 percent and *Agropyron desertorum* increased by 32 percent because of selective grazing (Johnston and Peake 1960). As with the previously mentioned work, clear elimination of other grazing influences was not made. Few documented observations on the influence of selectivity alone on vegetation are available; yet it is an aspect of grazing that underlies many management recommendations.

Wild animals have grazed through geological time without apparent destruction of their preferred forages. This suggests a number of hypotheses: that moderate intensities of grazing may be stimulatory and beneficial to the continued well-being of rangeland ecosystems; that forage species tolerate defoliation within certain limits; that grazing factors other than selectivity may cause vegetational changes; and that the separate influence of selective grazing has not been measured.

A large body of literature leaves no doubt that grazing animals influence the vegetation on which they feed, even under a light grazing intensity. However, innumerable accounts describe increases of all preferred plants when grazing pressures were lightened (Ellison 1960). Few examples exist where palatable species have completely disappeared because of grazing, especially light and moderate grazing. Intensity of grazing has a greater impact on vegetation than selectivity, but livestock depend upon selectivity to obtain their needed diet.

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Table 4-2 Food preferences shown by several large herbivores during four seasons of the year.

Animal	Season	Percentage in Diet: Grasses	Forbs	Browse	Location	Source
Hereford Cattle	Spring	35	40	25	New Mexico	Herbel and Nelson (1966)
	Summer	71	23	6		
	Fall	50	41	9		
	Winter	50	27	23		
Santa Gertrudis Cattle	Spring	58	30	12	New Mexico	Herbel and Nelson (1966)
	Summer	81	17	2		
	Fall	49	43	8		
	Winter	65	20	15		
Sheep	Spring	37	47	16	Texas	McMahan (1964)
	Summer	61	8	31		
	Fall	68	3	28		
	Winter	82	1	17		
Mule Deer	Spring	2	30	58	New Mexico	Boeker et al (1972)
	Summer	2	42	50		
	Fall	6	8	86		
	Winter	2	4	94		
Whitetail Deer	Spring	34	65	1	Texas	Drawe and Box (1968)
	Summer	5	71	24		
	Fall	27	66	7		
	Winter	37	59	4		
Whitetail Deer	Spring	38	18	43	Montana	Allen (1968)
	Summer	T	54	45		
	Fall	2	17	81		
	Winter	6	29	65		
Pronghorn	Spring	25	57	18	Alberta	Mitchell and Smoliak (1971)
	Summer	13	62	25		
	Fall	13	37	50		
	Winter	9	47	43		
Rocky Mountain Goat	Spring	70	14	14	Montana	Saunders (1955)
	Summer	72	23	3		
	Fall	76	21	1		
	Winter	58	16	25		
Roosevelt Elk	Spring	62	4	34	California	Harper et al (1967)
	Summer	58	20	22		
	Fall	56	23	21		
	Winter	76	2	22		
Angora Goat	Spring	40	25	35	Texas	Malechek and Leinweber (1972)
	Summer	65	8	27		
	Fall	47	12	41		
	Winter	47	4	49		

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5

Physical Effects of Grazing Animals

Whenever large grazing animals move, the exerted force affects soil, vegetation, and other animals. Major impacts on the land include eating action; trampling or treading which bruises and cuts plants; soil compaction; and covering of vegetation with soil and dung. The mechanics, magnitude, and control of soil compaction, as influences on herbage production, have received more attention than other major impacts. This emphasis stems from the fact that soil compaction increases in direct proportion to increasing intensity of rangeland use by animals.

One of the first recommended range practices was to eliminate trampling damage by avoiding repeated use of the same bedground by bands of sheep grazing summer ranges (Sampson and Weyl 1918). Large areas around each place of animal concentration, whether it is a bedground, watering point, gate, holding pen, or campground, becomes bare of vegetation. Designated livestock trails or stock routes throughout the world receive so much animal traffic that, typically, they are bare of vegetation and eroded. This chapter centers on the impact of animal movements upon the landscape.

ANIMAL MOVEMENTS

Each species of animal, and each individual, moves in its own repetitive behavioral pattern. These habits relate directly to the resultant physical effects on the land. For example, a highly selective grazing animal travels farther in mixed grassland to obtain its daily ration than does a less selective individual. Burrowing activities of rodents, wallowing by bison, dusting by birds, and mixing of soil by invertebrates are other types of behavior that affect rangelands.

Behavioral patterns of cattle and sheep vary according to type, breed, and age of animal; climate; season; available feed; topography; and other factors. Hafez and Schein (1962) and Hafez and Scott (1962) found in extensive literature reviews that cattle and sheep varied greatly in their daily activities as follows:

	Cattle	Sheep
Grazing time, hours	4 to 9	9 to 11
Distance traveled during grazing, km	3 to 5	5 to 13
Rumination time, hours	4 to 9	8 to 10
Number of grazing periods	4 to 5	4 to 7

Sheep spend more time grazing and traveling than do cattle. As the available forage decreases in quantity, both animals travel farther and spend more time grazing, as suggested by the numbers given above. Great variation in behavior exists among individual animals of the same species and in the same individual in different environmental conditions.

DIRECT EFFECTS ON PLANTS

Discarding of Herbage

Pulled and discarded plants may be found after grazing on nearly all range types. Plants are easiest to pull when the soil is wet. Such damage to *Bromus tectorum* by cattle is frequent. Horses and burros are known for their habit of pulling grasses and consuming only parts of them. Grasshoppers cut blades of grass but eat only parts. Rabbits and rodents have been observed to nip pieces from grasses and shrubs and waste most of the material. *Poa ampla* appears especially susceptible to pulling from the soil (Hyder and Sneva 1963). Plants differ seasonally in their resistance to pulling. For example, grazing cattle uprooted *Calamovilfa longifolia* and *Stipa comata* most often in July but *Bouteloua gracilis* in September (Quinn and Hervey 1970). These actions constitute efforts by some animals to obtain preferred foods and desirable nesting materials.

Bark Wounding

Animal damage to the bark of woody plants may cause material above the wound to die. Bark wounding, sometimes ring-barking, results from rubbing by mule deer removing velvet from their antlers; bears and cats sharpening their claws; rabbits, rodents, bears, beavers, and Australian opossums feeding on the inner bark; rodents ring-barking young *Populus tremuloides* under snow; birds feeding on the sap of trees; and insects depositing their eggs in or under the bark.

Perhaps the African elephant destroys woody plants more spectacularly than does any other animal. A herd may eliminate forests by breaking limbs for browse and pushing down trees or tearing them apart seemingly in fun. However, other situations can be striking. Ring-barking by voles killed as much as 84 percent of the *Artemisia tridentata* in some Montana stands (Mueggler 1967). Many more examples can be given.

Covering of Live Plants

Small, ground dwelling animals dig burrows, depositing soil on surrounding vegetation. Larger animals cover vegetation with dung. Dung patches killed 75 percent of the grasses and legumes under them in a dairy pasture during a 15-day period (MacDiarmid and Watkin 1971). Organic materials under the patches decomposed quickly but the affected areas produced little regrowth for a year. Dung patches averaged 0.07 square meter and were deposited at the rate of 13.9 per day (MacDiarmid and Watkin 1972). This calculates to a coverage of approximately 0.97 square meter per day or 354 square meters per year per cow. While many factors alter these calculations for field application, the conclusion must be accepted that coverage with dung constitutes an important physical effect. Because of slow decomposition, the effects are greater in dry areas than under moist conditions. High livestock density and high stocking rate concentrate that impact.

Fitch and Bentley (1949) claimed that herbage elimination by rodents in the California annual grassland amounted to more than 50 percent of the annual crop, but that the animals consumed less than 10 percent of the plant material that they cut off.

Mound building by soil dwelling animals buries live vegetation and alters the habitat for establishment of new plants. Pocket gophers disturbed as much as 25 percent of the soil surface in southwestern Oregon and reduced survival of *Pinus ponderosa* seedlings from 87 percent to 12 percent (Hooven 1971). Gopher impact was from both burial of plant and foraging on the roots. Julander et al (1969) reported 4,000 to 4,500 pocket gopher mounds per hectare in the Cache National Forest, Utah. Prairie dogs and ground squirrels may move as much soil as do pocket gophers.

Whether or not burrowing, mound building, and other activities of ground dwellers result in benefits to range forage production remains unclear. A drier habitat results where pocket gophers burrow than where they are absent; erosion may be increased from the freshly turned soil; and the new mounds provide sites on which germination and establishment of plants are difficult (Laycock 1958). Conversely, burrowing counteracts soil compaction; mixes soil and organic matter; covers erosion pavement; and increases water infiltration, soil porosity, soil aeration, and rate of soil formation (Ellison and Aldous 1952). Species of early successional stages often occur on abandoned 2- and 3-year-old mounds. There seems little question that rodents in peak numbers consume large quantities of forage and permanently reduce seeded and planted stands of grasses and trees by their physical activities. However, small populations may be more beneficial than harmful to rangeland ecosystems.

Trampling of Plants

Trampling affects plants directly as animals cut, bruise, and break them during walking and running. The damage changes according to the plant's moisture content, elevation of growing points, physical strength of leaves, and flexibility of plant parts (Edmond 1966).

Direct losses of herbage by trampling have been reported as 1 to 5 percent in the shortgrass type in Colorado (Quinn and Hervey 1970), 23 percent of the standing crop on sheep ranges in the mountains of Utah (Laycock et al 1972), and 68 percent of the lichen component by reindeer during a year of grazing (Pegau 1970). Artificial trampling and lodging of *Mertensia arizonica* var. *leonardi* during early growth increased production but decreased production if it occurred during flowering and fruiting (Laycock and Conrad 1969). The *Festuca scabrella/F. idahoensis* type in Montana was more resistant to trampling than nearby forest types (Cole 1988). Rhizomatous grasses as a group resist trampling more than do bunchgrasses.

Dry plant materials tend to break rather than bend under the hoof, so late seasonal effects often exceed growing season damage for many species. The breakage may be desirable if it lays dead grass materials on the soil surface where decomposition occurs rapidly, or it may be undesirable if it results in loss of soil protection.

By using an artificial hoof to simulate trampling Abdel-Magid et al (1987) found little difference in material detached in either continuous or short-duration grazing systems. Cattle walked on the spaces between the bunches (*Agropyron cristatum*) at all frequencies of walking and seldom trampled the tall bunches, suggesting that laying of dead material was minimal (Balph and Malecheck 1985).

CRYPTOGAMIC SOIL CRUSTS

Mosses, algae, lichens, and fungi often form dark crusts that bind the soil particles together. Probably the blue-green algae are the most effective. They have the capacity to stabilize desert soils, to fix nitrogen, and to conserve soil nutrients. As many as six species of blue-greens have been found in a soil sample (Rogers 1989). These covers protect the soil between the plants in arid and semiarid regions.

Once the crust is broken by trampling, it has taken as many as 18 years for crust reestablishment in ungrazed Utah exclosures (Anderson et al 1982b). Cryptogamic cover and diversity is reduced by any large animal activity. Anderson et al (1982a) claims that these soil crusts do not suppress vascular plants. The role of soil crusts in soil stability and vegetational succession is poorly understood (Dunne 1989).

EFFECTS ON SOIL

Large animals walking on the ground exert physical pressure on the soil by their weight, and they move soil particles about the land surface with their feet. Soil compaction may result from the first but the second often causes soil loosening and erosion. Small animals cause the same effects as do large animals; the only difference is in degree.

Soil dwelling animals may loosen the soil more than they compact it, thereby countering influences of large animals. For example, the eastern mound-building ant reduced bulk density of the soil by constructing channels and chambers and by depositing subsoil within and on the soil surface (Salem and Hole 1968). Many species of termites in arid and semiarid regions cement soil particles in their nest building. Those nests below ground form a cap that prevents water infiltration and seedling establishment for many years, but mounds favorable to plant growth are produced by some species of termites (Lee and Wood 1971). A wide variety of soil dwelling animals select, transport, rearrange, mix in organic matter, and cement soil particles. Plants respond to changes in soil, so perhaps the positive affects of animals on soil and vegetation outweigh the immediate negative physical effects of animals on plants.

Soil Compaction

Soil compaction is defined as the packing together of soil particles by forces exerted at the soil surface, which result in an increase in

specific gravity by decreasing the pore space (Lull 1959). The principal soil characteristics determining supporting capacity or susceptibility to compaction include texture, structure, porosity, and moisture content. These combine to give each soil condition a capacity to hold or support a load or to resist deformation. Examples selected from Lull (1959) show the approximate deformation point of several soil materials as follows:

	kg/cm2
Organic soils	0.21
Dry sand	2.0
Wet sand and dry clay	4.0
Packed gravel	8.0

Static loads exerted when rangeland vehicles and animals remain stationary approximate the following pressures on the soil. Values encompass a wide variation in load weights and track size or bearing surfaces for vehicles (Lull 1959).

	kg/cm2
Crawler tractor	0.32 - 0.63
Sheep	0.65
Wheel tractor	1.4 - 2.1
Horse or cow	1.7
Truck	3.5 - 7.0

The measurement of stationary pressures needed to exceed the supporting capacity of the soils has been used to evaluate soil compaction. However, as animals walk, their weights fall on restricted areas of their hooves, whereby weight per contact area exceeds the soil strength. The result may be chipping of dry soil surfaces, compaction of moist soils, or deformation of wet soils.

Maximum compaction occurs at soil moistures about midway between wilting and field capacity. Wetter soils give way or reform with less compaction than do those with intermediate moisture content. Puddling, or loss of structure, and compaction may occur with repeated traffic on heavy soils.

With constant pressures and soil moisture, soils with high porosity and a wide range of particle sizes are more susceptible to compaction than are other soils. When compaction occurs, small particles replace air spaces between the large pieces. Soils composed of particles mostly of one size usually do not compact unless a well developed structure has given them large pore spaces. Structureless sands compact very little.

Compaction readily alters or reduces structure and pore volume, thereby increasing soil density. Increased soil density in turn reduces infiltration capacity, permeability to water, water storage capacity, aeration, root penetration, and activities of soil dwelling animals. The result is less top growth of plants. The most common measure of soil compaction is change in soil specific gravity or bulk density.

Changes in Bulk Density

Bulk density is the specific gravity of the soil. Numerous, but not all, experiments that included measurements of physical effects of animals on soil have shown that grazing increases bulk density or decreases porosity of soil. Some of those indicating an increase include Duvall and Linnartz (1967) in longleaf pine/bluestem range of the southern United States; true prairie in Missouri (Kucera 1958); sandy soils in Oklahoma (Rhodes et al 1964); silt loam soils in New Zealand (Edmond 1958); and numerous other pasture and forest situations as reviewed by Reynolds and Packer (1963).

Studies in the shortgrass region of the United States have generally found that bulk density increases directly as intensity of grazing becomes more severe (Brown and Schuster 1969, Knoll and Hopkins 1959, Rauzi and Hanson 1966, Read 1957, and Reed and Peterson 1961); but this was not found with increasing grazing pressure on coarse textured soils (Van Haveren 1983).

Soil compaction was greatest after 25 years with continuous grazing, less under deferred and rotated treatments, and least in protected areas in eastern Nebraska (McCarty and Mazurak (1976).

After 19 years of heavy cattle grazing, Canadian workers reported lowered pH and changed carbon content of soils, but little effect on moisture tension, bulk density, total available phosphorus, and total nitrogen. One report was on fescue grassland (Johnston et al 1971) and the other on the shortgrass type, both on the Manyberries Station in southern Alberta (Smoliak et al 1972). Earlier, Lodge (1954) in southern Canada and Orr (1960) in the Black Hills of South Dakota found increased bulk density in some grazed soils but not in others. Bunchgrass ranges in southeastern Washington (Daubenmire and Colwell 1942) and subalpine grasslands in Utah (Meeuwig 1965, Laycock and Conrad 1967) showed no change in bulk density with heavy grazing.

Packer (1963) maintained that winter grazing by elk reduced plant cover and increased soil bulk density in the *Artemisia/Agropyron* areas north of Yellowstone Park. He suggested that ground cover should not be allowed to diminish below 70 percent and bulk density to increase above 1.04 grams per cubic centimeter. Standards have not been suggested for other soils. Interpretation of changes in bulk density requires care. Soil density changes with moisture content, as it did when soils were compared during early and late growing season (Laycock and Conrad 1967). Removal of mulch from the soil surface resulted in changes in botanical composition and significant increases in soil bulk density, without trampling by animals (Heady 1965). These results suggest that altering animal impact on the vegetation itself and thus changing species composition has an influence on soil density which is separate from the influence of compaction by trampling. Thus, all soil compaction may not be caused by animal trampling.

Soil Porosity (Infiltration)

Increased bulk density correlated with decreased soil porosity (Read 1957, Kucera 1958, Reed and Peterson 1961). Trampling with an artificial hoof increased overland flow of water in the *Agropyron spicatum/Bromus tectorum* type in southern Idaho (Packer 1953). On sandy loam and loam soils the infiltration rates after 15 minutes were higher for light and moderate grazing than for heavy grazing. On another site the sandy loam gave the same infiltration for all three grazing levels (Rauzi and Smith 1973). In New Mexico on one site, slope as great as 30 percent made little difference in infiltration under light grazing (Wilcox and Wood 1988).

Depth of soil compaction due to grazing seldom reaches 15 centimeters; frequently is limited to the surface 5 centimeters; and probably recovers in five to ten years after heavy grazing is reduced (Reynolds and Packer 1963). Lusby (1970) reported soil recovery in three years after removal of cattle from the salt-desert shrub type in Colorado. Soils on the Reynolds Creek Experimental Watershed in southwestern Idaho showed increased bulk density with increasing stocking rates and that two years without grazing were needed for recovery to no-grazing levels (Stephenson and Veigel 1987). Alternating swelling and shrinking, as with freezing/thawing and wetting/drying, reduced soil compaction in the studies described above. More than likely, freezing/thawing and wetting/drying together with the activities of microorganisms begin to reduce compaction as soon as it occurs. Payne et al (1983) using 2, 8, and 32 vehicle tracks repeated each month, May to September, found no carryover effects in the second year for the 2- and 8-trip treatments except when the soil was wet. Vehicular traffic that loosened soil also reduced infiltration and increased sediment yield in southern Nevada (Eckert et al 1979).

DESIRABLE TRAMPLING EFFECTS

Although trampling usually implies damage to vegetation and compaction of soil, a number of benefits result from the physical impact of animals. Without disturbance, the few millimeters of surface soil may become sealed, and thereby reduce intake of water and establishment of seedlings. The trampling action of livestock breaks the cap, moves soil, and helps to cover seeds. Holistic Resource Management (Savory 1988) emphasizes these benefits with little reference to physical damage by animals.

Trampling action lays standing dead material onto the soil surface, where decomposition increases the return of minerals to the soil. In addition, trampling reduces large accumulations of mulch and litter by breaking and stirring plant materials into the mineral soil. Like many other factors in moderation, a small amount of treading may be beneficial or show no detrimental effects.

Trampling or rolling for compaction of seedbeds on light soils tends to increase moisture retention, moisture per unit volume of soil, and improve several factors for plant survival (Hyder and Sneva 1956). Moderate trampling appeared to favor emergence of perennial grasses but heavy trampling favored *Artemisia* and some weedy annual forbs (Eckert et al 1986).

EFFECTS OF SOIL COMPACTION ON VEGETATION

Compaction of soil reduces root growth. Roots of *Bouteloua curtipendula* cv. Premier did not penetrate a compacted layer in old fields during the first year after seeding (Fryrear and McCully 1972). Soil compaction reduced yields of ryegrass/white clover pastures in New Zealand (Edmond 1963, 1966). Artificial trampling reduced ground cover and production of *Agropyron spicatum* and *Bromus tectorum* in southern Idaho (Packer 1953). Similar results were caused by elk on their winter range in southwestern Montana (Packer 1963). Compaction of soil below the plowed zone reduced emergence and first-year yields of seeded range grasses (Barton et al 1966).

Although most of these results confound grazing and trampling, they suggest that soil compaction reduces growth of roots and thereby lowers yield of tops. Apparently, dry soils do not compact easily. Extensive range grazing, much of it during the dry season, may have little effect on soil compaction and herbage yield.

Animals often walk the same paths again and again as they move across slopes or to and from water. In moist regions with a long growing season, the paths may be bare in the center and support annual grasses and weedy forbs along the edges. Tall growth at the path edge may result from increased soil water beneath the bare paths with less competition for it. Probably, treading exerts major influence in the paths and grazing exerts major influence away from them. These strips of different vegetational compositions in both dry rangelands and moist pastures suggest successional stages that result from various degrees of animal use.

EVALUATION OF PHYSICAL EFFECTS

Relating observed vegetational changes to their causes remains a difficult problem of separating multiple interrelationships. For example, disappearance of plant materials in grazed and ungrazed treatments may be due to foraging by insects, birds, and other animals; to trampling; to pulling or breakage of plants; to falling of mature plant parts such as flowers, lower leaves, and fruits; and to the shattering action of wind, rain, hail, and windblown materials. Regrowth may obscure these losses and further complicate measurement and interpretation.

Physical effects of animals are as ageless as the animal species themselves. England and DeVos (1969) reported the presence of fossil trails and wallows made by bison on the Canadian prairies. Burrowing animals have pushed more soil materials downhill than uphill for as long as these animals have existed. Ground birds have changed soil characteristics by their scratching and dusting; all animals have exerted pressure by walking; and many more physical effects have occurred during geological time. Therefore, trampling and other physical effects of animals are unavoidably parts of the grazing process.

As one evaluates these related effects, compensations or counter influences become increasingly obvious and the concept that physical effects mean damage becomes less acceptable. It is true that livestock compact the soil and break plants by their trampling, but immediately, other animals and the physical environment tend to reduce the compaction. Breaking of plants may stimulate them to new growth. Bare soil quickly becomes occupied with new plants. Populations of plants and animals succeed as their physical requirements become available, and they diminish as their surroundings become more favorable to other species. Thus, the physical effects of animals may be either desirable or harmful depending upon the context of evaluation.

Permanent changes in rangeland ecosystems can result from excessive physical effects of animals, but usually compensations quickly return the soil to its condition before the physical effects occurred.

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6

Energy Flow and Nutrient Cycling

The first two laws of energy in their simplest form are that energy can neither be created nor destroyed. In a grazing context, they imply that light energy captured by green plants will be transferred in excreta and heat to the atmosphere as it passes through the food chain.

The processes in the capture of energy, its flow, and cycles of carbon and minerals are the basic aspects of terrestrial ecosystem functioning. Understanding how herbivory affects those processes is the vegetational foundation of Rangeland Management. Investigating the interactions of plants, animals, and environment is in part determining the fate of energy and individual minerals in the rangeland ecosystem.

ENERGY CAPTURE

Through the photosynthetic process, plants capture energy from the sun, which is combined with CO_2 from the atmosphere and water and minerals from the soil to make the carbohydrates used in respiration. Part of the manufactured material is converted into more complex carbohydrates, proteins, vitamins, and other compounds that constitute the biomass of the plant itself. **Primary production is that biomass plus the respiration used to produce it. The net accumulation (respiration excluded) in one year is above-ground net primary production (ANPP), or NPP if the root system is included. Secondary production in the grazing context is the use of ANPP by herbivores.** They affect ANPP by a number of feedback mechanisms as shown in Figure 1-3.

Energy captured in the primary production of photosynthates and transferred to other trophic levels--herbivores, predators, and decomposers--is generally considered an inefficient process because most of the energy is dissipated along the way. Measurement and understanding of range ecosystem processes involve following such items as carbon, nitrogen, sulfur, phosphorus, potassium, and other essential minerals within each trophic level and from one level to another. The transfers of energy through biological systems and the cycling of minerals from soil through plants and back to the soil constantly change in rate and magnitude. Grazing systems or schedules are management tools to increase the efficiency of energy capture, harvest, and conversion of forage to salable products (Heitschmidt 1988).

ENERGY FLOW

Williams (1966) estimated that his range plots in the San Joaquin Valley, California, received 1,600,000 kilocalories of solar energy per square meter of which 700,000 or 44 percent were in the wave lengths usable by plants. ANPP amounted to 3,275 kilograms per hectare or 1,410 kilocalories per square meter. This was 0.09 percent of the total energy received at the site. Steers, one type of secondary producer on those plots, had a net productivity of 69 kilocalories per square meter for an efficiency of 0.004 percent relative to the total energy income. Snaydon (1981) shows that efficiency of energy use is in the neighborhood of 10 percent on a basis of energy of liveweight gain to energy in food consumed, 2.5 percent if it is to energy of herbage produced, and 0.017 percent if it is to total solar energy received.

Biomass and mean annual respiration of harvester termites in tropical regions may be of the same order of magnitude as that of mixed populations of mammalian herbivores in Africa and much greater than that of the marsupial fauna in northern Australia (Lee and Wood 1971). Macfadyen (1964) maintained that energy respired by a temperate meadow was divided about one-seventh by plants, two-sevenths by herbivores, and four-sevenths by decomposers. Microorganisms in the soil produce as much as 90 percent of the secondary production because of their large numbers and rapid metabolic rates (Macfadyen 1968). Apparently, far more energy is liberated through soil dwelling organisms than through above-ground herbivores. If this is so, the decomposers may limit range ecosystems, and "feeding them" through maintenance of soil organic matter and mulch would make more energy available for the secondary consumers in rangeland ecosystems.

MANAGEMENT BY ENERGY FLOW

Cook (1970) suggested that energy transfer presents a new approach to calculating biological efficiency of range ecosystems for domestic animals. On the assumption that 40 to 50 percent range utilization expresses forage consumption, between 18 and 25 percent of the herbage produced becomes metabolizable energy in cattle and sheep. Cook allocated that amount of energy among the various physiological functions such as reproduction, growth, maintenance of body heat, and travel. Different classes of animals had different energy requirements. For example, a yearling steer required energy equivalent to 0.85 of a nonlactating cow unit and about 0.67 of a cow-calf unit. A ewe and lamb rated 0.21 of a cow-calf unit on an energy basis. Cultural energy, nonsolar such as labor and gasoline, to produce a kilocalorie of meat was 2.24 kilocalories for sheep and 4.5 kilocalories for weaner calves (Cook et al 1976).

Energy transformation and animal responses can be used to establish standards for measuring range livestock production. Cook (1970) showed that summer mountain ranges in Utah produced about three times more energy than did desert winter ranges, and that steers converted dietary energy to meat about 45 percent more efficiently than did cows.

An energy budget shows the relative impact of different organisms. Partitioning of energy draws attention to points of energy dissipation where ecosystem modifications to increase efficiency of energy use may be effective. Because different kinds of animals use energy at different rates, biomass comparisons between such diverse species as grasshoppers, mice, and livestock have much less value than do comparisons of the energy they transfer.

Forage species differ in their ability to convert solar energy into a form that is digested by animals. Marlow (1984) found that *Agropyron cristatum* was more efficient in this respect than *Agropyron smithii, Bouteloua gracilis* and a number of other important range grasses.

Energy passes through biological systems with tremendous unrecoverable losses at each transfer. Because energy is not recycled, increased efficiency of energy use depends upon reduction of losses, and a gain of a few thousands of a percentage point is important to the land manager.

NUTRIENT CYCLING

A nutrient cycle includes the uptake or capture, utilization, and release of a nutrient into a form that can be reused. The nutrients of concern on rangelands are several minerals, carbon, and water.

Herbivores divert portions of plant nutrients into animal food chains. Unlike energy, which leaves the system when released from chemical bonds, nutrients return to the soil. They may be circulated from soil to plants to animals to soil numerous times. Each nutritive element follows its own particular pathway because each serves separate functions in the animal and is held by different chemical bonds. Grazing animals alter the pathways, change the rates of nutrient release by decomposition, and reposition nutrients in the pasture. The manager can add or remove a significant amount of nutrients from the area. Without herbivory, nutrients in vegetation leach directly to the soil or return to the air or soil via decomposition.

Generalized Nutrient Cycling

A generalized diagram of nutrient cycling is shown in Figure 6-1. The boxes represent nutrient accumulations, and the arrows show pathways of transfer from one sink to another. Descriptions abound of quantities of minerals in the various pools such as the soil and litter. A common type of study partitions or budgets the total quantity of minerals among all the compartments. Because increase in temperature indicates greater available energy and increased rate of growth, other studies have used the summation of degree-days to predict expected growth.

Detailed analysis of mineral reserves describes the system organization and provides a base for the study of mineral flow through the system, the system physiology. Such an analysis depends upon estimates of the size of the various nutrient pools and the transport of minerals from one pool to another. Transfers occur in both space and time. The annual cycle of plant biomass accumulation and litter decomposition has received much attention (Pieper 1974).

Grazing provides many routes of mineral transfer. Minerals in the dung and urine decompose at rates different from those of the uneaten plant litter. The herbivores may die, may be eaten by carnivores, or may be removed from the area by management (Fig. 6-1). Lemming cycles have been correlated with cycling of nitrogen, phosphorus, potassium, and calcium. Schultz (1969) speculated that primary production in the arctic grassland declines and the lemming populations crash when vegetation is overgrazed and a high proportion of the system's nutrients become unavailable in plant and animal detritus. As decomposition in the cold environment gradually releases the nutrients, primary production increases and the lemmings soon increase.

The pattern of accumulation and decomposition of dead herbage on rangeland is closely related to productivity. Early recognition of this point was evidenced in stipulations that proper utilization was removal of approximately 50 percent of the herbage crop. Mulch, litter, and plant residue, in terms either of amounts per unit area or of percent of soil cover, have been used to evaluate rangeland utilization, range condition, and trend. Generally, litter cover correlates directly with production, but an excess may decrease herbage growth.

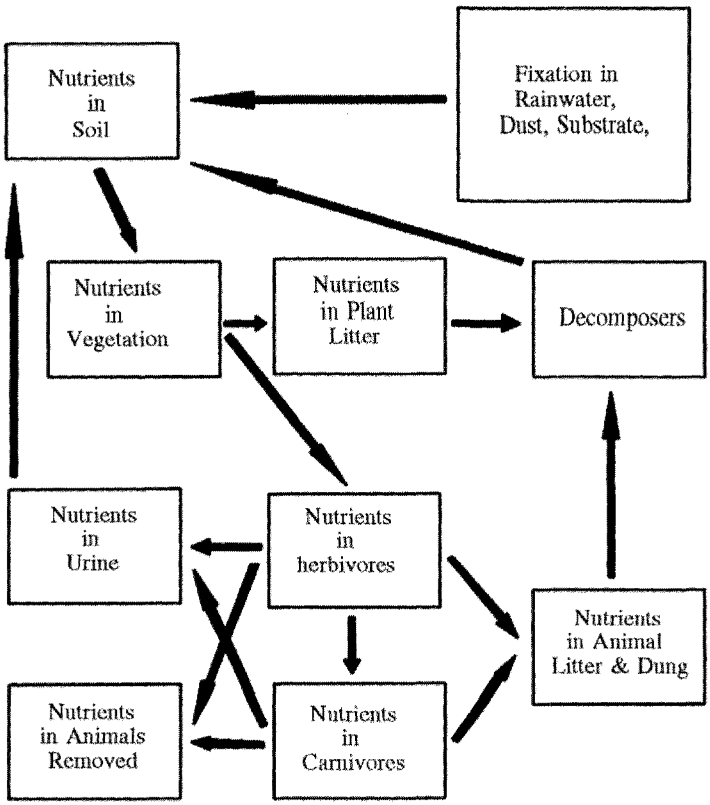

Figure 6-1 Generalized nutrient cycles in range ecosystems (Redrawn from Pieper 1974).

The dead herbage is an important but neglected constituent of pasture and rangeland systems. Beginning at the low point of plant residue accumulations, near the end of the rapid-growth season, amounts accumulate rapidly as current growth dies. Decomposition, consumption by invertebrates, and grazing by vertebrates gradually reduce the amount of residue until the next yearly increment. However, that addition does not occur as a single large amount at one time. Growth and decomposition overlap in time; for example, flowers and lower leaves in herbaceous vegetation begin to die very soon after they begin to grow. The living and dead herbage of grasses are tangled in space. Both the time-related and space-related variables are subject to modification by grazing as well as the physical environment. Dead herbage must be considered and used in the management of rangeland primary production.

After analysis of data in several papers, Pieper (1974) constructed an approximate budget of nutrient cycling in the desert grassland of southern New Mexico (Table 6-1). This table shows that domestic livestock at moderate stocking rates altered the routing of only a small quantity of minerals and that rodents were unimportant in the area. Commonly, amounts of soil minerals in reserves are many times the amounts of cycled minerals (Charley 1972). Microorganisms have been shown to use most of the net primary energy, so they probably cycle more nutrients as well.

Table 6-1 Annual compartmental budget, in kilogram per hectare, for quantities of five elements on a desert grassland range in southern New Mexico (Pieper 1974)

Transfer or Compartment	Nit.	Phos.	Pot.	Cal.	Mag.
Taken up by vegetation	6.6	0.3	4.5	1.4	2.1
Average wt. in herbage	4.4	0.2	3.0	1.0	1.4
Average wt. in litter	4.5	0.5	2.6	1.4	0.3
Transferred from litter to soil	4.5	0.5	2.6	1.4	0.3
Consumed by cattle	4.6	0.2	3.1	1.0	1.4
Consumed by rodents	0.19	0.01	0.13	0.04	0.06
Returned in feces	0.5	0.1	0.2	0.65	1.1
Returned in urine	3.8	0.03	2.9	0.25	0.2
Removed by sale of calves	0.26	0.07	0.02	0.10	0.003

Elements Returned to the Soil

Grazing animals return a large proportion of the consumed plant nutrients to the soil. Typical of data on the point are those of Hutton et al (1967) who found that dairy cattle voided most of the minerals consumed and retained less than 10 percent of any element. The elements were distributed in the following percentages:

	In Dung	In Urine	In Milk	Retained
Nitrogen	26	53	17	4
Potassium	11	81	5	3
Phosphorus	66	0	26	8
Sodium	30	56	8	6
Calcium	77	3	11	9

Most of the voided phosphorus and calcium occurred in the dung whereas the urine was rich in nitrogen, sodium and potassium. These values vary according to the nutrient content of the forage, condition of the animal, and physiological state of the animal. However, direct relationships were found for nitrogen in dung and in forage (Raymond 1966) and between nitrogen, phosphorus, and potassium in forage and in soil (Vandermark et al 1971). Between 80 and 95 percent of all ingested nutrients are returned to the soil in the excreta of domestic animals.

Elements from Other Sources

Rainfall, dust, and microorganisms that fix materials from the atmosphere continuously increase the reserves of nitrogen and several of the major minerals in the soil. Rock decomposition may be the only significant source of additional phosphorus for range soils. Decomposition of soil parent material adds other minerals to the available supply. Management adds minerals to any system by fertilization and supplemental feeding of livestock, which in effect borrows from some other system.

Fried and Broeshart (1967) showed that rainwater adds about 9 kilograms (range 2 to 45) of nitrogen to each hectare per year as a worldwide average. Sulfur additions in rainwater may be over 112 kilograms per hectare per year near industrial plants that burn large amounts of fossil fuel. Extensive rangelands receive less, perhaps as little as 100 grams per hectare per year. In Great Britain, Robertson and Davies (1965) showed that minerals added each year to a hectare of soil from rainwater in kilograms were calcium 7, magnesium 4, potassium 3, and essentially no phosphorus. Arid and semiarid regions with more dust than Great Britain have greater quantities of mineral in rainwater. Chlorine and sodium were concentrated near the oceans, potassium occurred uniformly across the continent, and calcium concentrated in dry regions (Junge and Werby 1958). Reduction of air pollution reduces mineral deposits on the soil.

Nitrogen fixation by *Rhizobia* on planted pasture legumes varied between 56 and 670 kilograms per hectare per year (Fried and Broeshart 1967). Most native legumes contribute nitrogen to rangeland ecosystems. Becking reported in 1968 that about one-third of the 330 species in 13 genera of nonleguminous seed plants were known to fix nitrogen symbiotically with the *Frankia* bacteria. Some of the genera are: *Alnus, Casuarina, Ceanothus, Discaria, Dryas, Elaeagnus, Gale, Hippophae, Myrica, Purshia,* and *Shepherdia.* Numerous species of bacteria, actinomyces, fungi, yeasts, and blue-green algae are known to be nonsymbiotic fixers of nitrogen from the air (McKee 1962). *Azotobacter* and *Clostridium* are nonsymbiotic nitrogen-fixing bacteria abundant in soil crusts of arid regions (Williams 1983). Nonsymbiotic nitrogen fixation is difficult to measure, but it is likely to be 22 to 56 kilograms per hectare per year on unfertilized pastures (Whitehead 1970). Nitrogen fixation literature is vast but an excellent summary is found in Vincent (1982).

Elements Lost from an Area

The bovine body contains about 20 percent ash and 80 percent protein on a combined fat-free and water-free basis (Reid et al 1955). Both water and fat contents vary tremendously but have little influence on the actual amounts of protein and ash. A 450-kilogram animal contains about 28 kilograms of 8 elements. If that animal were removed as a 2-year-old and had grazed the forage on 4 hectares, it would take with it less than 3.6 kilograms of the 8 elements per hectare as follows (Maynard and Loosli 1969):

Element	Amount in a 450 kilogram-cow, in kilograms	Amount removed per ha per year if animal grazed 4 ha for 2 years, in kilograms
Nitrogen	15.9	2.0
Calcium	5.9	0.7
Phosphorus	3.2	0.4
Potassium	0.9	<0.1
Sodium	0.7	<0.1

Sulfur	0.7	<0.1
Chlorine	0.5	<0.1
Magnesium	0.2	<0.1
Total	28.0	<3.6

Domestic animals that are sold or removed from the land take elements with them, but not large amounts. In contrast, grain crops may remove 67 to 78 kilograms per hectare per year of nitrogen, 11 to 17 kilograms of phosphorus, and 67 to 78 kilograms of potassium (Fried and Broeshart 1967).

Recoveries of fertilizer nitrogen in forages seldom reach 50 percent and many attempts have been made to account for the losses (Martin and Skyring 1962). Nutrients are eroded and leached from an area in runoff and ground water but the losses are seldom balanced against gains from the atmosphere, dust, and rock decomposition. Likens et al (1967) found that forested watersheds had losses of calcium, magnesium, and sodium but the losses were balanced with release from rocks through weathering.

THE NITROGEN CYCLE

Nitrogen, which is the largest component of air and tends to return to its relatively inert gaseous state in the atmosphere, is an ideal example of nutrient cycling. Unlike energy, which moves through an ecosystem once and is lost, nitrogen cycles continuously from the atmospheric and soil reservoirs to primary producers, to consumers, and back to the reservoirs. None is lost from the system, although time may need to be reckoned on a geological basis for completion of the longest cycles. Pathways that nitrogen may follow are numerous and complicated.

Figure 6-2 depicts a generalized nitrogen cycle for rangeland. It indicates that losses and gains occur continuously as nitrogen moves from place to place and alters in chemical form. Figure 6-2 should be considered a flow chart of possibilities, not a closed cycle or a steady state of nitrogen movements. Nitrogen was selected to illustrate cycling because of the key role it plays in range production, the large body of available information about it, and the emphasis on urinary nitrogen describing animal influences.

Urinary nitrogen from cattle and sheep is approximately 76 percent in urea form, 12 percent in amino acids, 1 percent ammonia, and the remainder in numerous other nitrogenous compounds. Most of the amino form of nitrogen is glycine. Depending upon temperatures and soil moisture, urinary nitrogen moves rapidly through the various pathways in the nitrogen cycle (Fig. 6-2), and its effects on plants may disappear in a few weeks.

Nitrogen deposited on the leaves may be absorbed or returned to the atmosphere. Most of it, however, is added to the soil reservoir, where it changes to ammonia, to nitrite, and finally to nitrate. At each step, nitrogen may be absorbed by plants, lost by leaching, or returned to the atmosphere. Volatilization results when ammonia is formed from chemical decomposition of nitrogen oxides and by enzymatic reduction of nitrogen oxides.

Simpson and Freney (1967) found that nitrogen reactions were most rapid in soils with low quantities of nitrogen. However, Power (1972) claimed that fertilizer nitrogen may become immobilized in any part of the cycle and suggested a 3- to 4-year cycle of complete nitrogen turnover in the northern Great Plains. The rate of nitrogen release from dung is probably slower than from decomposing plant litter. On balance, turnover of nitrogen is accelerated by passage through animals but, like other nutrients, it may go into reserves anywhere in the cycle.

Hannon (1958) in Australia suggested that less than 0.1 percent of the total nitrogen in soil actually cycles. Williams (1964) working with improved pastures, accounted for 7 percent of the total nitrogen that annually cycled through plants and animals. Nitrogen fixed in the yearly crop of California annual grassland averaged less than 22 kilograms per hectare and accounted for less than 0.5 percent of the total nitrogen in the soil/plant system.

THE SULFUR CYCLE

Sulfur, like nitrogen, is cycled (Fig. 6-3) from soil through plant and animal and back to the soil (Blair 1971). The sulfate ion (SO_4) is the principal form of sulfur used by plants. The sulfur cycle begins with the oxidation of rock sulfides and elemental sulfur into sulfates. These may be leached from the soil, precipitated as sulfate salts, absorbed on the surface of clay particles, absorbed by organisms, or reduced to sulfides. Sulfur is added in fertilizers, introduced into the cycle in rainwater, and absorbed as SO_2 from the atmosphere. The sulfur that becomes bound in organic matter is unavailable to plants and must be converted to sulfate form, largely by microbial action, before it can be used again.

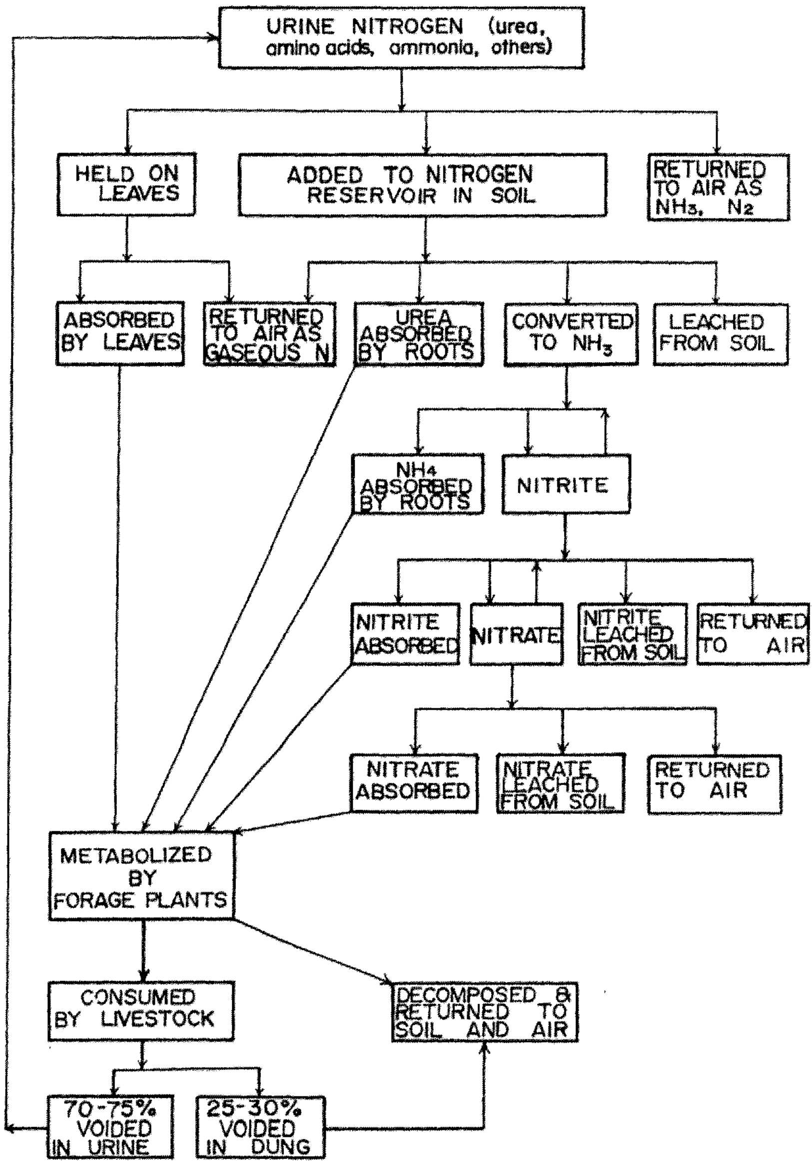

Figure 6-2 The nitrogen cycle on rangeland, with emphasis on urinary nitrogen.

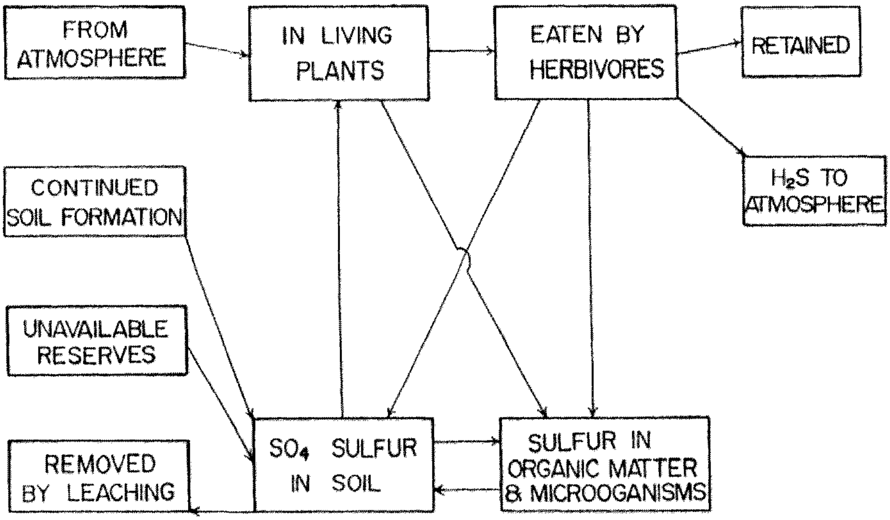

Figure 6-3 The sulfur cycle in a rangeland context. (After Till and May 1970)

The ultimate source of sulfur, unlike that of nitrogen, is the soil parent material, which releases sulfates during weathering. Much of the sulfur in range ecosystems is associated with plants, animals, and organic detritus. In Australia, Till and May (1970) found about 200 kilograms per hectare total sulfur of which 14 kilograms were available to plants and 100 kilograms were in the cycling pools (Fig. 6-3). Undoubtedly other grazing situations would show different amounts. These authors maintained that the sulfur cycle formed a highly complex closed system with few losses and small additions from fertilization. A 450-kilogram steer has about 0.7 kilogram of sulfur retained in its body. It probably consumed 9 kilograms of sulfur in a year, nearly all of which was returned to the soil. Voided sulfur is about 30 percent in dung and 70 percent in urine (Walker 1957).

CYCLES OF PHOSPHORUS AND POTASSIUM

Animals influence rates and amounts of other cycling elements as well as those of nitrogen and sulfur. Voided phosphorus occurs almost completely in the dung, where it apparently is more concentrated than in the original feed. It leaches slowly from dung, especially that of sheep and other animals that produce pellets. Approximately 20 percent is inorganic and readily available to plants (Bromfield and Jones 1970). Organic phosphorus in dung becomes slowly available to plants as the dung decomposes. Phosphorus in the herbage amounted to approximately 0.2 percent of the total in the vegetation/soil system (Heady 1965).

Complexity of mineral cycling is further illustrated by phosphorus turnover within the ruminant animal (Tomas et al 1967). Saliva constitutes the principal source of phosphorus for rumen organisms. It determines the inorganic phosphorus level in the rumen fluid. The cycle is from gut to blood to saliva to rumen.

Potassium, mostly in the urine, is readily absorbed by plants; hence its effectiveness disappears in a few months. Potassium is the third element in the label on fertilizers. The key to a favorable response to fertilization with nitrogen and phosphorus on some soils may be potassium in the urine of grazing animals. Nutrients in animal excreta have interacting influences with fertilization.

MANAGEMENT BASED UPON MINERAL CYCLING

Animal matter is likened to a chemical engine that transforms the energy of plant biomass to usable form. Minerals are important to that transformation. Availability to plants of all minerals except phosphorus appears to be enhanced by passage of herbage through grazing animals. Animals increase the rate of cycling, especially of those ions, such as chlorides and nitrates, which move easily in soil solution. Evidence supporting this contention appears in the relationships of animals to pasture productivity. Frame (1970) showed that dung patches in pastures have the equivalent of over 112 kilograms per hectare of phosphorus and 224 kilograms per hectare of potassium. Urine spots equal fertilizer rates of nitrogen above 336 kilograms per hectare and potassium rates above 560 kilograms per hectare. From 50 to 60 percent of the deposited nutrients become effective in forage production.

While many of the results described were found on pastures with high stocking rates, it would be logical that they should apply to rangelands. Low rainfall and low stocking rates should change only the speed of cycling and the amounts of nutrients in the cycle. Although not reviewed here fertilization of rangelands nearly always increases above-ground biomass production (Wight and Black 1972). Equally important is the below-ground biomass and soil organic matter because they are directly related to rapid and sustained nutrient cycling (Woods and Schuman 1986).

Decomposition rates of dung from large animals depends upon coprophagous insects in many regions of the world. Their activities incorporate dung into soil, reduce infective stages of parasitic worms, reduce breeding areas for flies, and increase rates of mineral cycling. Dung-feeding insects have been shown to vary in kinds and numbers in different adjacent vegetation types (White 1960). Dung beetles have been imported to many parts of the world to increase organic matter decomposition and improve soil fertility.

The managerial bottleneck in mineral cycling rests in the slow decomposition of organic accumulations. Management to increase the rate of mineral turnover includes trampling and laying of standing dead materials so that contact with moisture and soil organisms is increased, addition of nutrients to reduce imbalances, and spreading of unnecessarily large accumulations of litter and dung.

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7

Redistribution of Minerals by Plants and Animals

The supply of nutrients in the ecosystem constantly changes. Increased and improved nutrient availability results from weathering of rocks, deposit of erosion products, precipitation and fixation from the atmosphere, immigration of organisms, and fertilizer applications. This chapter describes the redistribution of minerals attributable to the presence of plants and actions of animals. Displacements in quantities of minerals occur vertically and horizontally. An influx one place means an outflux from another. Although nitrogen is a gas, many references to nitrogenous compounds are made in this chapter.

REDISTRIBUTION BY PLANTS

Roots gather minerals from a wider area than that receiving most of the litter fall; thus localized concentrations of minerals and organic matter occur under perennial plant canopy. This movement of minerals has been examined in many ways: as a vertical and horizontal mosaic of minerals, microhabitat, and kind of organism; as an annual cycle of production, deposit, and decomposition of litter; as variations among regions due to climate and vegetational types; in relation to plant succession and changing species composition; and as the reason for changing mineral status of soil.

Gradients of minerals, organisms, and microenvironments occur because perennial plants are discrete and live sufficiently long for striking patterns to develop. Open canopies foster mosaics, which may be highly regular or random in their distribution. Once formed the pattern may remain, as shown by gradients of nitrogen around stumps of the legume *Acacia aneura* and chlorides of sodium and potassium around *Atriplex vesicaria* (Charley 1972). Perennial herbaceous plants and even annuals contribute to the mosaic, which are also patterns of foods and cover for animals. They may be altered in their development by grazing animals.

Trees

The transfer of various chemical elements between trees and soil follows a number of routes and occurs at different rates according to the species of plant, kind of chemical, and weather. Radioactive elements introduced into roots and stems rapidly pass into other plant parts, from which they may be leached by rain, fall in leaves, bark and woody material, and released from the roots. Rainfall under *Pseudotsuga menziesii* contained as much phosphorus and twice the potassium as that dropped in litter fall (Will 1959). Potassium, calcium, magnesium, and sodium occurred as leachates in rainwater that dripped through tree canopies and flowed down the stems (Carlisle et al 1967). Part of the nutrients taken-up by the roots return to the soil without intervening leaf fall and decay.

After rapid initial leaching of soluble nutrients, further release from wood and litter occurs slowly by decomposition, which may be the limiting factor on rate of nutrient cycling (Olson and Crossley 1963).

Botanical composition of the herbaceous vegetation differs under tree canopy from that in open areas. Plant development may be somewhat later under the trees, and differences in selectivity of forages occur between shaded and sunny sites. These differences may be due in part to the combined redistribution of nutrients by both plants and animals. If the woody plants are removed, soil phosphates and other accumulations slowly decrease to the grassland levels but evidence of the mosaic may last for decades.

Engle et al (1987) found the standing crop under *Juniperus virginiana* trees to be less than in the open. Armentrout and Pieper (1988) described differences in botanical composition radiating from the bases of *Pinus monophylla* and *Juniperus osteosperma*. The influence of *Acacia karroo* on grass production in its vicinity appears to be little different whether there are few trees or no trees at all (Stuart-Hill et al 1987) but grass decreases above a threshold of 300 trees per hectare (Aucamp et al 1983). Biomass production of California annual grassland is generally higher under scattered *Quercus douglasii* and *Q. wislizenii* than areas without the tree canopy (Frost and McDougald 1989). Above a certain threshold of canopy density understory growth will decrease.

Shrubs

Shrubs as well as trees accumulate minerals from the adjacent openings and enrich the soil beneath their canopies. Nutrient and organic matter gradients become increasingly sharper with increasing aridity, especially where individual shrubs are separated by unoccupied surface soil, as in most arid shrublands. Closed canopies often show little pattern in the distribution of nutrients (Charley 1972). Generalized distribution of nitrogen under a bush of *Atriplex vesicaria* (Fig. 7-1) illustrates concentration near the soil surface and somewhat to one side of the central stem due to wind action, slant of the sun, and gravity on sloping land. Oxygen uptake and nitrification under *Atriplex* bushes averaged about twice that in the interbush area. The shrubs may be cycling nitrogen, speeding the nitrification process, or doing both (Rixon 1971). Nitrogen in soils under *Acacia greggii*, *Cassia armata*, and *Larrea divaricata* decreased significantly as a function of distance from the center of the shrub canopy (Garcia-Moya and McKell 1970).

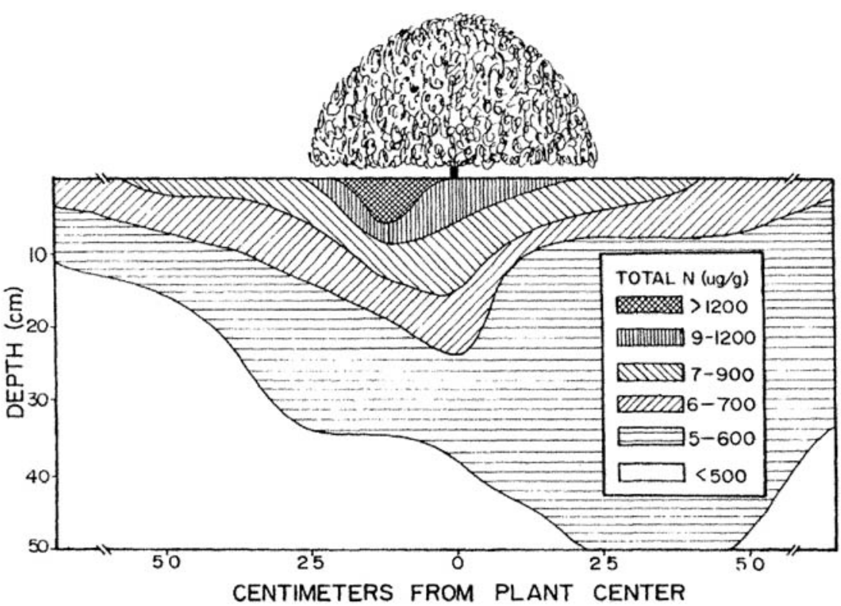

Figure 7-1 Distribution of nitrogen in the soil beneath a single bush of *Atriplex vesicaria* (Charley 1972).

Distributions of other nutrients, as well as nitrogen, correlate with shrub presence. Several species of *Atriplex* concentrate salts of sodium, potassium, calcium, and magnesium in their leaves and fruiting bracts (Sharma 1973, Sharma and Tongway 1973). These minerals tend to reach constant accumulations in the plant parts, regardless of soil content. Species vary in their ability to concentrate minerals in their structure, hence the soil beneath them. For example, *Grayia spinosa* had abundant potassium in the leaves and so did the soil under the canopy, but *Sarcobatus vermiculatus* showed the same relationship with sodium. *Bromus tectorum* reflected the concentration with higher sodium content when growing under *Sarcobatus* shrubs than between them (Rickard 1965). *Prosopis juliflora* gathers nutrients and changes physical characteristics of soil under its canopy (Tiedemann and Klemmedson 1973).

REDISTRIBUTION BY LARGE HERBIVORES

Large herbivorous animals tend to concentrate near water, salt, feeding areas, bed-grounds, and shade. These are focal points to which animals move in more or less regular daily or seasonal migratory patterns. By consuming forages away from the focal points and depositing excreta near them, animals cause a redistribution of minerals. Hilder (1966) found that sheep deposited about a third of their excreta on only 5 to 7 percent of the total area of pastures 40 hectares in size. About 30 percent of the pasture tended to became enriched and 70 percent impoverished. Earlier in the same study, Hilder and Mottershead (1963) showed that sheep bed-grounds, in comparison with areas 128 meters away, had twice the total nitrogen and exchangeable calcium, 5 times the magnesium, 14 times the available phosphorus, and a 130-fold increase in potassium.

Weir (1971) described a situation in Wankie National Park, Rhodesia, in which herds of about ten species of wildlife gathered around water during drought. Accumulation of minerals occurred within a kilometer of water and depletion occurred from 3 to 5.5 kilometers away from water. Losses of minerals were likely in the area along the edges between grassland and woodland, a favorite grazing habitat for several species. Not only do animals redistribute nutrients that they consume, but also they remove nutrients disproportionately because of their selectivity for certain forages and locations (Van Dyne and Heady 1965).

Many factors alter these influences. Effects of urine decrease outward in a linear manner from the patch center. The greatest impact of dung on vegetation occurs under the deposit and at its edge (MacDiarmid and Watkin 1971). Rapid losses of moisture and ammonia immediately follow deposition of both dung and urine. After initial decomposition of fine materials, disappearance of dung occurred at a slow rate and from the soil surface upward. If the upper surface of the dung pat dries, it tends to shed rainwater and remain for a year or two before disappearing. Both the magnitude of effect and rate of decomposition directly relate to precipitation and temperature, to rate of plant growth, and to actions of coprophagous insects (Davies et al 1962).

The return of dung and urine to pastures may increase production of forage and alter botanical composition. However, effects are temporary except where animals congregate and enrich the soil with large accumulations. On rangeland this is less than 5 percent of the pasture but it may be important on riparian habitats.

Forage production on ranges and pastures depends upon grazing intensity, selectivity by animals, trampling, and many other influences that have not been separated from the redistribution of nutrients by animals. Little wonder that contrasting results accrue from different studies. Still, abundant observations have established that the congregation of grazing animals increases soil mineral content, which becomes noticeable in the species composition of the vegetation. Management should consider techniques of mechanical spreading of dung concentrations and of rotating the deposition away from central water points.

REDISTRIBUTION BY OTHER ANIMALS

Other animals in addition to the large herbivores consume foods in one place and concentrate their waste at a central point in their territories. Some cache organic materials as well as concentrate waste. Termiteria in Africa are richer in nutrients than are the surrounding soils because of the gathering of plant materials by the termites and their use of salivary and fecal materials to cement the soil. Lee and Wood (1971) found 2- to 10-fold increases of nitrogen, phosphorus, calcium, and potassium in a mound of *Nasutitermes triodiae* in northern Australia. These authors cited other studies that illustrate nutrient gathering by several soil animals as shown in the Table 7-1.

The conclusion that all animals alter the distribution of nutrients seems reasonable, although the influence of many species on their habitats has not been determined.

Table 7-1 Nutrient gathering by several small animals	In termite galleries	In anthills	In earthworm casts	In soil
Nitrogen, %	0.102	0.126	0.192	0.087
Phosphorus, %	1.200	0.058	0.061	0.041
Potassium, %	0.610	0.370	0.390	0.480

MINERAL BUILD-UP DUE TO LIVESTOCK FEEDING

Confinement and feeding of animals, as with dairies and feedlots, accumulates waste materials resulting in high mineral concentrations in soil and water. Stewart et al (1967) found about 100 kilograms per hectare of nitrate in a natural grassland in the North Platte River Valley and 16 times that amount under corrals. The element of greatest concern is nitrogen because it may exceed health standards, which differ from one area to another and over time as new data become available. Nitrate standards are based on dangers of methemoglobinemia, which may occur when the body converts nitrates to nitrites. Excessive concentrations of nitrates in feed and water endanger both livestock and humans.

Minerals concentrated in corrals or in home and community sewage systems often find their way into ground water, streams, and lakes. This fertilization of the water may increase algae and other aquatic plants, eventually resulting in large amounts of decaying organic matter that reduce oxygen content of the water, kill fish, and cause unpleasant odors. Other sources of leached minerals include fertilizers used on rangeland and cropland; decomposing crop residues; industrial discharges; and natural sources such as erosion, fixation from the atmosphere, rainwater, and rock decomposition.

Nitrogen undergoes rapid and complex transformations as it moves in and out of soil reservoirs. The principal soil losses of nitrogen are leaching of nitrates, denitrification, and volatilization of ammonia. Shallow wells and surface water generally have much more nitrate than do deep wells. Smith (1967) maintained that most nitrate in water comes from natural sources and that little comes from fertilizer nitrogen. The most common minerals in underground water are calcium, sodium, potassium, magnesium, and ammonium. Usually, abundance of these and other minerals relates directly to composition of local soil and rocks.

However, excessive nitrate in water does occur in relation to livestock concentration and to crop fertilization.

High amounts of phosphorus and other elements that rapidly become fixed on soil colloids result from direct discharges of sewage and industrial wastes. Eroded soil material from runoff plots in Wisconsin contained 3 times the available phosphorus and 19 times the exchangeable potassium found in the soil proper (Massey and Jackson 1952). Radioactive phosphorus, potassium, and calcium moved more rapidly into a forest soil as a result of colloidal particle transport and faunal activity than by leaching (Riekerk 1971). Normally, water filtered through soil does not contain large amounts of readily fixed elements until saturation has been exceeded.

MANAGEMENT BASED ON MINERAL DISTRIBUTIONS

Movements and distributions of minerals are important to rangeland management, especially when the whole range is considered. Corrals need to be below the domestic water supply to lessen danger of pollution. Winter feeding of livestock should be located in a different area each year to lessen concentration of nutrients that increase danger of discharges into surface water and shallow wells. Domestic water supplies should be sealed and wells adequately cased to prevent contamination from corrals, septic tank drain fields, and fertilization of crops and gardens. Each ranch presents its peculiar problems in positioning of water supply, homestead, and livestock.

Nitrate leaching and cycling appear to be related to depth of moisture penetration (White and Moore 1972). Where annual precipitation is too low to leach minerals beyond the root zone, an occasional flood or unusual weather may cause pollution of water supplies if care has not been taken in positioning the various ranch functions.

Grazing management obviously plays an important role in nutrient cycling and redistribution. Proper grazing protects the soil resource from accelerated erosion that carries away valuable elements. Control of animal distribution minimizes nutrient redistribution by preventing local overgrazing and longterm livestock concentration. Recognition that patterns of minerals and organisms occur naturally and that the animals themselves contribute to the mosaics, provides the land manager with a better understanding of the landscape.

The mineral pattern formed in one vegetational type continues when another vegetation is established. The effect may be seen as varied results of plot treatments, varied success in seeding, patterned response to fertilization, and areas selected by animals for grazing. The "tracks" of previous plant and animal communities may disappear slowly.

Reestablishment of original assemblages often follows the original pattern.

People on small acreages in Africa and other parts of the world have used redistribution and management of minerals to increase total production and kinds of products from their farms. The central effort is to stall feed a cow or two with hand-cut and carried forage, and poultry in cages away from predators. Manure from the stall and the poultry goes to the cropland as each new crop is established.

Normal expectations from establishment of this mineral-management system would include (1) as much crop productivity from less land than before because of improved soil mineral status and physical conditions; (2) improved nutrition for the family because of better quality crops, proteins in the diets from the stall-fed animals, and more eggs from the chickens; (3) less soil erosion because forage crops are rotated with food crops; (4) more cash flow to the small farmer; (5) reduced livestock trespassing on crops; and (6) relief to overgrazed rangeland surrounding the farms. Professional range managers find that rangeland improvement may come more easily with an indirect attack, as illustrated by this example, rather than with a frontal attack on the rangeland itself.

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8

Distribution of Plants by Animals

The fact that a plant grows on a spot of soil indicates that somehow a seed or other bit of germplasm arrived there and became established. Aspects of plant/animal interactions include plant/microbe associations, pollination, seed predation, seed dispersal, and herbivory (Archer and Pyke 1991). Any one of these factors may influence the composition of vegetation over time and space (Louda 1982). This chapter principally concerns the dispersal of plants by herbivorous animals.

Aside from human activities, animal dispersal of seed plants probably is the most effective means by which plants are moved. Wide distribution of seeds by animals was claimed by Willson et al (1990) to be of importance in understanding vegetational changes, especially on reclamation projects. A large number of plant species have developed animal dispersal mechanisms. Apparently, every animal that is large enough to move seeds does so. Animals actively transport disseminules to nests and caches. They egest unharmed at least a few seeds of most ingested species, and they passively carry disseminules that adhere to fur, feathers, and feet. The materials moved may be seeds, fruits, living pieces of plants, and whole plants. **Distribution of plants by animals is considered here to mean movement of disseminules beyond the territory where they normally would occur without animal influence.**

ACTIVE TRANSPORT

Among small mammals, birds, termites, and ants, numerous species gather and store plant disseminules in their nests and in other hiding places, usually small excavations in the soil. More material is collected than consumed, caches may not be found, and mortality of the caching animals results in hidden material not being eaten. Active transport may be the principal dispersal mechanism for large fruited species such as oaks, walnuts, and hazelnuts. Obviously this activity, as well as other types of dispersal, peaks at the time of seed maturity.

Birds and rodents are the most effective transporters. For example, the jay in England actively buries acorns, one per hole, for about two months each autumn in a radius of about 1 kilometer from the source (Chettleburgh 1952). La Tourrette et al (1971) stated that active transport influences the dynamics of plant populations by enhancing plant establishment. Caching of *Purshia tridentata* seeds in small soil pits by rodents has occurred as far as 300 meters from any seed source (Nord 1965, West 1968).

Clusters of perhaps a dozen seedlings may appear if a cache is not disturbed. Saunders et al (1973) wrote that clumps of *Ribes velutinum* are the result of rodent activity. The kangaroo rat and Great Basin pocket mouse in Nevada cache seeds of *Bromus tectorum, Agropyron intermedium, Agropyron cristatum, Chrysothamnus* spp. and many other species in soil pits about 5 centimeters deep and 3 centimeters wide. One pit contained 65 plants and 155 seeds of *Bromus tectorum*. Heteromyid rodents generally recover few cached seeds, leaving many planted (McAdoo et al 1983). Other species of kangaroo rats and pocket mice in Arizona cached and favored establishment of *Prosopis, Opuntia,* and large-seeded grasses (Reynolds 1950). Rodents have been shown to decrease seed reserves in the California annual grassland (Borchert and Jain 1978). Spores of 15 genera of mycorrhizal fungi were found by Maser et al (1988) in the stomachs of 575 small mammals (16 species).

The seeds collected by harvester termites and stored in their nests may be exposed and planted by termite-eating mammals that destroy the nests. Bare soil and vegetation of low density around termite mounds often become colonized with *Cynodon* spp. in subtropical grasslands. Collection of seeds helps establishment of the particular vegetation found on and near termite mounds.

Accumulation of seed and chaff from consumed seed around an ant mound indicates that harvester ants occupy the burrow. They do not transport seeds for great distances, but the diffusion of plants in the locality is altered and planted seed for rangeland improvement may be eliminated. Working on the Sonoran Desert of southern California, Tevis (1958) found that the ant *Veromessor pergandei* selected and gathered 8 percent of the seed crop of three planted species. He concluded that *Veromessor* had no significant influence on supply of native plants.

INGESTION AND SPREAD OF FRUITS

Animals spread plants by ingesting seeds at one location and egesting them at another. Passage through the digestive tract often increases percentage germination. In reviewing 94 papers on the dispersal of viable seeds by birds, McAtee (1947) found that crow droppings contained more than two viable seeds per gram and that some 50 avian species ate and voided the seeds of *Juniperus virginiana*. Predators that feed on seed eaters secondarily disperse seeds. The killdeer and mallard duck egested seeds of many aquatic and semiaquatic plants in viable condition. Many hydrophytes have small, hard seeds; thus they can pass unharmed through the gizzard and are resistant to digestive acids (DeVlaming and Proctor 1968). Ringnecked pheasants and bobwhite quail destroyed beyond recognition the seeds of 3 common fencerow plant species but voided at least a few seeds of 16 species (Krefting and Roe 1949). Olson and Blum (1968) found viable seeds in all parts of the digestive tracts of tropical birds.

Riegel (1941, 1942) recovered viable seeds of several grasses and *Opuntia* spp. from pellets of cottontails and California jackrabbits. Ten herbaceous species germinated from deer fecal pellets placed on sterile sand in a glasshouse (Heady 1954).

Apparently ruminant animals will pass a few seeds of nearly every species that they consume. Burton and Andrews (1948) recovered the following proportions of seeds fed to dairy cows: one-half of *Paspalum notatum* and *Cynodon dactylon*, one-third of *Axonopus affinis* and *Sorghum halepense*, one-fourth of *Paspalum dilatatum*, and one-eighth of *Lespedeza striata*. Seeds of six common farm weeds were recovered at average rates of 11 to 24 percent when fed to calves, horses, sheep, and hogs, but few survived digestion by chickens (Harmon and Keim 1934). McCully (1951) recovered half the *Rosa bracteata* seeds fed to mature cows, and 90 percent of the seed showed no damage. Thirty percent of hard seed but only 3 percent of scarified seed of *Trifolium repens* passed through sheep (Suckling 1952). Sheep grazing rangeland in California voided 15 species as determined by germination tests with seeds in fecal pellets (Heady 1954). Based on germination tests of seed in dung, Dore and Raymond (1942) claimed that in a grazing season a single cow on pasture redistributed 36 species totaling over 900,000 viable seeds.

Seeds that pass through digestive tracts unharmed include desirable pasture grasses and legumes, undesirable range species, and weeds of cultivated crops. Fecal pellets of sheep and jackrabbits collected where animals had been grazing areas heavily infested with *Halogeton glomeratus* contained 14 and 18 viable seeds, respectively, per 500 grams of material.

This quantity is sufficient for sheep to have spread *Halogeton* over its wide area of distribution (Cook and Stoddart 1953).

Studies to determine the reasons for *Prosopis* invasion into semiarid grassland of the southwestern United States implicate livestock, deer, peccary, cottontail rabbits, jackrabbits, coyotes, rodents, and Gambel's quail for their roles in seed dispersal (Reynolds 1954). Between 12 and 45 percent of hard *Prosopis* seeds passed through livestock unharmed (Reynolds and Glendening 1949). Twenty-seven percent of the total seeds fed to sheep germinated after egestion (Glendening and Paulsen 1950). Many rodent caches remained unopened and produced *Prosopis* seedlings, sometimes several years after the cache was deposited (Reynolds 1958). Rodents, most of which have small home ranges, may not carry the seed more than 100 meters and would seem to be less important distributors than are the larger animals. Livestock trailed at the rate of 15 kilometers per day might transport *Prosopis* seeds in their digestive tracts more than 100 kilometers.

Some seeds show improved germination following passage through a digestive tract. Passed in dung, *Rosa bracteata* seed germinated at a 50 percent rate whereas the controls and stratified seed failed to germinate (McCully 1951). *Opuntia* seed germination increased 50 percent after passage through jackrabbits (Timmons 1942). Pronghorn appear to be spreading *Astragalus cicer*. Consumption of the wild tomato (*Lycopersicon esculentum* var. *minor*) by the giant tortoise on the Galapagos Islands broke dormancy of the seed and increased germination from 0 to 80 percent (Rick and Bowman 1961). Many more examples were reviewed by Howe and Smallwood (1982).

The seeds of different species germinate differently in response to passage through the digestive tract. About half the species fed to pheasants and quail showed no change in percentage germination (Krefting and Roe 1949). *Cynodon dactylon* was the only one among seven southern forage species which increased in germination rate after passage through cattle. The other species decreased (Burton and Andrews 1948). *Atriplex confertifolia* was the only one among seven common species of the sagebrush/grass type in southern Idaho which showed increased germination by passage through sheep. *Bromus tectorum, Elymus caput-medusae,* and *Agropyron cristatum* exhibited >90 percent germination before and <2.4 percent after consumption by sheep, but jackrabbits reduced germination of the three species to <0.6 percent (Lehrer and Tisdale 1956). The soft seeds of grasses quickly lose viability in the bovine intestinal tract and so will hard seeds if they remain in the rumen after completion of scarification (Archer and Pyke 1991).

PASSIVE TRANSPORT

Adaptations of seeds and other plant parts which facilitate their dispersal by animals include burrs, hooks, barbs, mucilaginous coverings; and retrose arrangement of hairs, spines, spikelet parts, etc. Large accumulation of *Xanthium* burrs in the tails of livestock, *Stipa* and *Erodium* fruits under the skin of sheep, and cactus joints hanging on the faces of cattle illustrate obvious dispersal mechanisms. One hundred eighty hares of 369 (*Lepus capensis*) collected in Kenya had 810 disseminules in their fur that included 17 plant species (Agnew and Flux 1970). Since these hares groom themselves daily, the number of seeds they carry in a season must be considerable. The magnitude of seed dispersal by animals may be greater than commonly realized.

Seeds of *Elymus caput-medusae* are carried and spread by humans and machinery as well as by animals. Clifford (1956), working in England, listed 43 species that he found in dried mud on footwear; the maximum disseminule number in one sample was 176. In a later Nigerian study (1959), he found over 40 species in samples of mud taken from automobiles. This material averaged one to two seeds per 10 grams of mud. Clearly, people and their equipment are agents of plant dispersal.

Robbins (1940) listed 526 alien species growing without cultivation in California and stated that the invasion began in 1769 with the first permanent settlement at San Diego. Very likely, alien plants arrived to stay in California before 1769. Packing materials and livestock debris cast overboard from sailing vessels along the California coast no doubt contained seed as well as that carried by animals and men put ashore on short trips. The first European settlers into Mexico and the eastern United States arrived long before 1769, and plants brought by them could have been spread by migrating birds and mammals. In fact, once an alien plant species arrives onto a new continent, it has potential to spread and occupy suitable habitats throughout that continent without further dispersal by people.

People have been responsible for the movement of many plants and animals from one continent to another and from one small location to a spot nearby. Let a few examples of noxious species suffice rather than extensive literature review. The rhizomes of *Convolvulus arvensis* have been spread by machinery from one field to another; introduced ornamentals have become pests; several Eurasian *Centaurea* species spread readily from rangeland to farmland; and *Taeniatherum asperum* has been spread over rangeland by sheep.

MANAGEMENT IMPLICATIONS

Dispersal of plants by animals and humans has a number of implications for management of rangelands. Clean feeds, seed, truckbeds, shoes, and trouser cuffs obviously reduce chances of invasion by undesirables.

Duration of Seed Retention in Digestive Tracts

Apparently cattle retain a few seeds in their digestive tracts for seven to ten days (McCully 1951, Burton and Andrews, 1948). After feeding known quantities of *Trifolium repens* seed in gelatin capsules to sheep, Suckling (1952) found the first seed in the dung 24 hours later, the maximum number on the second day, and decreasing amounts through the sixth day. One autopsied sheep had 1,559 seeds in the digestive tract, mostly in folds of the omasum, six days after feeding. Sheep in Idaho were found to retain viable seeds for nine days, and New Zealand rabbits still had seeds after four days (Lehrer and Tisdale 1956). Trailing and hauling of animals spread the retained viable seed along stock routes.

Other animal species may retain seed for various intervals; for example, the maximum seed retention time was five days for killdeer and four days for mallard ducks (De Vlaming and Proctor 1968). Different seed species pass through a single animal at different rates. Details are largely unknown, but small, hard seeds are likely to be retained longer and with less reduction in germination than are large seeds and those that rapidly imbibe water. Cud chewing, grinding in gizzards, and contact with digestive acids do not destroy all seeds.

Longevity of Seeds in Dung

Harmon and Keim (1934) found that seeds of six common weeds lost their viability within four months of burial in fermenting manure, but *Trifolium repens* showed 16 percent germination after burial in dung for five months. Manures used for fertilizer may contain viable seed of undesirable species. Although return of feedlot manures to rangeland may not be a common practice and seeds may not survive long storage in manure, alien plants may become established in a corral area where shipped livestock are unloaded. They may spread from there.

The Use of Animals to Spread Seed

Animals can be used to spread desirable forage plants. Burton and Andrews (1948) mentioned cattle as a factor in the spread of *Axonopus affinis* in the South and suggested this method as an aid to reseeding in the piney woods. *Medicago hispida, Oryzopsis miliacea,* and *Trifolium hirtum* have become established by feeding seed to sheep and cattle, but the practicality of this method of seeding rangelands is doubtful, although interest in the practice continues.

Feeding hay with seed attached results in subsequent seed dispersal by animals. For example, a number of northern European hay grasses are common in mountain meadows in North America. Their presence there dates from the time grain was carried into the mountains for horses. Winter feeding on rangeland should be rotated from place to place to spread seed and reduce undesirable effects of concentrated animals.

In rough country, such as cutover timberland, planting of forage species often can be done only in irregular patches or strips. Animals will spread the seeded plants when grazing occurs at the time of seed maturity.

Seed Collection

Squirrel caches yield seeds of coniferous species. Many rodents pile grass seeds around or in their burrows. Farmers have raided these caches to obtain seeds of wild plants, for example, *Bromus rubens* seed gathered by giant kangaroo rats. Hard seeds that pass through the digestive tract become concentrated in the dung, which may be collected more easily than seeds gathered directly from plants. Improved germination may give a double advantage to the use of these seeds.

Effective Dispersal Distance

Duration and rate of travel by animals determine dispersal distances. For example, a migrating mallard duck flying at 75 kilometers per hour could easily carry seeds for distances of 1,000 or more kilometers before they were voided. DeVlaming and Proctor (1968) believed that the characteristic widespread distribution of many aquatic and semiaquatic plants is due to migration of aquatic and shore birds.

The classic study (Ridley 1930) of vegetation on the island of Krakatau after all organisms on it had been destroyed by volcanic eruption in 1883 gave a rough estimate of dispersal rates. This island lies in the path of prevailing sea and air currents from Java, 30 kilometers away. Thirty-six years after the eruption, many plants had reached Krakatau. Many were not present on similar islands further from Java (Table 8-1). These data and Ridley's interpretations suggest that distance is a factor in dispersal, that seaborne dispersal is highly effective, and that birds carry disseminules for greater distances than does wind.

Table 8-1 Number of flowering plant species with different dispersal mechanisms on three islands at different distances from Java (From Ridley 1930).

	Distance from Java, km	Age of island	Sea borne	Wind borne	Carried internally by birds	Adhere on birds	Carried in mud on birds
Krakatau	30	36 yr	60	34	34	9	3
Christmas	225	Eocene	44	9	36	15	0
Cocos-Keeling	1,125	Unkwn.	17	0	0	5	0

EFFECTIVENESS OF PLANT DISPERSAL BY ANIMALS

On a small scale, say one or two square kilometers, animals probably serve to keep plant populations thoroughly mixed. They bring disseminules to each point of ground in such numbers and variety that every species growing nearby has potential to become established on each new bare area. This vicinity effect from neighboring stands functions directly with distance, and alters the pace of vegetational change.

Animals consume seeds and fruits of many plants in amounts varying with individual preferences and seasonal availability. A portion of the seeds consumed passes through the animals in viable condition, that portion being dependent both on the hardness of the seed and on characteristics of the animal. The dispersal may be beneficial or undesirable depending upon the evaluation of the investigator.

The rapid naturalization of hundreds of species alien to the flora of North American rangelands probably began before the arrival of Europeans. However some came by riding the wind and on birds. These new natives that have become widespread owe their distribution to the movements of animals as well as people.

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9

Fire as an Environmental Factor

This chapter develops the premise that fire is a part of natural systems, just as are plants, animals, moisture, and energy. It describes ecological effects of fire; Chapter 22 describes the use of fire. Research studies on rangeland fire number in the hundreds. Several books and conference proceedings have reviewed fire characteristics on grassland, shrubland and woodland, and have described the planning and use of prescribed fire (Biswell 1989, Booysen and Tainton 1984, Gillon 1983, Wright and Bailey 1982).

Many writers have stated that fire causes grasslands. This particular vegetational type does burn frequently, but the presence of fire does not prove that grasslands need or are caused by fire. Most other vegetational types burn occasionally and some frequently, yet many do not become grasslands with repeated burning. The ponderosa pine-type in Arizona has a record of burning every 7.3 years (Weaver 1951), mixed pine in California burned about every 8 years (Show and Kotok 1924), and the California coastal redwoods burned every 25 years (Fritz 1931). *Cercocarpus ledifolius* with a few scattered ponderosa pine in central Idaho burned every 13 to 22 years from 1700 to 1900 and less frequently afterward (Arno and Wilson 1986). Data such as these could support the hypothesis that fire causes grasslands and forests. Where climate and vegetation favor burning, fire occurs frequently and species exhibit differing mechanisms for resisting damage.

Fire does result in ecosystem changes, and range managers have used fire to gain their management objective. The characteristics of fire and its ecological effects need to be known before fire can be used as a modern tool in vegetational management.

PREHUMAN SOURCES OF FIRE

Lightning is a common source of fire in natural vegetation. It is a weather phenomenon that is associated with both frontal and convectional movements of air. Lightning fire depends on the presence of dry organic materials, either in dry climates or in dry seasons. These climates have existed on earth for many millions of years, almost certainly from earlier than the beginnings of mammals and grasslands in the late Cretaceous Period.

Evidence has accumulated that prehistoric fires were prevalent. Fossil charcoal shows that fire destroyed vegetation in the Mesozoic era (Harris 1958), long before man learned to use fire. Charcoal in woodrat middens is evidence of fire in the grass/sagebrush region since the last glacial period (Mehringer and Wigand 1990). Shinn (1980) found 24 references in the journals of early travelers to burning by native peoples.

Arnold (1964) estimated that 1,800 lightning storms are occurring at any given moment on earth. On a basis of 10,000 km^2 and forty years of records, the average number of lightning fires per year was 6.0 in mixed prairie in eastern North Dakota, 22.4 in south central North Dakota, 24.7 in western North Dakota, and 91.7 in the pine/savanna in northwestern South Dakota and southeastern Montana (Higgins 1984). Fires originating in woodlands and forests, if unchecked, burn into adjacent grasslands. Fire has been a factor in natural selection throughout the evolutionary history of higher plants and animals.

THE EVOLUTION OF TOLERANCE TO FIRE

Ecosystems that contain abundant forage resources as well as grazing animals are subject to burning. These ecological types include grasslands, shrublands, woodlands, and open forests. Dense temperate forests, tropical rain forests, and deserts, which seldom burn, have few large grazing animals. Thus fire must be considered along with grazing in the coevolution of plants and animals on rangelands.

As each new mutant and recombination of factors in the gene pool was subjected to the sorting effects of fire, as well as the physical environmental factors and grazing, those individuals most fire tolerant and fire escaping survived in greater proportion than the less well adapted. Fire was intermittent in its effect because of irregular time periods between its occurrences. The physical factors, although constantly required for growth, were likely to be most selective at intermittent times of extremes, especially after fire and heavy grazing. Effects of catastrophes in climate, in overgrazing, and in fire differ in degree. All serve to select plants and animal species best adapted to each particular ecosystem.

If plant species have developed mechanisms for surviving fire and grazing, they may also depend on fire and grazing for successful regeneration. They may possess characteristics that enhance flammability and attractiveness to grazing animals. Some vegetational communities burn readily and are fire-dependent while others appear to be fire-independent. In either, elimination of grazing or fire results in changed species composition. Shift in any environmental factor results in ecosystem changes. All are part of the ecosystem, no one part is more causative and natural than another.

Humans, especially with modern domestic animals, are a relatively new factor in the environment of vegetation. They have changed the kinds of animal populations and the intensity of grazing by animals. Since the ancients learned to carry fire the intensity and frequency of burning has also changed. Humans have possessed fire and used it to enhance their lives for a period far longer than the age of grazing by modern domestic animals. Only in degree do the current effects of fire and grazing differ. Both have been duplicated in experiments using clipping and mechanical disturbances.

FIRE-TYPE AND FIRE SPECIES

The terms fire-type and fire species refer to the vegetation and species that are favored by burning. These are the types and species that are adapted to frequent fire and may require burning at regular intervals to maintain their vegetational position. They may be climax species such as those in grasslands and chaparral, which survive frequent fires by sprouting from unburned crowns. At the same time they would be climatic climaxes and or grazing climaxes. The fire-types and fire species are stable under a combination of factors that include burning.

These terms are applied to successional stages that follow a fire, for example *Pinus contorta* originates from seeds dependent upon the fire to open cones. A second fire before seed production kills the stand. Pioneer and temporary successional stands of annuals such as *Epilobium angustifolium* in forests and *Emmenanthe penduliflora* in chaparral are called **fire species.** They regenerate abundantly after fire, but normal plant succession replaces them in a few years.

The terms should be restricted to those types that owe their origin to fire and to the species that dominate the types. Characteristically the stands are monospecific and of even age. Whether fire is needed or tolerated in the climax-types is not clearcut, and to call them fire-types is confusing.

ADAPTATIONS OF PLANT SPECIES TO BURNING

Adaptations of herbaceous species that permit them to resist, evade, or endure burning and grazing include short basal internodes; sprouting from stem bases, rhizomes and stolons; abundant seed crops, hard seed, seeds that bury themselves, and adaptations of fruits to rapid distribution and burial; and a short period for vigorous stem elongation and maturation followed by dry season dormancy. Many spring-aspect plants and early maturing broadleaved herbaceous species in grasslands are favored by fire, which removes smothering mulch.

Trees and shrubs have some of the adaptations of herbs and additional means of avoiding damage by fire. Sprouting that occurs from adventitious buds high on the stem of certain trees, on stumps, from root crowns, and in buried lignotubers permits them to live even though above-ground live woody material has been removed. Thick, corky, and insulating bark protects many trees as they begin to mature, although when younger, they may be highly susceptible to fire. Seeds of many species in the chaparral types require heat to break dormancy. Still other trees and shrubs produce seed early in the growing season before the plant material is dry enough to burn.

Perhaps the most effective combination of adaptations to burning is that of grasses that produce seed in a short time, die to ground surface each year, have perenniating buds on live stems near or in the soil, can withstand repeated defoliations, and produce small seeds that tend to fall into soil cracks. Numerous species have these characteristics and their abundance in grasslands allows the type to evade damage by fire. At the same time, they produce fuel that tends to remove competing species. Yet not all grasses, shrubs, and trees are equally resistant to fire. Here is the relative response of a number of species:

Damaged	Undamaged
Festuca idahoensis	*Bromus tectorum*
Stipa comata	*Agropyron desertorum*
Carex filifolia	*Koeleria cristata*
Phlox canescens	*Balsamorhiza sagittata*
Purshia tridentata	*Symphoricarpos albus*
Artemisia tridentata	*Quercus gambelii*
Cowania mexicana	*Tetradymia canescens*

EFFECTS OF FIRE ON SOIL

A fire in grassland, chaparral, forest, or any other natural vegetation reduces the litter and mulch, consumes most of the standing dead, and can remove above-ground living material. The degree to which soil cover is removed and the degree of exposure of mineral soil is determined by the intensity of the fire. Following a fire and depending to a large degree upon the remaining cover and subsequent weather, changes occur in soil temperatures, organic matter in the soil, soil dwellers such as nematodes, ground surface environmental conditions, available nutrients, population of soil micro- and macroorganisms, soil acidity, water infiltration, and erosion. Either an increase or decrease may occur in each of these characteristics. Fire intensity governs the degree of response. Notwithstanding statements that fire is damaging, the mass evidence indicates little permanent deterioration in soil is caused by burning.

Soil Temperature

A thin cover of plants and litter rather than a thick cover results in more heat from the sun reaching the soil surface. A black surface after a fire readily absorbs heat, but so did the preburned colors of the soil surface. Maximum spring temperatures in the top 2.5 centimeters of soil were raised as much as 10 °C, but minimum temperatures were not greatly altered following fire in the true prairie region of the central United States (Kucera and Ehrenreich 1962). An uncovered soil has greater temperature fluctuations than does a covered soil. As green plants cover the soil, temperatures in the burned area become equal to those in adjacent unburned areas. The short period of higher soil temperatures, coincident with the beginning of growth, may be the cause of earlier growth of herbaceous plants on burned areas. However the new green growth may only be more obvious without the preburn accumulation of plant residue.

Soil Organic Matter

Burning affects above- and below-ground organic matter, although the fire may not cause high soil temperatures. Burning alters amounts available for decomposition by reducing above-ground portions and often increases soil organic matter by killing plants, making their roots available for decomposition (Daubenmire 1968). Fire changes the cycle of annual deposition of litter, at least during the first year after burning. In savannas, the organic layer on the soil after a fire may be in patches several centimeters thick beneath the tree canopy, or reduced to ash.

Termites prevent natural accumulation of litter on the soil in many tropical grasslands. In parts of the California annual grassland, decomposition is complete each year. A single fire, which removes the standing dead, alters the habitat at the soil surface but has little influence on soil organic matter. However, Meiklejohn (1955) found that with burning of the tallgrass in Kenya, fungi were reduced for one or two months, *Actinomyces* and bacteria had not recovered in three months, and *Clostridium* were not affected.

Grazing and hand clipping, as well as burning, alter the amount and position of litter. Normal litter cover in ungrazed grassland may take from one to six years to accumulate after a fire. Repeated removal of plant residue by hand for eight years reduced soil organic matter as well as changed the botanical composition in the California annual grassland (Heady 1956). Fire and hand removal of ungrazed herbage resulted in similar vegetational changes in South African grasslands (Scott 1970).

Grasslands with a pine overstory in the southeastern United States frequently show increased soil organic matter after burning. Fires before the growing season in grasslands often have similar results. Moore (1960), working in Nigeria, found that 30 years of annual early dry season burning increased soil organic matter but late dry season burns decreased it in comparison with complete protection. High soil temperatures that stimulate growth, a temporary abundance of annual pioneer plants, and decay of roots from plants killed by the fire are given as reasons for increased organic matter after fire (Daubenmire 1968). General statements of increases or decreases in soil organic matter due to fire should be questioned.

Nutrients in the Soil

Ashes left after a fire in vegetation are composed mainly of potassium, calcium, magnesium, and phosphorus as simple salts. The first three are basic in reaction. There is little direct loss of these due to burning except as they are released from organic binding and are moved by wind and water. Carbon, nitrogen and sulfur are volatilized and lost, especially where the fire is hot enough to leave white ash. If the ash is black, indicating a light burn, there is little loss of any mineral from the system.

The major influences on soil nutrients appear to be a rapid release of minerals and generally a fractional increase in pH. Both influences are temporary and of little significance in grasslands where accumulation of ash is slight. Although nitrogen is lost in the smoke, reports do not always show a loss of nitrogen from grassland systems due to burning. Pioneer plants often include annual legumes that fix nitrogen. Higher soil temperatures during and after fires result in increased nitrification. The ash from a forest fire may contain sufficient amounts of nitrogen to stimulate subsequent growth. Prescribed burning in the ponderosa pine-type resulted in a nitrogen loss from the organic material on the soil and a nitrogen gain in the top inch of soil. The increase was attributed to leaching of the partially decomposed material left unburned (Klemmedson et al 1962).

Soil Moisture

Burning of grasslands may reduce or increase soil moisture. Higher soil temperatures increase evaporation, and more plant growth increases transpiration. Without cover, runoff is high, but that situation may be eliminated quickly as new growth covers the ground. Soil moisture may be increased because there is less interception of rainfall by plants and litter, a higher proportion of pioneer and shallow rooted species, and less total transpiring cover. Apparently, the infiltration rate remains unchanged or the change is minimal (McMurphy and Anderson 1965). Lack of soil cover and higher soil temperatures during the interim between the fire and establishment of a new cover appear to result in a temporarily drier soil surface after burning than before. Likely, the principal effect occurs in the altered moisture regime in the top few inches of soil and is related to fire intensity.

Erosion

Wind erosion is likely to increase briefly after burning in dry areas (Blaisdell 1953). Water erosion will increase after burning if grazing is heavy and if slopes are steep. The risk of erosion is highest before a ground cover is reestablished. In southern California, where chaparral is on land steeper than the angle of repose, creep erosion occurs immediately after a fire, and erosion by water can be great during the first growing season if precipitation rates are intense. In most situations, accelerated erosion after a fire on relatively level land is of little consequence. A paired watershed study showed negligible effect on erosion when a chaparral cover was converted to grass (Davis 1989).

Hydrophobic substances in plants, litter, and duff volatilize at 390 to 550 °F (200 to 290 °C) and the vapor may move into the soil and condense into a nonwettable zone. This occurs in chaparral fires and increases the risk of erosion. Wetting agents have shown varied results (DeBano and Conrad 1974).

EFFECTS OF FIRE ON ANIMALS

Fire effects on animals relate to reduced cover and the secondary plant succession that follows. Insect populations may be reduced or increased depending on species. Many individual insects are killed by fire, but enough escape to replenish populations. Certain insect species flourish on specific food plants that are abundant in different successional stages after a fire. Other insect species are abundant in relation to the amount and type of cover following burning.

Burrowing rodents generally escape all but the hottest fires because they take refuge in burrows. They are dependent on specific foods and cover, both influenced by burning. Vole populations crash when their habitat is burned, but whitefooted mice may be little affected. Rodent populations quickly return to preburn levels when cover is reestablished. After a spring fire, species composition changed very little but populations of small mammals were low for one year. Recovery time was longer after a fall burn (McGee 1982).

Because fire often affects both food and cover, bird populations respond to burning. For example, prescribed burning with hot fires in the southeastern United States promotes herbaceous legumes and bobwhite quail, but the absence of burning and light burning reduce legumes and quail (Martin and Cushwa 1966). Ground nesting birds are vulnerable to burning until the hatchlings are able to escape fire. Bird species dependent upon shrubs and trees will be effected negatively.

Grassland fires have little effect on the larger animals, and most escape forest fires by running, but they soon return to the new foods. Young sprout growth from surviving woody crowns, sometimes within days after the fire, generally is highly palatable and nutritious. Small burns and the edge of larger burns attract the animals and may become overused for several years by mule deer, bighorn sheep, and elk. However, animals may avoid areas for part of a year if burned in the fall after plants are mature and no regrowth occurs (Skovlin et al 1983). Chaparral or shrubs that have grown beyond the reach of deer can be improved by burning off the tops so that sprouts and seedlings develop.

EFFECTS OF FIRE ON PLANTS

Fire damage to individual plants depends upon the temperatures reached in live tissue, the length of time certain temperatures are maintained, and the physiological state of the plant at the time of burning. Growth stage, growth form, and size of plant influence the susceptibility of live tissue to heat damage. Lethal temperatures for meristematic tissue appear to vary between 45 °C and somewhat above

60 °C (Daubenmire 1968). Many seeds have a much higher heat threshold and withstand temperatures over 100 °C. For example, seeds of *Erodium botrys* withstand temperatures of 100 °C for 4-hours. Heat treatments, such as those that occur during burning, have increased germination of several species, including *Andropogon gerardi* and *Ambrosia artemisiifolia* (Curtis and Partch 1948).

Numerous studies have shown that stage of growth is an important determinant of fire damage. Invariably, a grassland fire occurring when some species are green and other are dry will do more damage to the green species than to the dry ones. A fire that occurs after cool season species begin to grow in the true prairie region will damage them but will do no harm to the unsprouted warm season species (Towne and Owensby 1984). In the California annual grassland, the differential between the presence of sufficient mature annuals to carry a fire and the falling of *Taeniatherum* seed is about ten days. Yearly burning during that period may reduce but not eliminate the *Taeniatherum* by destruction of seed (McKell at al 1962).

Annuals depend upon seed that must survive during a fire. Heat generated by a grass fire may kill most seeds that have not fallen and part of those on a dry mulch surface. Seeds lying on bare soil, buried in soil cracks, or buried by the twisting action of awns survive in great numbers (Bentley and Fenner 1958).

The position of growing points on plants often determines temperatures attained in the live tissue and severity of damage. Fire is more damaging to *Festuca idahoensis,* which has nodes and buds at or above the soil surface, than to *Agropyron spicatum,* the buds of which are in the soil (Conrad and Poulton 1966). Small crowned species of bunchgrasses usually sustain less damage than do large bunches because of differences in fuel contained near the basal nodes (Wright and Klemmedson 1965).

New growth on burned areas may differ in chemical composition, moisture content, and growth stage from new growth on unburned areas. Generally, percentages of crude protein and ash in grasses are raised immediately after a fire (Killinger 1948). Reasons for this response are not clear, but among the explanations are increased amount of available nutrients from the ash left by the fire and elimination of old stems that are using more food than they manufacture. The difference may be due to age of material analyzed, because the new growth after a fire may be younger or older by a few days than unburned material nearby. Several authors showed that the moisture content of new herbage is higher in burned than in unburned areas (Mes 1958). Daubenmire (1968) discussed these relationships and mentioned exceptions to all of them. One point is clear. Effects of burning on speed of growth and quality of forage are shortterm, seldom lasting beyond the second year after a fire and usually disappearing during the first growing season.

Annuals have been reported to be shorter the first season after a burn (Hervey 1949) and after hand removal of litter (Heady 1956). Perennial grasses in the sagebrush/grass of southeastern Idaho were shorter after a fire, but production was higher due to an increased number of culms (Blaisdell 1953). As litter accumulates in tallgrass communities, basal area and size of plants decrease. Burning that reduces litter in these types generally stimulates growth, but on drier sites, frequent burning reduces cover and vigor of perennial grasses and may cause their replacement (West 1965).

Decreased size of perennial grass plants following a fire commonly is accompanied by increased flowering and seed production for one or two years. The species that respond in this manner are mainly warm season species of the true prairie and of the tropical and subtropical grasslands. After burning, short grasses and bunchgrasses of dry and cool grasslands tend to have fewer inflorescences than do warm season grasses (Daubenmire 1968). In some species removal of litter without burning has the same effect.

VEGETATIONAL RESPONSES TO FIRE

There seems little doubt that species composition of the vegetation in many parts of the world has changed in concert with changes in the frequency and intensity of burning. Increased woody plants and reduced grassland followed closely after fire reduction in southern Texas (Lehman 1965). Protection from fire has resulted in dense, stagnant thickets of *Pinus ponderosa* in New Mexico (Weaver 1964) and in the Sierra Nevada in California (Biswell 1959). Fire played a role in maintaining desert grasslands of the southwestern United States, and the reduction of fire increased woody plants at the expense of grasses (Humphrey 1962). Fires that reduce the treeline forests in the Arctic bring on succession, increase diversity, and lichens in a few decades for favorable caribou habitat (Klein 1982).

Species Composition

Fire in forest types that are not frequently burned reduces the proportion of climax woody species and sets the succession to begin at a seral stage. For example, burning of *Picea glauca* in well-drained northern forests results in successive dominance of moss, broadleaved herbs, grass, hardwoods, and the return of spruce in about 20 years (Fig. 9-1). Removal of trees by burning has resulted in an intermediate stage dominated by *Purshia* and *Artemisia* (Blaisdell 1953). A second fire sets that succession back further by reducing the shrubs. Changes from dense woodland to savanna and then to grass with repeated burning in tropical and subtropical areas are further examples of the establishment of new types of vegetation from which plant succession proceeds anew until the next fire.

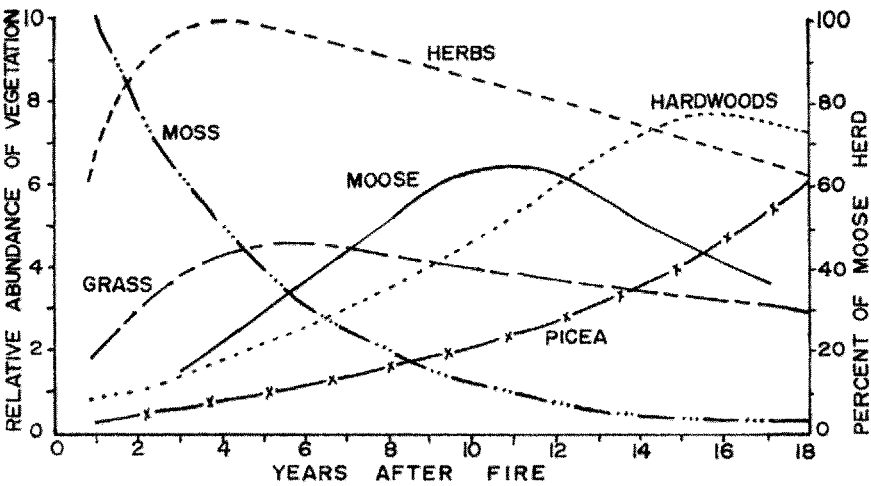

Figure 9-1 Vegetational succession following the 1947 fire on the Kenai National Moose Range, Alaska. From 10 to 12 years after the fire, over 50 percent of the moose herd was feeding in the burned area because abundant herbs, grass, and browse were available. As the *Picea glauca* and *P. mariana* increased, the other plants declined in quantity and moose feeding diminished. A succession of fires could provide the best moose habitat over time. (Adapted from Spencer and Hakala 1964).

Those vegetational types closely attuned to frequent burning soon return to normal after a fire. The chaparral in California may appear to be destroyed by a fire because the above-ground parts of the shrubs have disappeared from the landscape (Horton and Kraebel 1955). Soon, however, the shrubs sprout from root crowns and dominate the site in four to six years. The shrubs sprout mainly from the original plants, but some develop from seed. It takes several fires at close intervals and heavy browsing for the chaparral to be reduced significantly. However, Ahlstrand (1982) suggested that burning the Chihuahuan Desert near Carlsbad Caverns at 10- to 15-year intervals would favor grass over shrubs and cactus. Stands of *Quercus gambelii* change little with burning in any season because of sprouting (Harrington 1989).

Grasslands show slight changes in composition as a result of burning. The Mediterranean-type annual grassland has more broadleaved annuals and fewer grasses for one year after burning than before burning (Hervey 1949). *Andropogon scoparius* decreased and *Andropogon hallii* increased with burning in western Oklahoma (McIlvain and Armstrong 1966). In the South African veld without burning, grasses give way to forbs but when the grasses are subjected to different burning regimes, the proportion of grass species changes considerably (Scott 1970).

Change in the botanical composition of vegetation is related to the intensity and season of burning. One forest may be set back to bare soil or to the very beginning of plant succession, but another may be converted to a shrub stage with a scattering of the climax dominants still alive. Fires frequently reduce the taller layers of vegetation and promote those near the ground. Grasslands and shrublands are favored when forest is destroyed. Shrublands, *Artemisia* for example, can be removed almost completely in a single fire, and a grassland can result, but in time the shrubs return. Those shrub types that are successional to forests seldom are perpetuated by repeated fire. Grasslands are more permanent than shrublands under frequent burning, but their composition can be manipulated.

The apparent permanence or vegetational change due to burning is related to generation times of dominant plants in the different successional stages. Evidence of a fire in the species composition of annual grassland may last for only a year or one generation of plants. Perennial grasslands recover in 1 to 3 years, but California chaparral takes about 10 to 15 years before evident shrub dominance is complete. Dominance of *Epilobium* after burns suggests a fire within the last 5 years, but a *Pinus contorta* stand or any evenaged group of trees indicates a fire slightly older than the trees. Plant succession after a fire moves rapidly or slowly depending upon lifespans.

A comparison of the reports on the effects of burning the grass/sagebrush type in British Columbia and farther south in the United States showed similar responses by *Artemisia tridentata* and associated annuals. *Chrysothamnus nauseosus* reacted differently (Johnson and Strang 1983). Extension of local results to broader areas should be tested before applications are made.

Production

The production of forage is increased or decreased by different burning situations, just as other results of burning vary. Burning increases the productivity of forage grasses in the *Arundinaria tecta* understory in South Carolina (Hughes 1957), for *Andropogon* spp. under pine in Louisiana (Duvall 1962), and on the coastal plains of Florida (Hilmon and Lewis 1962). In Florida, the coarse *Aristida stricta* is burned for improvement in the quality and palatability of livestock feed, although production per unit area is decreased. In several western United States, perennial grasses increase when *Artemisia* and other woody species are reduced by fire (West and Hassan 1985). These are examples of an increasing grass production per unit area in direct relation to removal of competition by woody plants.

Some grasslands increase production following fire, as shown in the true prairie of the central United States (Kucera and Ehrenreich 1962) and in tallgrass of wet sites and regions in Africa (West 1965). Burning usually lowers forage production in mixed prairie (Launchbaugh 1972), California annual grassland (Hervey 1949), and other dry vegetational types, but Cave and Patten (1984) reported enhanced rangeland productivity in the upper Sonoran Desert.

Burning at different seasons has different effects on biomass production in grasslands. The growth in a grassland dominated by *Andropogon scoparius* in the Flint Hills of Kansas varied with time of annual spring burning (Anderson 1964). In the Northern Territory of Australia, wet season burning of the annual *Sorghum intrans* reduces it sufficiently that Townsville stylo (*Stylosanthes humilis*) can become established (Stocker and Sturtz 1966).

FIRE AS A REGENERATIVE STIMULANT

When an area is burned, changes occur in animals, soil, and vegetation. For many organisms, a fire is a major disturbance since conditions favoring their development are destroyed. They must retreat to unburned areas and await the return of suitable habitat. The waiting time may be short in a grassland or centuries long if mature climax trees are required. For other organisms, burning brings conditions favoring their development and the abundance of many plant and animal species is related to number of years following fire.

The succession of plants and animals following a fire, the dependence of many animals upon the various successional stages, and even the restriction of animals to certain stages and strictly defined niches, suggest that fire has been a relatively constant and continuously present ecological factor over geological time. The complement to the destructive role of fire is the grazing and other activities of animals in swarm numbers.

Fire and succession result in great fluctuations of herbivorous animals and changed habitat conditions. It should be looked upon as one of the forces that reduce large stores of organic materials to available nutrients,which stimulate regeneration first in plants and then in animals. This is a healthy process since it permits and supports a succession of different organisms and it fosters replacement of the old by the young. Over thousands of generations the process has resulted in situations where burning is necessary for many species. A greater variety of landscape conditions and a larger number of species exist than would be the case if burning did not occur. Fire is a regenerative force that keeps natural ecosystems healthy, fosters a wide diversity of species and habitats, and even prevents the extinction of species.

Many contradictions occur in the literature on fire. By carful selection, one can show that burning has either favorable or unfavorable effects on plant species, communities, animals, and soil. This chapter has attempted to show that situation. Literature during the 1970s and 80s has not greatly changed the wide variability of fire effects from earlier work. However, a major and important conclusion is that the effects of fire are temporary. **Similar to effects of climate disturbances on organisms, rangeland ecosystems recover to preburn levels**. Extensive increases have occurred during the 1970s and 80s in the use of prescribed fire. (see Chapter 22.)

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10

Rangeland Synecology

The skilled range manager encourages or works against the changes in rangeland ecosystems. The cause of change may originate within (endogenous) or from outside (exogenous) the ecosystem. Each alteration of grazing, plant population, animal population, small organism, soil mineral, infiltration, fire, human presence, or any other environmental impact results in a new set of ecosystem changes. For the purpose here, the subject will be limited to the ecosystem dynamics of the landscape (Forman and Godron 1986) which is a diverse collection of subunits that are often called "range sites" or "ecological sites." They are composed of collections of organisms living in a more or less similar abiotic condition of herbivory, climate, soil and fire, and with interactions from site to site. The aim is to present a discussion of such concepts as types of vegetational change, succession, climax, diversity, site, range condition, trend, stress, disturbance, and others that are commonly within the term **synecology of rangeland vegetation** (Heady 1975).

SEVEN GROUPS OF VEGETATIONAL CHANGE

Ecosystem changes occur in overlapping scales of time and space. Short time scales are often those of physiological processes within the individual or within a life cycle, while longer terms are evolutionary or geological. Exclosures, container plants and treated pastures illustrate small space scales in contrast to geologic base leveling and climatic changes that occur on large areas (Bartolome 1989).

Daily, Weekly, and Seasonal Changes

The shortest changes for our purposes are the numerous twenty-four hour cycles that can be observed; for example, varying concentration of water and photosynthates, position of leaves, and flower opening.

Grasshoppers sit on the vegetation at different heights above the ground during night and day. Numerous animal rhythms have peak activity keyed to day, night, twilight, and perhaps lunar influences. The second group of intraannual changes are the longer cycles and random changes that correlate with wet/dry and hot/cold annual seasons.

These physiological, morphological, behavioral, and phenological responses raise no particular argument as to their existence, but their reactions to range management practices are of major importance and only partly known. For example, study of effects of defoliation or grazing on the capture, transport, use, and storage of carbon has extended over the last 100 years, but new principles have emerged since 1975.

Interannual Changes in Vegetation

The third type of rangeland ecosystem change results from uncontrollable influences of weather, especially unusual events. No two annual weather patterns are ever alike. Alternating periods of drought and above average precipitation may extend over several years. Organisms respond with differences in phenology of their life cycles, growth rates, reproduction, and mortality. Rodents and insects exhibit lengthly demographic cycles.

Intra- and interannual changes are so thoroughly superimposed (Fig. 10-1) upon successional changes that their separation and measurement have not always been attained. Field sampling of vegetation must be accomplished in a manner that the various natural cause/effect relationships do not become confused with responses to treatments. Of particular importance is recognition that many types of intra- and interannual changes occur every year whether the vegetation is changing rapidly after a disturbance or is in relatively stable condition.

Successional Changes

Succession is a fourth type of change. Certain species dominate immediately after a disturbance such as on mine spoil. Later they give way to the dominance of others, which in turn are replaced in subsequent years. This **directional replacement of species is succession and it is often accompanied with soil building**. The height, massiveness and structural differentiation of the community increases. Changes in microenvironment and increasing autogenic factors may exceed the tolerance limits of some organisms or favor others in competition for survival. The early dominants are likely to be small in size, mature quickly, and have a short lifespan. Production of biomass may expand rapidly and reach a plateau before compositional stability is reached.

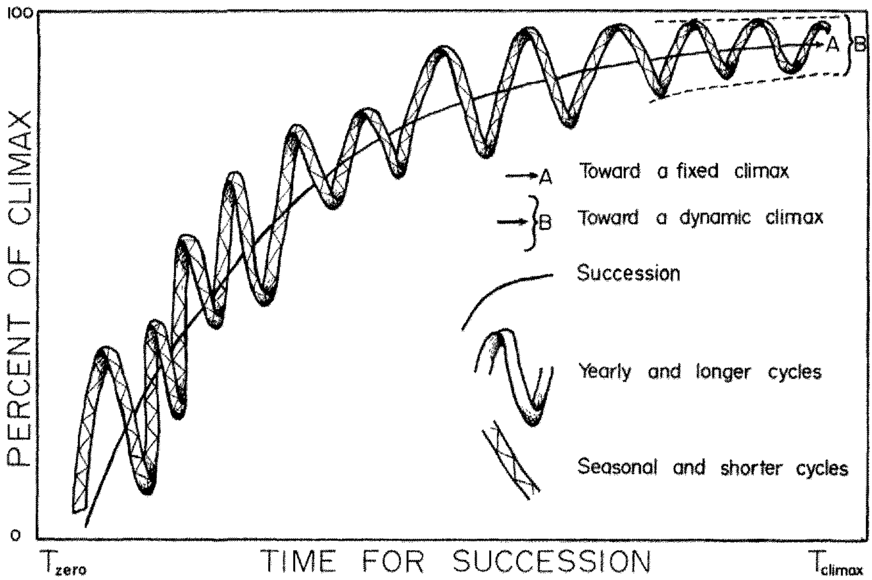

Figure 10-1 Stylized succession asymptotically approaching a dynamic climax (B) which includes variations associated with daily, seasonal, and yearly phenomena. The absolute climax might be defined as the midpoint of these variations at A.

The successional process defined in detail by Clements (1916) has been the subject of considerable controversy; however, observations, many of them longterm, have shown that directional changes in species composition do exist after disturbance and removal of stress.

Vegetational development begins with the **migration or replacement and planting** of plant propagules. Next is **plant establishment,** which Clements called **ecesis**. It may be enhanced with supplementary water and minerals. Established vegetation causes **reaction** or modifies microenvironment and soil development. **Succession** of species follows, which is largely the result of competition acting among a few in the shortterm and many more organisms later as reactions in the system become highly complex (Van Hulst 1978). Lastly, **stabilization** begins when species composition remains about the same in successive generations. During succession exogenous factors show little directional change, i.e. grazing has followed the same pattern and intensity. Endogenous influences have multiplied, especially the symbiotic relationships between vegetation and soil systems, and competition for resources is severe. Often this stage is called **climax**. The stability is dynamic because the organisms and processes continue to change intra- and interannually.

The succesional process leading to a single and extensive climatic climax in a region as defined by Clements (1916, 1936) has been the subject of considerable controversy. His was a hollistic view claiming the convergence of greatly different successional changes over numerous habitats toward a regional climax. Examples of the different views include the polyclimax suggestions of Cowles (1901) in which each site goes through a succession and reaches more or less stability. Another is the individulistic concept by Gleason (1939) that postulates that in vegetation composed of species with different environmental requirements and tolerances, individuals usually become established at random, resulting in a continuum of species composition. Gleason emphasized the independence of parts of ecosystems. Although the different views perpetuate, they may be more a matter of perspective about the concepts of succession and climax.

Johnson and Mayeux (1992) claim that current research and rangeland ecosystem evaluation lean more heavily on Gleason's ideas than on the Clementsian system. However, the Clementsian defined successional process is used in building successful reclamation of mine spoil (Redente and DePuit 1988). Also, the Clementsian based rangeland condition and trend system of evaluation as developed by Dyksterhuis (1949) remains in use by the Soil Conservation Service (SCS). Details of the procedure may be obtained from any SCS field office. Questions of appropriate application appear to be on some shortgrass types, shrublands, and Mediterranean annual grasslands.

Primary succession refers to the process outlined above when it begins on new substrata such as thick deposits of volcanic ash, new lava deposits, and in some situations following surface mining. Few areas of primary succession occur in rangeland management, because nearly all disturbances damage but do not destroy the soil and plant resources. If the disturbance extends over time as with overgrazing, the vegetation is said to deteriorate toward a pioneer stage in a sere called **regression** or **retrogression**.

Secondary succession refers to development of those seres that follow the partial destruction or disturbance of existing communities.

Disturbance is used here to mean an event that upsets the normal functioning of the ecosystem. It begins on soil already formed, which encourages remaining organisms to develop rapidly toward the original vegetation (Fig. 10-2), but more likely toward new stable vegetation if the inputs are permanent (Fig. 10-3).

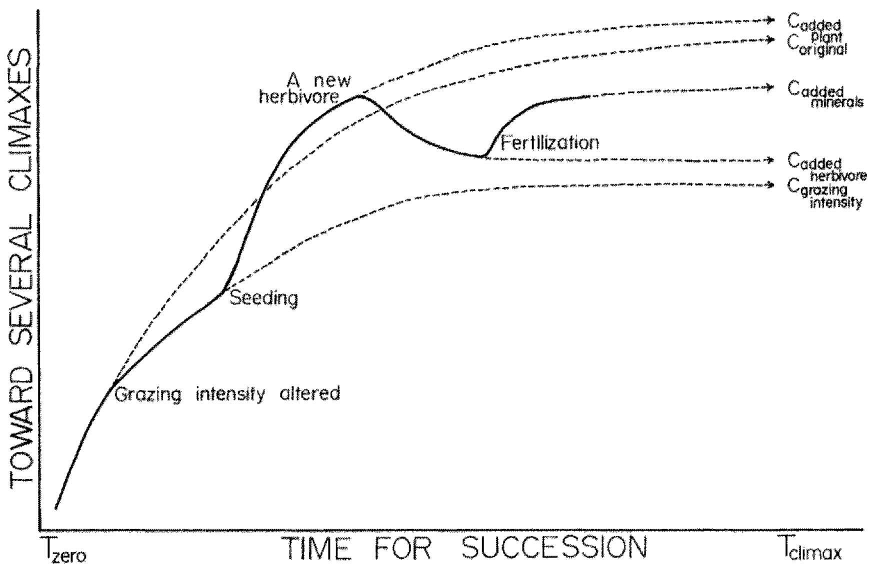

Figure 10-2 Permanent rangeland inputs alter successional patterns and result in new stable compositions. Grazing disclimax, as an example, has been widely accepted. It is contingent upon continued heavy grazing that maintains a certain rangeland appearance. This graph extends that concept to include permanent additions and removals of plants, animals, and minerals. Examples include introduced game animals in Texas, *Agropyron desertorum* on sagebrush-grass ranges, *Eragrostis lehmanniana* spreading on the Santa Rita Experimental range in Arizona, and many more. Permanent alterations in rangeland ecosystems should be recognized as such when their removal becomes impossible in practical terms.

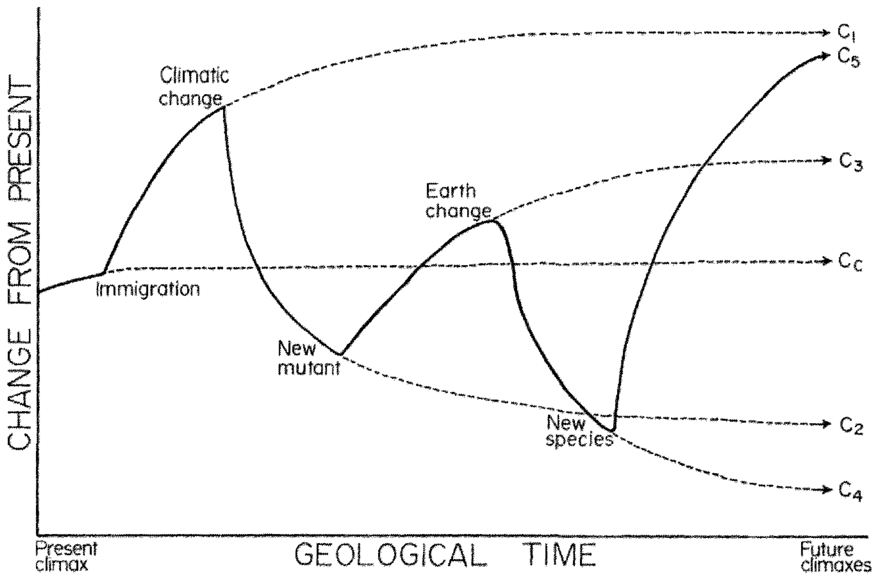

Figure 10-3 Plants, animals, and ecosystems change over geological time in response to immigrations, evolution, and climatic drifts; the latter most likely due to earth changes. These long-term influences result in gradual drift of ecosystems, of which only five new ones are shown. The real number at any one geographic location would be much larger because the factors act simultaneously lt as well as continuously. This graph should be visualized as including the simultaneous variations depicted in Figure 10-1 and extending them on a geological time scale with exaggeration in the vertical scale.

Extremes of drought, wind, and freezing; severe fires; and epidemics of herbivores may catastrophically eliminate the current dominants. Succession is set back to proceed again. Pioneer stages occur locally under a dung pat, on pocket gopher mounds as well as over large areas from other causes. Disasters large and small, continually present conditions that permit species in low stages of succession within larger climaxes. Regardless of setback, oscillations, and whether or not climax is ever attained, natural systems tend toward stability. It results from interactions within the ecosystem and indicates ability of ecosystems to remain or return to normal in the face of external disturbance.

Sere, stage, and condition class are terms that are commonly associated with plant succession. Secondary succession may begin with bare ground, proceed through an annual weed stage and a perennial grass stage to a point of near stability--the total being a sere and stages being its parts. The first description of secondary succession in a rangeland context and the stage names still used are those of Sampson (1919). The whole, in fact, is a continuum; the stages being a necessary convenience for communication. The mix of successional stages on the landscape may be the result of disturbances, topography and soil, climate, uses of the land, management prescriptions, vegetational classification categories, and evaluation procedures (West and Van Pelt 1987).

The importance of space differences must not be overlooked in understanding succession and stability on rangeland. The space under consideration may be large, as for example comparison of plant succession patterns on arid areas of five continents; or on small locally defined microsites for seed germination studies, patch grazing, range sites, and management units.

The **climatic climax** hypothesis stated that given enough time for base leveling and regional soil development under a regional climate, there would be a comparable regional or climatic climax vegetation (Clements 1936). This may be true as shown by similarity of vegetation over large areas, such as the tallgrass region of central United States. On a smaller spatial scale suitable for site evaluation and land management, the theoretical climatic climax loses much of its value, because many sites in a region have apparently stable but different vegetations. Changes in vegetation and succession in particular are difficult to measure in arid and semiarid shrublands. Early ecologists recognized the existence of small scale stability and called them **subclimaxes, disclimaxes** or **polyclimaxes**.

A recent model of management scale vegetations called **state-and-transition** (Westoby et al 1989, Friedel 1991, Laycock 1991) is a help in organizing information about vegetational stability and change. In simple terms **state** is a present vegetational type, as that of condition classes on a range site, and **transition** shows the direction of change from one state to another. Catalogs of both state characteristics and transition factors are made and revised as information becomes available. The model recognizes the successional changes without human influence and predicted change under active management.

Immigrations

A fifth type of change results from immigration of organisms and minerals. Many species have potential to move because of highly evolved dispersal mechanisms. They ride wind and water currents for great distances. Animals that migrate, especially birds, move seeds about the earth. For several centuries increasing travel by humans has multiplied the number of plant and animal immigrants. A safe assumption is that immigrations have occurred for as long as there have been organisms to emigrate.

Many newcomers quickly become **naturalized** and a part of the local succession and climax. They are **new natives** rather than aliens. Examples include *Salsola iberica, Sisymbrium altissimum, Bromus tectorum* in western North America, house sparrows and European starlings across the United States, and the European rabbit in Australia. Hundreds of new arrivals on North American rangelands have found habitat and environment suitable to their requirements, and they are permanently established. By so doing they found a place in the vegetational changes and stability of their new home. Many are desirable plants such as *Poa pratensis* in mountain meadows and the seeded *Agropyron* species. Dislodging many of them now in favor of the so-called old natives is beyond practicality. If promotion of only the original native plants were to become policy, the introduction and improvement of rangeland forages through genetic research would be severely hampered.

In like manner minerals are moved by wind, water, animals and humans. They alter the receiving systems, likely on a permanent basis, and result in new climaxes as well as new successional patterns.

Early-humans altered successions and climaxes by burning the vegetation and harvesting animals and plants. These influences should be considered as natural phenomena as well as the resulting successions and climaxes. Current influences by land managers differ from the older ones more in degree than in principle. Thus immigrating organisms continue to change their receiving systems, but old processes such as disturbance and competition continue.

Evolution

A sixth type of change results from evolution of new characteristics and species, usually replacing older ones. Every individual lives in a place and within a community where it struggles for survival. Those best adapted to the extremes of living conditions and associations survive, altering their gene frequencies to a small degree, their population characteristics, and the system in which they live. As one species evolves others react, so structure and function of the whole assemblage changes through geologic time. Evolution of communities and ecosystems seems as reasonable as development of individuals and populations. Genetic gradients are in harmony with geographic diversity. Community characteristics, such as diversity, physiognomy, succession, climax, and nutrient cycling, are cumulative effects of species evolution and multiple steady-state processes. Significant adaptations, whether developed suddenly as a single evolutionary step or gradually over eons of time, alter successions and climaxes.

Climatic Change

Changing climate causes a seventh type of ecosystem change. Unusual climatic events, yearly variations, and cycles of a few years are well-known causes of vegetational change. On a longer scale, a cool period known as the "little ice age" occurred from about 1600 to 1900 AD. It was followed by global warming until 1940 and then cooling until 1970 (Neilson 1987). For the last two decades temperatures have increased.

An increase of carbon dioxide (CO_2) content of the atmosphere is given as a major reason for recent global warming. Composing approximately 50 percent of the gases that trap solar energy, it influences climate as well as being required for plant growth. CO_2 in the atmosphere has been increasing because of burning that releases carbon from fossil fuels and carbon pools in woody plant materials. If earth temperatures increase significantly, vegetation of the earth will respond with expansion of tropical and subtropical species into temperate zones and C4 species replacing C3 species. Mayeux et al (1991) have demonstrated that increasing CO_2 levels confers a physiological advantage upon C3 over C4 plants. This gives rise to another hypthesis that additional atmospheric carbon explains in part why C3 shrublands have replaced C4 grasslands and savannas. Much remains to be learned about the effects of CO_2 in the atmosphere.

Precipitation changes as well as temperature. Neilson (1986) suggested from an analysis of 130 years of climatic data for Las Cruces, New Mexico that before 1900 the winters were drier and the summers wetter than after 1900. It is well known that wet winters favor cool season plants and warm season plants do best in wet summer climatic-types.

A drift in macroclimate is a response to geological base leveling and tectonic earth movements. Paleontologists describe this type of change when they list plants and animals in the geological strata that are different from those organisms existing there today. In recent geological time, say a few thousand years, fossil records in pollen profiles and middens of various sources give credence to this type of vegetational change. Packrat middens show abundant pinyon pine from 40,000 to 12,000 years before present (BP) from Durango, Mexico to Texas and New Mexico where none existed after that time (Van Devender 1987). After 12,000 BP the type shifted upward more than 1,000 meters and northward over 600 kilometers.

More recent vegetational changes are illustrated by Mehringer and Wigand (1987) from their studies in southeastern Oregon where the present vegetation is sagebrush/grass. If juniper pollen reflects abundance, the period following the latest Wisconsin glacial retreat witnessed retreat of forests and gains of shadscale, grass/sagebrush and juniper. The fluctuating areas occupied by these vegetational types extend to the present. The authors suggest expanses of juniper 4000 to 2000 BP, others at 1600 and 850 BP, and still another that began 400 BP only to wane after 200 BP. A high for juniper in another place occurred in deposits dating 500 BP. As juniper decreased there was an increase in sagebrush fluctuating with grass pollen and changes in charcoal in the midden strata. Because these changes have always occurred, presumably organisms have adapted to them or were redistributed accordingly.

VEGETATIONAL CHANGE AND STABILITY

The preceding sections related vegetation changes to time and space, defined a number of terms, and mentioned others. Let us return to factors and processes in vegetational change and stability for an understanding leading to application in the inventory and management of rangeland.

Disturbance and Stress

Disturbances may be catastrophic and overwhelming as by removal of vegetation, soil, and overburden in surface mining or covering by molten lava. They initiate primary succession which is an ecosystem building process. Other disturbances may be local deviations from the average and as small as a moment of grazing. They proceed slowly over time, nevertheless initiating ecosystem changes. **Disturbance** is useful as a general term as well as one covering anything that causes change in rangeland ecosystems.

The distinction between disturbances due to natural and human causes is to be treated with care because most human disturbances have nonhuman counterparts; only the frequency and intensity are changed.

Vegetational changes following catastrophic fire are similar whether the fire was set by lightning or a manager. Other pairs of influences include construction of ponds by manager and earth movements, overgrazing by wild and domestic animals, destruction of vegetation by insects and herbicides, and actions of machinery and burrowing animals.

Identification and description of disturbances and what they do gives understanding of their affects on ecosystem processes and a means of evaluating the use of disturbance. Usually an undisturbed or stable reference point is required. The reference point of value for rangeland vegetation management is accurate prediction of ecosystem behavior through the time-route of vegetational change.

Disturbance at some level is natural, frequent, and a factor in evolution of species in rangeland ecosystems. The universality of disturbances support the belief that stability or climax never occurs. Modern influence by an increasing human population has added variety, frequency, and intensity to the natural disturbances (DePuit 1986).

The most striking feature of rangeland ecosystems is their capacity to adapt to and reassemble after disturbance, whether or not the result is similar to the original. This is the stimulation of catastrophe, but it does not mean following the same pathways to the same stable state as before the disturbance. Some disturbances, rainfall variation for example, are normal and organisms have become adapted to them.

Studies in the mixed prairie in western South Dakota have shown that removal of prairie dogs and bison gave additive results in terms of increased biomass and changed botanical composition (Cid et al 1991). This is an example of the vegetation reaching for a new stability when stress factors are removed and as diagrammed in Figure 10-2.

Another example is shown in a series of annual photos taken for forty years in the *Atriplex confertifolia* type in southern Idaho (Sharp et al 1990). During the 40 years there was no grazing by domestic livestock.

The changes in species dominance were the result of changing stress from weather and insects. Other interactions may also be involved but no large animals--only an occasionally abundant herbivorous scale insect. It has been argued that vegetational oscillations such as those shown in the 40-year photo set negate the concept of stability and climax. Others say that stability is relative and dynamic, thereby encompassing the variations.

For practical purposes in the evaluation of range condition and trend, the changes illustrated by Sharp et al (1990) indicate that a single year of vegetational sampling does not always measure the vegetation of another year. The principles are that wide fluctuations in vegetation occur and that single year measurement can be highly misleading, regardless of the system used to evaluate condition and trend. The time and space variations must be known before adequate evaluation can be made.

Year	Dominant Plants	General Precipitation
1951	*Atriplex confertifolia*	About average
1958	*Poa secunda* *Sitanion hystrix* *Sphaeralcea grossulariaefolia* *Atriplex*	After dry years and scale insect on *Atriplex*
1960	*Halogeton glomeratus*	Dry spring
1963	*Atriplex confertifolia*	Wet spring many seedlings
1964	*Sphaeralcea grossulariaefolia*	Very wet spring
1967	*Atriplex confertifolia* *Sitanion hystrix*	Very wet spring
1971	*Bromus tectorum* *Sitanion hystrix*	Wet year
1972	*Atriplex confertifolia*	Dry spring
1973-85	*Sitanion hystrix* *Atriplex confertifolia*	'74 dry, '80 wet, '84 dry Scale insect again
1986	*Bromus tectorum* *Atriplex* dead *Lepidium perfoliatum* *Sisymbrium altissimum*	Wet spring
1987	Grasshoppers and mixed plant species	
1990	*Sitanion hystrix* *Poa secunda* *Sphaeralcea grossulariaefolia* *Halogeton glomeratus* *Atriplex* seedlings	Wet spring

Rangeland ecosystem disturbances are studied as to their own characteristics; such as the properties of fire and the grazing factors. Indirectly, disturbance may influence vegetational composition by acting upon competition and the supply of resources. The latter requires definition of normal system behavior and how its reactions can be manipulated. Rangeland management involves increased intensity and frequency of disturbance or the suppression of them to alleviate stress that retards attaining objectives.

Stress is defined as a restraining action on rangeland organisms and ecosystems. The restriction is measured by the change when the stress is relieved. Behind each disturbance that causes vegetational change is a stress of some kind. Thus, adding nitrogen and water to desert ecosystems relieves restraining influences. The amount of increased biomass production is a measure of the normal stress in the system. If the system does not respond to added fertilizer, there is no stress from lack of minerals. Another view is that wet years can increase soil bicarbonate and iron deficiency, parasites such as dodder (*Cuscuta* spp.), soil salinity, lack of oxygen in the root zone, and more disease organisms. Two or more of these factors may be sequentially additive or synergistic causing low vigor and dieoff from an apparent single cause when it results from numerous causes (Wallace and Nelson 1990).

Competition

Competition is a process which occurs when one organism withdraws a resource needed by another, such as water, nutrients and space, from their common environment. It is a process and not a result. It emphasizes the interaction, usually in the same trophic level, by which one organism deprives another of needed resources. A species that grows earlier than another often has an advantage. Patch grazing of one plant or a small area may reduce photosynthetic material to a point that the vegetation changes in favor of the ungrazed neighbors. Competition is measured and understood in terms of results such as change in population size and biomass production. Competition is only one but probably the most important synecological interaction in succession.

Competition between organisms, may be inter- or intraspecific, and caused endogenously as with high plant density. The availability of resources must partly govern the intensity and effects of competition (Samuel and DePuit 1987). Effects may be compensatory and interacting. A central part of the competition concept in synecology is that a short supply of a needed requisite causes a change in the organism, even death. Evolved special mechanisms in response to pressures of competition should be considered results. The "struggle for life" is divided into three parts: (1) against abiotic conditions, (2) against herbivory, predation, parasitism, and disease, (3) competition for food, light, and space.

Each organism has an ecological range of abiotic and biotic environments where it is best able to live. This probably is an environmental plateau because most organisms have a tolerance for a range of environments. Consequently a common belief is that species do best where they originate. The success of numerous species when they are introduced to new areas casts doubt on that principle. Perhaps because predators are left behind, new arrivals may do well and adapt as new natives, becoming a part of the accepting ecosystem.

A longtime result of competition is natural selection which tends to make organisms adapted to a short supply of resources or to make them more efficient in the use of the available supply. This is evolution toward the use of all available niches and adaptation to niche diversification that develops through ecosystem succession. Comparisons of *Agropyron smithii* and *Bouteloua gracilis* in and out of longterm exclosures in western South Dakota have shown genetic fixing of greater competitive ability for the exclosure plants of both species. Dissimilar populations have developed in response to defoliation and competition (Painter et al 1989). Clearly, herbivores influence species development.

Decrease in vigor, less growth, and even the death of a plant by overgrazing and excessive defoliation treatments have been related to contents of proteins and carbohydrates. Mueggler (1972, 1970), Archer and Detling (1984), Olson and Richards (1989), and Painter et al (1989) have shown that the effects of defoliation have been less in the field when competition from nearby plants was removed. Change in botanical composition under heavy grazing may be related as much to competition from plants nearby as to the effects of defoliation itself.

Biodiversity

Biological Diversity (biodiversity) has come to mean species richness or number of species within a defined area and/or the evenness of species distribution in abundance or biomass throughout the area. Biodiversity is usually given as a scale or index and is often used for comparison of a plant or an animal community with a standard or objective. Obviously, determination requires a species list and some of the biodiversity indices include a measure of importance such as density, production, or cover. Biodiversity may also be in terms of life-forms or groups of species. The methods of analysis can be categorized as calculation of indices, rank correlation tests, and similarity indices. Methodology and comparison of several of these are given by Chambers (1983), Chambers and Brown (1983), and Magurran (1988). The Shannon index is the one commonly used.

However measured, diversity has become an important parameter of above- and below-ground organisms. High diversity is considered to be a desirable characteristic that indicates rangeland ecosystems are vigorous and in good health; sustain high forage production; provide nutritional improvement through mixed diets; give greater niche differentiation, more mutualistic or sympatric interspecies benefits, and increased ecological stability of vegetation and soil. While all these may be true on certain sites, it is well to record that the greatest species richness often occurs at intermediate successional stages, does not always correlate with greatest stability, and can only be maintained with managed herbivory (livestock grazing) as reviewed and tested by Collins et al (1987).

Measurements and standards of biodiversity are required by law in certain states for bonding release in mined land reclamation. In 1991, ten federal, state, and university agencies in California agreed by memorandum of understanding (MOU) to work together on the proposition that: "Sustaining the diversity and condition of its natural ecosystems is a prerequesite for maintaining the state's prosperity" (Anon. 1991). Biodiversity was understood in the MOU to include genetic make-up, species, populations, communities, ecosystems, landscapes, and regions. There is little doubt that biodiversity has long been a concern of ecologists, and more recently central to claims and actions by conservationists, environmentalists, and land managers. However, biodiversity indices are difficult to interpret and have not been accepted by those who favor more simple measures such as species lists and measures of abundance and distribution (Magurran 1988). Diversity needs further development to make it a tool for rangeland managers.

Generation Time

The varied time scale of the seven groups of ecosystem changes needs emphasis in terms of generation time. Changes that occur interannually often repeat within the lifespan of dominant animals and plants. In most successions, the sere requires a few generations; a generation may be a single year in annual grassland, half a century or more for sagebrush, or several centuries in forests. Evolutionary changes and climatic drifts normally span many generations. Successful migrations occur in one generation but time between migrations may be long. Dryness of habitat increases the time for succession to proceed and there comes a point in increasing dryness when intervals between regeneration events are longer than the lifespan of the individuals. The dominants do not replace themselves, patches of evenaged dominant trees occur, or desert shrubs expand by ever increasing rings (Johnson and Mayeux 1992).

Vegetation scientists, being the evaluators of ecosystem changes, tend to center their measurements and judgments upon a spatial scale restricted by easy travel and a time scale based on their own effective lifespan. The daily, seasonal, and yearly changes or an unusual event caused by weather come so rapidly and with so little response to managerial efforts that measurement of them is ignored. In deserts these types of change may be supreme with little evidence of succession. In less extreme climates, successions of species attract attention because of the relatively quick responses to climate and the applied practices. When lifespans reach beyond investigator comprehension, as in forests, successional stages may appear as climax. The average lifespan of many shrubs and perennial herbaceous plants is unknown. Therefore it may appear that desert shrub types have no succession and any combination of species is a stable community.

Climax

How should stability or climax be viewed to express real situations in the face of the seven types of changes over time and the influences of stress, disturbance, and competition; all superimposed on many different types of ecosystems? **Ecosystems** in this sense are of the size called **habitats, range sites, ecological sites**, etc. The time span is **now** for effective rangeland management; **therefore,** climatic climax is too far into the future and may never occur. The polyclimax view projects stability on a shorter time scale, but more important, it has a spatial base that supports the concepts of sites and habitats. The individualistic theory that organisms occur at random may be true on a small scale, but it is rejected because it doesn't recognize site differences. Another concept is that vegetational change moves continually. Stability in the latter view may increase and become asymptotic. Whichever view one prefers, the fact still remains that in the longrun, forests replace forests, grasslands return after disturbance and so do the deserts, although all will be different from the pristine.

Climax or a stable state results when abiotic and biotic factors operate without directional change in species organization. Climax is difficult to determine and requires interpretation of trends, responses to weather, numerous kinds of cycles, variability, probability, and qualitative relationships as well as repeated measurements. Exact definition remains elusive. Here is an example.

> The Park Grass Experiment at the Rothamsted Experiment Station in England began in 1856 with the object of determining the effect of different and continuous fertilizer regimes on the yield of hay from permanent grassland. Over 80 years of data were used to test the relationships between biomass, species diversity, species number and time (Silvertown 1980). The treatments selectively increased some species and decreased others, but **all treatments**

came to a stable composition in the longterm. Annual variations occurred in compositions that were temporary vacillations from a floristic equilibrium. Annual rainfall amount influenced biomass more than composition. Species diversity (Shannon function H) and species number were negatively related to biomass. Two results are emphasized. (1) A new equilibrium in species composition was reached and maintained with annual fluctuations when a treatment was maintained. (2) Greatest diversity occurred when the biomass was less than in the highest biomass yield treatment.

Evaluation of rangeland vegetation depends upon an understanding of vegetational changes and the time taken for change to occur. It also depends upon an understanding of the composition toward which succession is pointed, and that the magnitude of changing species composition gradually lessens, but never stops. Therefore, definition of a fixed endpoint, or a species composition that exists without change, becomes highly theoretical. It is a range of compositions. Acceptance of plant succession does not require acceptance of a completely stable end usually called **climax**. Although subject to debate, **climax** is used here in the sense that the best possible definition of vegetation to which succession leads is useful for evaluating rangeland ecosystems.

Indicators of Stability

Identification of climax and stable vegetation for rangeland purposes is based on relic vegetation and soil, evaluation of vegetational changes attributed to reduced grazing pressure, interpretation of ecological research, review of repeat photos and other historical accounts, and comparisons of relic areas along a continuum. Observations, measurement, and evaluation of climax contain a large measure of personal opinion. Criteria used to judge stability are one or more but never all of the following:

- Species composition changes relatively little in stable communities. An individual that dies is likely to be replaced by another of the same kind.
- Dominant species do not change, sagebrush/grass continues to be sagebrush/grass.
- Longevity of the dominants increases as the succession proceeds and the largest organic structures come to dominate the system.

- Ecosystem structure reaches a plateau and becomes highly developed as shown by well organized strata, numerous interspecific dependencies and symbiotic relationships, complex life cycles, small niches, narrow adaptive specialties, varied territoriality, and fascinating mimicry. Individually, these conditions may stabilize before the system as a whole. This complex diversity tends to be repetitive and regular in its horizontal pattern, as each south facing slope or each stand of many species tends to be like the next over wide geographical areas.
- Life-forms within successional seres converge toward the prevailing regional normal. This criterion tells us that successions in a region are widely varied at the beginning and that they converge toward similarity in life form. For example, several adjacent abandoned fields in the tallgrass region may have different plants as pioneer dominants but become similar grassland communities as succession proceeds.
- Dispersal mechanisms tend to be adapted to movement by animals rather than by wind and to vegetative continuations rather than by seed.
- Stable communities of widely spaced desert shrubs and others dominated by sprouting chaparral and grass species have a pulse stability or no succession, if one prefers. When these types are destroyed, as by fire, the dominants regenerate immediately without an extensive sere. In other words chaparral replaces chaparral.
- Biomass quantities remain relatively unchanged; accumulation and dissipation of energy are in balance.
- Net production is low in the climax; maintenance takes much of the energy.
- Factors influencing succession tend to become more autogenic and less allogenic as stability develops.

RANGE CONDITION AND TREND

The general concept of range condition and its application in the evaluation of rangeland appeared in the beginings of range management. However, extensive application began as a part of the conservation movement in the 1930s. Different systems with numerous variations were proposed. The Soil Conservation Service adopted the one proposed by Dyksterhuis (1949) that was based on the principles of Clementsian plant succession. Other agencies and range ecologists have not fully accepted the system.

The concept of range condition embodies and expresses the characteristics of a named site at a given time and is in terms of nearness to an ecological or use standard. Trend is the change in those characteristics toward or away from the standard. Range condition is the subject of inventory. Trend is an objective of monitoring.

Parameters used in the measurement of condition and trend have been proportional species composition but the species have been classified differently. Abundance, cover, forage value, biomass, successional status, and palatability have been used, none of which have been satisfactory for all purposes. Soil condition and erosion hazard have been secondary parameters because they are difficult to combine with the vegetation measurements into a single term. The use of one or several parameters for determination of condition and trend is a subject of disagreement.

Conceptual problems with dependence upon the fundamentals of Clementsian grassland succession and climax arise in application. Vegetational changes may not progress toward a climatic climax, complicated spatial differences may be difficult to delineate, successional stages in desert shrubland may not exist, introduced species add new dimensions to the vegetation, some vegetational changes are not reversible, and due to biological inertia present vegetation became established at and earlier time and is not in equilibrium with the present climate. Parallel changes in biomass production and ecological condition are usual for natural grasslands but unusual for climax shrubland and forests. Examples of vegetation that changed little after livestock grazing was reduced or eliminated caused search for other factors. Basically, the problems are lack of synecological understanding and concepts about with succession and climax (Lauenroth 1985).

The range profession developed with forage and livestock in mind. Yet the types designated as sagebrush, pinyon pine/juniper, mesquite, prickly pear, creosotebush, and many more woody types are climax in their own areas of rangeland but their condition often has been classed as poor for livestock in the mistaken belief that the climax is grassland. The annual-type grassland in California has been automatically classified in "poor" condition because most plants are exotic. New natives everywhere will remain to find a place in our native vegetation. Society will come to recognize that humans and nature add species as well as remove them from any given place. In California, evaluation of livestock rangeland management is based on plant residue because of ease in measurement, relation to soil protection, and unknowns about the successional ecology.

There are several other problems with definition and application of range condition. In the popular press and conversation among ranchers, it often means: **Has the rainfall given us a good forage crop?** Nonrange professionals of all types give more credence to range condition categories than was intended by range management professionals. Condition classes for one use are not always the same as those for other types of use. The commonly used classes of excellent, good, fair and poor have not been universally applied, inviting criticism.

The United States Congress has been drawn into a definition of range condition. The Public Rangelands Improvement Act of 1978 emphasized multiple objectives in use of the rangeland as follows:

> Section 3(d) The term "range condition" means the quality of the land reflected in its ability in specific vegetative areas to support various levels of productivity in accordance with range management objectives and the land use planning process, and relates to **soil quality**, forage values (whether seasonal or year round), wildlife habitat, watershed and plant communities, the present state of vegetation of a range site in **relation to the potential plant community** for that site, and the relative degree to which the kinds, proportions, and amounts of vegetation in a plant community resemble that of the **desired community** for that site.

That definition calls for consideration of site including soil quality, relation to potential plant community, and desired community. The procedural details of how to do this to multi-user satisfaction are yet to be accepted. We need to change the way we determine and report resource conditions--to change from forage condition to include other uses (Eshelman et al 1989).

Basically, there are two problems of condition evaluation and use on each site, determining potential conditions and management objectives. The potential is not accurately known for many sites. Objectives of management change and the vegetation that best fits the objective is often a guess. Reporting range condition on a management unit or nationwide on the above basis cannot be accurate without stating the management objectives.

Approaches to range condition and trend in the southern African climatic climax grassland have varied, but the principal system appears to be on a weighted key species method (Hurt and Bosch 1991) and the degree of rangeland degradation. Theoretical condition is poorer as degradation becomes greater. The procedure establishes a degradation gradient based upon percentage species composition with species in groups. Response to grazing, community dynamics, and recovery potential obtained through research, ordination, and regression supply the data and analysis (Bosch and Gauch 1991).

Rangeland managers must be able to determine the current state of the resource and predict the future state when certain management practices are applied. At this writing, the actual measurement and use of range condition and trend have seen little change. The ferment over the concepts will remain just that until field testing indicates improved practical use.

NEW DIRECTIONS IN RANGE CONDITION ASSESSMENT

The above sections for the most part described vegetational changes on the basis of time, the scale being hourly to geologic. Each type of change is also associated with a space or **site**. The three terms, **ecological site, range site,** and **habitat,** are of long standing. Others are in the process of definition and usage. These terms have essentially the same definition: **A unit of land supporting or capable of supporting a distinctive climax vegetation (Shiflet 1973). Ecological sites** and **range sites** may be less extensive and included with others in the **habitat type. Plant community is a general term commonly referring to a collection of plants with no successional status or size implied, seeded or nonnative vegetation included. More specific usage is not widely accepted.**

These concepts have much in common as a conceptual basis for classifying natural ecosystems, differing more in their application to land classification for multiple-use purposes than to ecological differences (Leonard and Miles 1989). They are based on the proposition that vegetation is an integrated expression of abiotic and biotic characteristics and that stability, as succession to climax, reflects the site and habitat potentials.

Range sites and habitat types emphasize potential vegetation while community (type) and ecological site give most attention to the present vegetation. The purpose of using these concepts is to provide a basis for inventory and land management; not to prove succession and climax. Site definition in terms of potential can hardly be used in rangeland inventory and management without defining present vegetation and its relation to the potential. **That is range condition; an inseparable complex of site, present vegetation and potential vegetation.**

The habitat type method of classifying land was first described by Daubenmire (1952). It has become a widely used system for land classification in forests and more slowly for shrublands and grasslands. The concept of potential vegetation has been gradually enlarged to include seral vegetation, soils, landforms, and management (Wellner 1989). Classification of habitat types is ecological and not colored by "**for what use.**"

An effort has been made to separate the range condition concept of Dyksterhuis (1949) as used by the Soil Conservation Service into two concepts. One is **ecological status defined as: The present state of vegetation and soil protection of an ecological site in relation to the potential natural community for the site** (Jacoby 1989). **The second redefines range condition by giving the vegetation on an ecological site a resource value rating (RVR) for a particular use or benefit** (Jacoby 1989). Both concepts are applied to the same range site. If the vegetation is non-native, RVR is used. The revised concepts emphasize and separate plant succession from multiple-use values.

The potential vegetation is being defined as the stable vegetation community that could eventually occupy a site without human influence. It is currently called **potential natural vegetation** or **potential natural community.** With or without human influence, potential plant community is one of several that may become established on an ecological site. Still another is **desired plant community**, one identified in a management plan as desirable. The Society for Range Management (1991) by action of its Board of Directors has accepted and encouraged new directions in the assessment and reporting of range condition. Rangeland should be classified by **ecological sites** and the management objective should be defined in terms of **desired plant community** for each site. Protection of the site against erosion should be assessed in terms of a **site conservation rating** and where accelerated erosion begins is the **site conservation threshold**. Wide acceptance of procedures using these concepts is in the future. However, terms and concepts are needed that give clear interpretation of present vegetation, likely changes, possible stability, planned use, and potential vegetation.

Westoby et al (1989) suggested a state-and-transition model for research and management of rangelands. Data would be catalogs of different states of the vegetation and of the possible transitions among the states. The states have been illustrated as a series of boxes that describe different combinations of dominant plants. Arrows between the boxes suggest different states when factors such as fire, herbicides, and grazing change the vegetation. Lower successional steady states, for example a dense sagebrush stand, can be shown with reference to various treatments. An advantage of the model is that several steady states can be shown for an ecological site--not just one climax. Incorporation of this type of model into range condition assessment is yet to be done (Laycock 1991).

Two site classifications have made their way into rangeland inventory and management practice. Ecological site (Bureau Land Management) is similar to the range site (Soil Conservation Service) and percent of similarity presumably means to potential natural community or climax as follows:

Percent Similarity	Range Condition	Ecological Condition
76-100% of climax	Excellent Potential	Natural Community
51-75%	Good	Late Seral
26-50%	Fair	Mid Seral
0-25%	Poor	Early Seral

Procedures for field sampling and determination of each condition class are defined within the using agency. The terms for range site emphasize **use for what purpose** and for ecological condition currently accepted.

LIVESTOCK AS A TOOL TO MANAGE RANGE CONDITION

Successful use of livestock grazing as a tool to enhance habitat for any purpose requires establishing specific goals and livestock handling procedures for accomplishment. That entails planned control of grazing intensity, frequency, seasonality, and distribution of animals. Anything less will be unsatisfactory.

Aldo Leopold wrote in (1936) "cover is controlled by controlling plant succession." On rangeland that control rests with livestock grazing and other tools such a water development, seeding, and prescribed fire. Improperly used, these and other manipulations of vegetation adversely affect vegetation, animals, and soil for realizing the intended purpose. However, prescribed fire and reduction of woody species by machinery are accepted tools for wildlife habitat improvement. The use of livestock to enhance habitat for many species and management of grazing big-game species to improve habitat need more scrutiny and attention.

The problems of re-creation or restoration of high diversity grasslands are gaining attention worldwide. After only two years of study in the calcareous region in England, Gibson et al (1987) found that 43 of 75 species found near the study site migrated and established in greater numbers on spring and fall grazed areas than on ungrazed controls. Diversity and abundance of species (including one national rarity) were increased by grazing. Literature review has indicated that grazing livestock can be used to attain four objectives for wildlife habitat management as follows (Severson 1990):

- To alter species composition of the vegetation
- To increase total biomass or of selected species
- To increase nutritive quality
- To alter diversity, height, openness of vegetation

Application of the above may be limited, but in any habitat improvement program at least two of the four will be applied. Careful planning to better the habitat for a target species will reduce adverse effects on nontarget species; however, there will be tradeoffs in most instances. Increasingly, livestock grazing is being used as a tool to improve wildlife habitat.

Altering Composition

In Utah heavy cattle grazing resulted in thick shrubs but later overbrowsing by mule deer in winter killed the shrubs and the vegetation returned to grassland (Urness 1990). A common belief is that overgrazing in the past resulted in monospecific stands of various *Artemisia* species, but many of those stands including the close associate *Purshia tridentata* have been converted to grass stands. These shrubs can be encouraged in many places by heavy spring grazing by livestock. The best bobwhite habitat on rangelands are high cover for nesting but low seral stages for food; thus requiring either patch grazing or overgrazing in spots or various degrees of grazing in adjacent pastures (Guthery et al 1990).

Increase Selected Species

Urness (1990) reviewed the published information on the chain of events beginning with overgrazing and fire suppression in the late 1800s that promoted increases of shrubs into former open grassland. Unregulated hunting kept deer populations low. Regulated hunting in the early 1900s set in motion an increase in mule deer that lasted into the mid-1900s. Reductions of livestock grazing beginning in the 1930s and heavy use of shrubs by deer were accompanied with increased grass and retreating shrublands. About 1950 deer numbers began to decrease. Urness (1990) also reviewed a number of trials that showed how carefully managed livestock grazing can improve deer habitat. To do so the whole plan must include deer herd management as well as livestock management.

Cattle select grasses during early spring grazing but not *Purshia tridentata* until a later time; cattle should be removed from deer winter range during summer and fall. Spring grazing can reduce the grasses which has been shown to increase the growth of *Purshia*. Spanish goats will reduce *Quercus gambelii* allowing other shrubs to increase, but in some areas the better species for deer have also decreased.

Nutritive Quality

To improve the nutritional value of herbaceous plants they should be grazed early and the animals moved at a time that will allow regrowth. This has delayed plant maturity a few days and the regrowth matures at a smaller size than ungrazed. Although differences are small, the shorter material has less percentage lignin and strengthening components, therefore higher nutritive value. Also, removal of leached old growth of grasses makes new growth more available to the grazing animal.

Cover, Diversity, Height, Openness

Kantrud (1990) summarized the habitat needs of breeding waterfowl in the prairie pothole region of northcentral United States on the basis of 163 literature items. Breeding waterfowl prefer openings in the marsh canopy and avoid dense cover. A mixture of cover and open water provides better food, higher hatching success, and resting sites along the shorelines. Broods increase as diversity of shoreline increases, as do other marsh dwellers. Monospecific stands of large emergent plants (*Typha, Scirpus, Phragmites*) have very low diversity. Their manipulation might be attained with control of water depth. Effects of burning have varied. Overgrazing that destroyed most of the cover during the nesting season was damaging to waterfowl. Light to moderate grazing after the hatching period opens cover, increases diversity, and provides the best brood habitat. Reductions of dense cover has increased invertebrates. The damage and the improvement of wetland habitats by grazing are matters of seasonality, frequency, and intensity of grazing.

A study of the effects of 5 grazing systems on the nesting and success of several duck species on the Central Grasslands Research Center in North Dakota found that nesting success on nongrazed prairie was consistently lower than on grazed treatments (Sedivec et al 1990). The following recommendations were given: Grazing should not begin until late May to allow nesting. Vegetation dominated by *Symphoricarpos occidentalis* should be protected until that time as it is the favorite nesting site for ducks and sharp-tailed grouse. A twice-over rotation grazing system was best suited to production of livestock and birds.

Although livestock grazing seldom destroys wildlife habitats, it alters them. Changes in vegetation structure and species composition benefits some animal species but harms others. In northeastern Oregon, when cattle were removed the elk increased from 120 to 320; later a cattle grazing plan to increase forage quality supported an elk increase to 1100. Livestock grazing improved mule deer, bobwhite, and Canada goose winter habitats.

In the absence of grazing in the California annual-type grassland tall grasses increase and forbs decrease, resulting in a poorer habitat for some 84 vertebrate species. The grazing pattern should be light to none in late fall and winter and heavier in the spring to reduce grasses. In Sierra Nevada meadows of California and the same data base, 68 vertebrate species showed an affinity for short-herb rather than tall-herb vegetation. Moderate grazing is used to attain that vegetation (Kie and Loft 1990). After 37 years, the vegetation in the sagebrush/grass type in Oregon was not significantly different between grazed and ungrazed (Sneva et al 1984).

Heavy Grazing as a Tool

Overgrazing usually causes undesirable changes in the species composition and other undesirable results such as soil loss and wildlife habitat deterioration. However, situations exist where the composition of the vegetation can be changed only with heavy grazing. Heavy grazing, then, becomes a tool in achieving the desired and planned objective. It should be considered "bad" only when it causes the rangeland ecosystem to move away from a planned objective.

"Overgrazing" in the public press and the attitude of many persons does not admit that grazing can be anything but heavy. The term is also used for light and moderate grazing and always with a negative connotation. To accomplish the four goals for wildlife habitat improvement, grazing and often some degree of heavy grazing are necessary. Grazing that changes vegetational structure invariably helps some wildlife species while damaging others. If livestock grazing were removed completely, the vegetation would change to the detriment of many other species. Both managed grazing and no grazing require planning and decision making, which depends upon inventory, thorough knowledge of ecosystem dynamics, and an intimate knowledge of species tradeoffs, both plant and animal.

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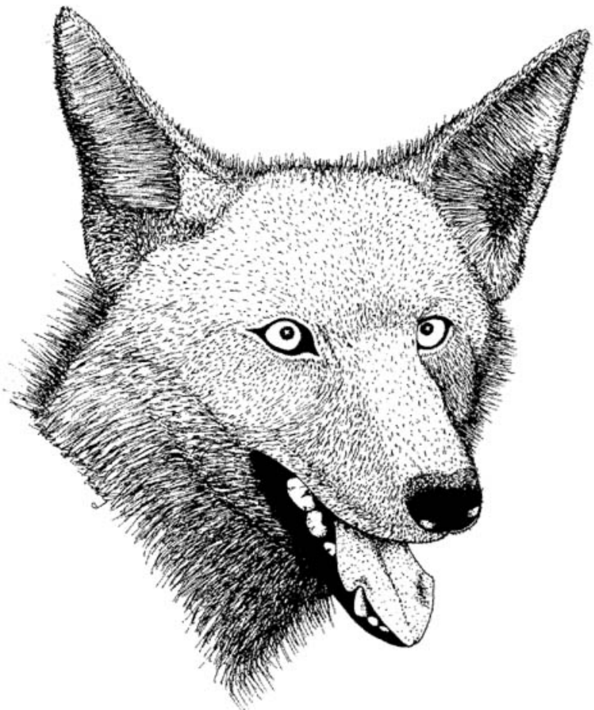
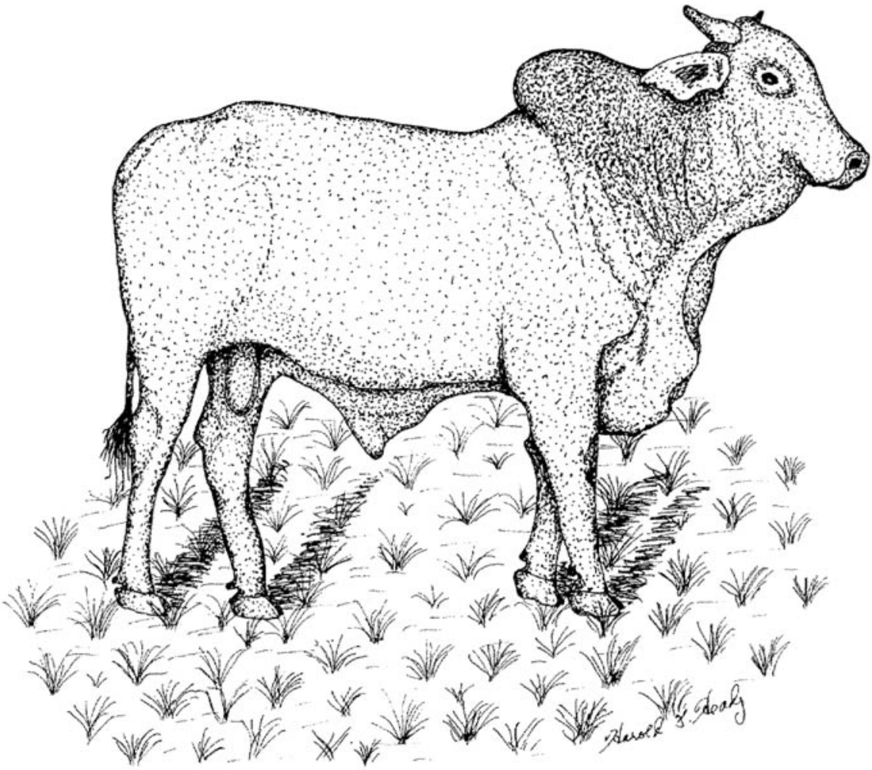
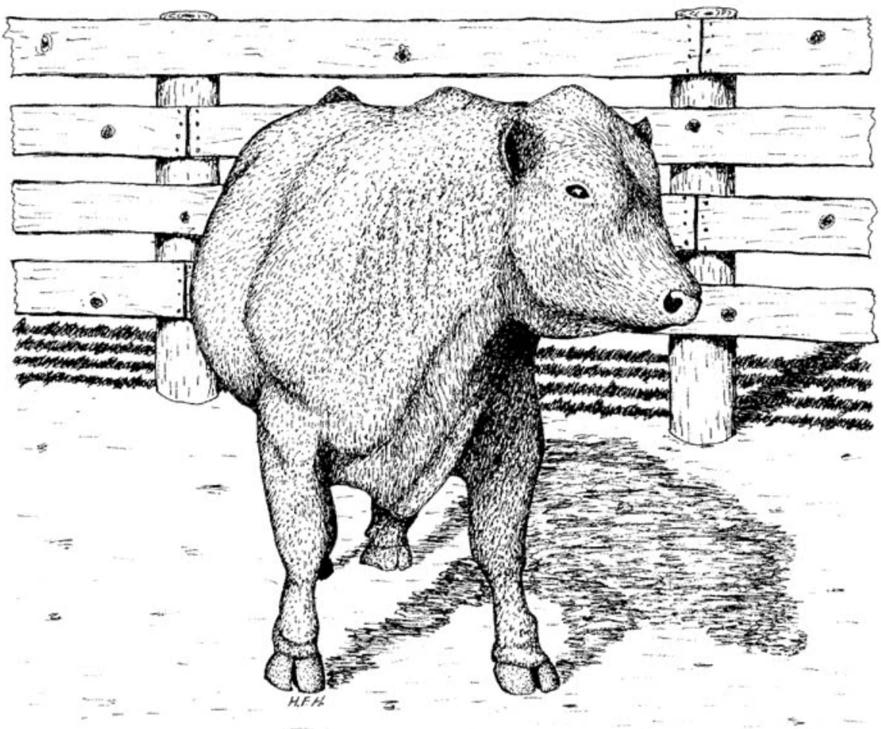


PART TWO

Grazing Management

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11

Numbers of Animals

Control of animal numbers is the first and most important rangeland management principle. As each animal grazes, it reduces available herbage both in quantity and quality, thereby changing the habitat for itself and altering future animal/habitat relations. The timing and degree of forage utilization by animals are the principal controls over species composition and forage production in the manager's hands. Stipulation of animal numbers and the degree of forage utilization have little meaning without describing kind of animal, grazing distribution, and season of use. These are the four cardinal aspects of grazing animal management.

On rangeland, regeneration of desirable plants maintains good range condition. Grazing by too many animals or too heavy use by a few animals results in overuse, loss of vigor, and ultimately disappearance of the desirable plants. Deterioration of the range vegetation begins when less valuable forage species replace the desirable plants. Diminished land values, lowered income, and soil instability eventually result.

Replacement of destroyed vegetation by seeding remains expensive. Furthermore, animal numbers must be strictly controlled if new seedlings are to become established. Other range improvement practices also require relief from heavy grazing. If range resources are to be perpetuated at the highest productivity levels, the range must be properly stocked and utilized.

Excessive forage utilization by either livestock or game reduces growth rates, weight gains, and animal values. Coordination of forage utilization with forage growth through control of animal numbers usually determines the success or failure of other range practices and the economic stability of the operation. This principle cannot be overemphasized. Many stocking rate experiments, for example, Woolfolk (1949), Hurtt (1951), Launchbaugh (1957), Klipple and Costello (1960), Reed and Peterson (1961), Beetle et al (1961), and Merrill and Miller

(1961) have shown that moderate and conservative stocking rates give greater longterm returns than does a heavy stocking rate. With moderate and light stocking rates there are improved animal condition, more wool, greater percentage calf crops, higher weaning weights, fatter cull animals, less death loss, less supplementary feeding and higher selling prices.

CONCEPTS AND DEFINITIONS

Rangeland resources result from more than the physical characteristics of the site. Individual resources increase or decrease in importance and new ones are created as demands of society and inputs by management change (Lime and Stankey 1971). The concept of rangeland resources signifies a synthesis of physical environment, plants, and animals as enhanced by the manager and produced for society. One hears the term **related resources for range forage, game, recreation, watershed, soil, timber, etc. and multiple-use when two or more of grazing of livestock, wildlife production, recreational facilities, more water, timber production, etc. occur on the same land. These general terms for resources and uses are of value as specifics in local planning.**

Many organizations have had a longterm interest is grazing animals and grazing lands and have used different terms to define the same concept. Other terms are used with different definitions, some obscure and conflicting, by interest groups. A Forage and Grazing Terminology Committee of 33 people representing 15 organizations and 2 foreign countries has published "Terminology for Grazing Lands and Grazing Animals." Allen (1991) was Committee Chair. Terms are organized under four headings--forages and grazing lands, management concepts, measurement, and method of grazing. The bibliography in the paper includes two range glossaries (Jacoby 1989, Trollope et al 1990) and numerous books on cultivated pastures and rangelands.

Carrying Capacity and Grazing Capacity

Range management literature lists many terms related to numbers of animals. **Grazing capacity refers to the average number of animals on a defined management unit that will produce an objective of animal performance without ecosystem deterioration over a long time period.** The management unit may be a pasture, an allotment, a ranch, or a series of pastures grazed in rotation. Often this definition is the same as for **carrying capacity.**

The number of animals in a management unit for each year or grazing season that goes into calculating the average grazing capacity

is the stocking rate. Some definitions state "maximum" and others "optimum" numbers of animals rather than "average." The objective "of animal performance" determines which word applies. "Greatest livestock financial return" often implies optimum numbers. Use of animals as a tool for another purpose, such as to improve wildlife habitat, to reduce fire hazard, or to improve range condition may require maximum stocking rate in one situation, average in another, and varied rates for another purpose. Clarity in describing grazing capacity for specific situations requires careful choice of words.

Range resources are supplies of commodities and services, each with a capacity of production and a capacity for off-take. One of these resources is forage, but the production varies season-to-season and year-to-year. The relative utility of range resources results from an integration of physical and environmental factors, effects of organisms, available technology concerning resource use, and current potential value to society. Extensive changes in the use of all wildlands, including livestock grazing land, have come from new demands for the types of goods and services available. Persons with many different land-use objectives are interested in the land capacity for their particular interest. Carrying capacity in this context could be the total of all product capacities, one being grazing capacity. To use carrying capacity in the sense of livestock grazing alone results in misunderstanding by those interested in resources other than forage. The notion of carrying capacity as a biological constant becomes untenable, as does the concept of sustained yield when applied to a single often-changing product.

Many factors determine grazing capacity for both livestock and wild grazing animals. The principal limits on livestock are quantity and seasonal availability of feed. Also for wildlife, and availability of preferred habitat and cover must be considered. Winter snow lowers food availability limiting populations to less than complete use of available forage during other times. High-quality summer forage promotes large individual size and good health that enhances winter survival and reproductive success. Thus, the desirable herd size of any animal population on a summer range may be considerably different from that of the same herd on a winter basis (Wallmo et al 1977). Alternating wet and dry seasons in the tropics have effects similar to those of alternating winter and summer seasons. **Efforts to increase grazing capacity center on the limited resources or on increasing the feed supply at the time of greatest stress.**

Where both feed supply and livestock numbers cycle, three types of calculations have been used in quantifying basic herd size for yearlong operations. One method requires identifying the feed supply and number of animals supportable during the months of least available forages. A second method determines a yearlong herd size on the basis of average monthly feed supply; but this method usually gives higher estimates of animal numbers than can be maintained. A third method arrives at the basic herd size by comparing month-by-month estimates of feed supplies (forage production) and requirements (dry matter or nutritional intake) by animals of all ages (Workman and MacPherson 1973). Flexibility in the stocking rate can be attained by allotting a certain percentage, say 75 percent, of the grazing capacity to the breeding herd and adjusting total numbers through varied animal removal as the feed supply dictates.

Merely increasing the feed supply cannot increase grazing capacity where overriding behavioral mechanisms control numbers. The populations of Uganda kob are limited by territoriality (Buechner 1963). In Wyoming a fence limited mule deer movements and their overgrazing caused mortality of *Artemisia tridentata* subsp. *vaseyana* (McArthur et al 1988).

Many ungulate populations in a new or changed habitat increase slowly, erupt, crash, and then reach a relatively steady density. The latter, in equilibrium with stable habitat conditions, is different from those at the beginning of the population cycle. This is an **ecological carrying capacity** in contrast to a managerial carrying capacity or grazing capacity concerned with livestock production, hunting, aesthetic values, etc.

Grazing capacity is more difficult to define in populations that "explode" or cycle than in those that tend to be stable, such as the numbers of livestock on a ranch. Examples of exploding populations are those of species introduced onto islands; two examples are the reindeer on St. Matthew Island in 1963-1964 (Klein 1968), and the moose on Isle Royale in Lake Superior (Mech 1966). Both rapidly increased and then crashed. In these instances, there seemed to be only one limiting factor--the food supply. The common sequence of events is a geometric population increase beginning with a few animals, summer food in short supply, and animals entering the winter in poor condition. Extreme weather conditions result in a heavy dieoff. When a second limiting factor, predation, was introduced onto Isle Royale, the numbers of moose fluctuated much less severely than they did with only changing food supply.

These examples illustrate the difficulties in defining and interpreting the concepts of carrying capacity and grazing capacity. To avoid misunderstanding, one should use them sparingly after tersely defining them for each given situation.

Units of Animals and Grazing

Allen (1991) defined a standard livestock unit (SLU) or animal unit (AU) as **One mature nonlactating bovine weighing 500 kilograms and fed at maintenance level, or the equivalent, and expressed as weight at the 0.75 power in other classes of animals of the same species.** The use of AU in publication should specify the species and breed, class, sex, size, age, and physiological status of the livestock. It was assumed that an AU has a dry matter intake of 8 kg/day.

In range management, it is common to consider an AU as a mature cow (450 kilograms and a dry matter intake of 12 kg/day) either dry or with calf, or their equivalent. Horses, sheep, and goats commonly are converted to animal units at the rates of 1.25, 0.2, and 0.17, respectively. Depending upon size and gain per day, young animals between weaning and maturity vary from 0.6 to 0.9 of their adult female equivalent animal units. Adult bulls are about 1.25 AU, but large ones may be as much as 2 AU. These conversion factors are indicators of equivalent amounts of forage needed by different kinds and classes of domestic animals with similar diets. In other words the AU is a unit of animal but an AU-day is a demand for feed (Scarnecchia 1985). Animal equivalents have little application in expressing equivalent impacts on range vegetation from animals with wide differences in food habits.

An animal unit month (AUM) is the amount of forage required by an animal unit for one month of grazing. In range management it is common to express the usable forage in a pasture as AUMs per acre or acres per AUM. Related terms for specific instances include **sheep day, band day, cow day, cow month,** and others that refer to different kinds of animals and time periods.

Animal unit equivalents are used to describe the forage needed by mixtures of grazing animals. The equivalents allow allocation of forage to different kinds of animals, to varying forage requirements as young animals grow, and to grazing at different seasons. Coordination of varying AUM requirements and forage increments in day-to-day livestock management still is a matter of judgment by the manager. Scarnecchia and Kothmann (1982) give a mathematical framework that shows the relationships among these terms.

Animal unit months of grazing, or a variant such as steer months, are widely used as leasing units and as a basis for pasture rental. Grazing fees on public lands and on many private pastures are attached to animal units on a basis of grazing season or time.

Grazing Pressure

Grazing pressure is the animal to forage relationship at an instant of time and is expressed as AU or AUM to weight of available forage. It quantifies the demand for forage by animals in a ratio to the standing crop of vegetation available to them (Fig. 11-1). This function is related only indirectly to numbers of animals and area of pasture. Hart (1987) found that the animal gains from several grazing systems were the same with the same grazing pressure.

Labeled as herbage supply in Figure 11-1, the standing crop of new forage available for grazing begins at 0, proceeds to a peak at plant maturity, and falls to 0 as herbage is consumed by herbivores and decomposers. In many vegetational types, the cycle of herbage produced one year overlaps part of the following cycle before it disappears. The peak supply may be sharp as shown, broad and relatively flat under favorable moisture conditions, irregular when occasional rain brings repeated growth, and show great annual variation.

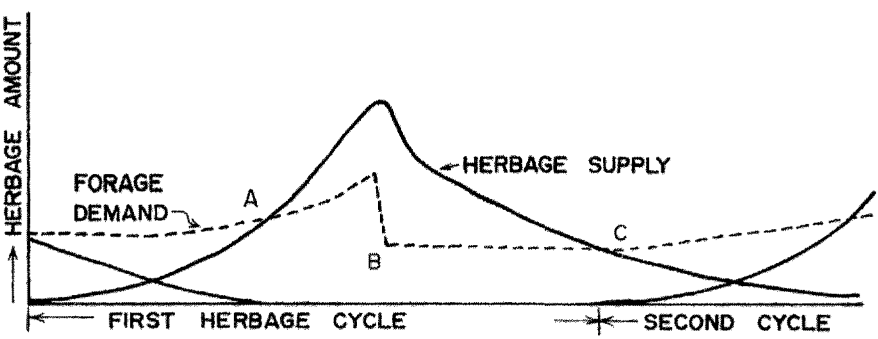

Figure 11-1 Grazing pressure expressed diagramatically. The supply of forage for one full yearly cycle, which overlaps the end of other cycles, appears as an accumulation and decay of standing forage crop (solid line). Demand for forage (dashed line) increases as young animals grow and suddenly decreases at sale time. **Grazing pressure is light when daily consumption is less than the daily increment in forage supply and when available forage is well above daily consumption.**

General nutritional values are not shown in Figure 11-1 but they can be visualized. Crude protein is high in new-green foliage and the proportion of high-fibrous stems is low. As growth proceeds crude protein becomes less in percentage of plant materials and fiber increases. The quantities of these nutrients on an area basis is different from the percentages in a plant because of the accumulation of standing crop. These and other relationships can be superimposed on Figure 11-1 illustrating seasonal progression of grazing values.

Animals, or their demand for forage, are imposed on the cycle at a more or less constant rate in a few range operations. However in most, demand for forage by young animals gradually increases, a sudden decreased grazing pressure occurs at sale time or hunting season, and the demand remains relatively constant until the next addition of young animals. Figure 11-1 suggests the supply/demand for feed for yearlong operations that dominate in Mediterranean annuals and the wet/dry tropical and subtropical regions.

Many other situations exist. Complete use of feed during the forage growing period is the objective in steer operations, hence all the feed would be used at sale time, point B. Cow/calf operations on temperate rangelands often begin grazing at point A and end at point C when the animals go to nonrange feed. If points A and C are below the supply line the grazing is light and heavy when above the supply line.

Thus, almost all range grazing programs result in varying seasonal grazing pressures on the vegetation. Grazing pressure is light during times when the daily herbage growth increment is greater than the daily harvest and during times of grazing on accumulated mature growth. Heavy pressure occurs when daily consumption exceeds the daily growth increment and available forage supply is low. Yearly as well as seasonal variations alter these relationships.

Expressions and measurements of grazing pressure on rangeland have embodied the concept that the degree or percentage of forage utilization signifies the influence of grazing on the vegetation (Campbell 1937). This relationship suggests that grazing pressure is proportional to the amount of herbage eaten during a season or a year. A better expression of grazing pressure for rangelands and pastures may be one relating numbers of animals to available forage (Hyder 1954, Heady 1956, Mott 1960). In 1966 Campbell expressed this concept of grazing pressure as a ratio of animal days per 1,120 kilograms of available dry matter per hectare. The influence of day-to-day changes in grazing pressure (ratio of forage demand to supply) on range condition and production needs further clarification.

Stocking Rate and Stocking Density

Stocking rate is the actual number of animals or animal units on a unit of land for a specific period of time, usually for a grazing season. Where the grazing season is yearlong, a time period may not be stipulated, but in temperate and mountainous regions, stocking rate commonly defines all the grazing that occurs during a year, for example, 30 AUs per hectare for four months of grazing. It may be expressed as 120 AUMs per hectare or 1 AUM per 0.0092 hectare. This is an animal-to-land relationship.

Stocking density describes the animal-to-land relationship at an instant of time (Booysen 1967). Stocking density is a function of herd and pasture size. It differs from stocking rate which expresses animal-to-land allotment for the entire grazing season.

The distinction between stocking rate and stocking density becomes important in rotational grazing plans. For example, number of animals per 5 hectares would be the density of animals when all animals are in one unit of a 5-pasture (each of 5 hectares) rotational system, but the stocking rate for the system is 5 animals for the 25 hectares.

A high stocking density often requires a short grazing period and it is used to attain full forage utilization before regrowth can be grazed. Also it is useful to describe animal-to-animal behavioral relationships. Stress has been shown to be density-dependent in some species of animals, and therefore a function of animal density.

Stocking rates have been expressed as units of area for each animal as well as animals per unit area. These expressions of stocking rate have shown differently shaped functions when plotted against a third variable such as animal gains per individual or land unit. Animal-to-area expressions are preferred because they are more directly related to grazing pressure and production per hectare than is area per animal (Shaw 1970). However, in regions with low grazing capacity, the ideal designation may be area per animal because it avoids the use of fractional terms.

PRODUCTION PER HECTARE VERSUS PER ANIMAL

Figure 11-2 is a diagrammatic expression of the relationship between production per unit area and weight gain per animal. The left- and right-hand scales indicate low production rangeland. They are different for high producing pastures and rangeland. Stocking rate, the horizontal scale may be expressed in AUM/ha, ha/AUM, percent utilization, and range condition. Bement (1969) used ungrazed herbage on upland blue grama rangeland in Colorado. Multiple uses give opportunity for other horizontal scales. Hart (1986a) and Wilson and MacLeod (1991) have reviewed the variety of functions proposed to describe responses to different stocking rates.

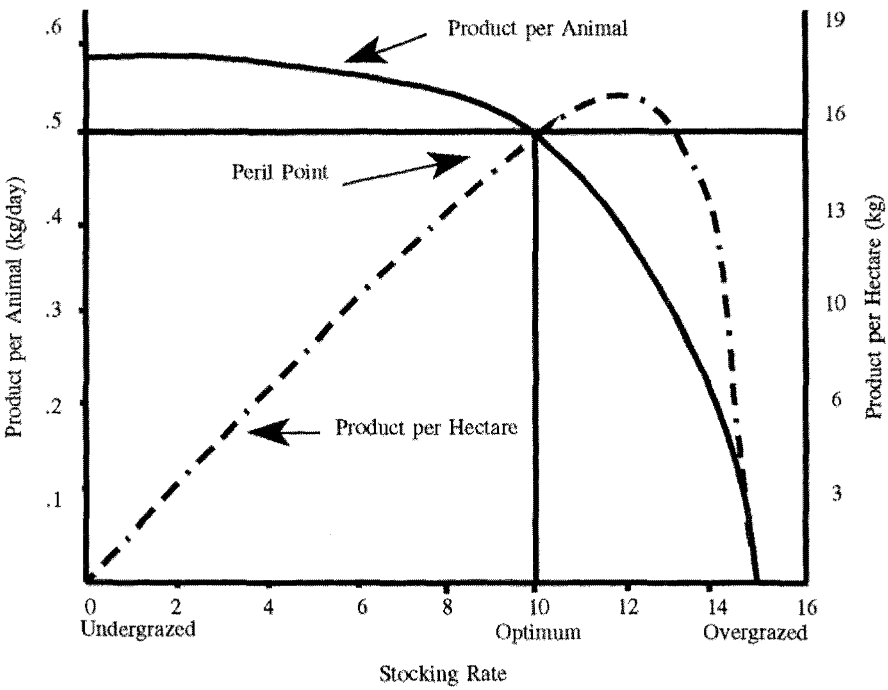

Figure 11-2 Diagramatic expression of product per animal and per hectare in relation to stocking rate. (Adapted from Mott 1960)

Given the same grazing system and length of grazing period, as numbers of animals are increased per unit area, closer utilization, less available feed, and less nutritious forage per animal result. Animals gain less and if the situation continues, they eventually lose weight (Fig. 11-2). Slow-growing animals and those with great fluctuations in weight must be fed for a longer period of time and often to a heavier weight than animals that are rapidly grown. Stocking at rates that reduce weight gains per animal often leads to range and financial problems.

If product per animal is plotted against numbers of animals per unit area, the relationship usually is linear and the two factors negatively correlated within the range of low and moderate grazing pressures (Fig.

11-2) (Riewe et al 1963, Peterson et al 1965, Bement 1969, Blackburn et al 1973, Pearson and Whitaker 1974, Hart et al 1988, Wilson and MacLeod 1991). This relationship is one of animal response to nutrition and genetic potential rather than to stocking rate or feed availability (Harlan 1958, Heitschmidt et al 1989).

At low stocking rates, individual animals show little response to changing numbers because the feed supply is beyond their capacity to use it. Individual animal potential rather than pasture productivity is defined when few animals graze abundant forage (Morley and Spedding 1968). Occasionally in practice, low forage utilization may allow plants to become coarse and of low quality, resulting in less gain per animal than at moderate stocking rates. The optimum stocking rate is usually lower and never higher than the biological at maximum sustained yield according to Workman and Fowler (1986).

At high stocking rates, gains per animal fall rapidly with relatively small change in numbers of animals (Mott 1960). The point where the curve breaks, the optimum level or slightly to the right of it in Figure 11-2, has been called the peril point for management (Harlan 1958). Gains per area and gains per animal cross at that point; animals are beginning to lose weight and condition. At stocking above that point range forage availability declines, range condition deteriorates, and animals rapidly lose condition. Stocking below the peril point gives more leeway in management and little response to changing stocking rates.

A 12-year stocking rate experiment with sheep grazed yearlong yielded data that approximated the schematic curves in Figure 11-2 (Tadmor et al 1974). Hart (1978) reviewed the work of others on the relation of liveweight gain and stocking and it is arguable whether the curve, to the left of the peril point is straight and flat or curved as shown in Figure 11-2. Jones and Sandland (1974) presented a different model than Figure 11-2 that seemed to emphasize animal response more than relating animal responses to pastures, especially in the longterm (Bransby and Tainton 1979). The preferred model should relate profit per hectare to the level of standing herbage and vegetational condition (Booysen et al 1975, Bransby and Tainton 1979, Mentis and Tainton 1981, Bransby 1985).

Quantities of animal products per hectare increase directly as stocking rate increases, reach a peak, and fall rapidly at excessive stocking rates (Fig. 11-2). Many but not all studies have shown the greatest per-hectare productivity with the high stocking rates (Riewe 1961). Experimental treatments in the narrow range of stocking that gives peak gain per hectare are difficult to select; therefore, many experiments have missed them. Furthermore, managers and experimenters alike deliberately eliminate high stocking rates in order not to damage range and livestock.

Maximum gains per hectare over the longterm indicate ample opportunity for animals to select nutritious feed without range damage. Animal numbers and duration of stay in a pasture normally should not exceed a degree of forage utilization that causes excessive weight loss.

After assuming equal beginning weights, grade changes, and other animal characteristics; taking no account of pasture and fixed costs; and selling steers at the same price per kilogram as the purchase price, Riewe (1961) calculated that the highest gross returns came from a stocking rate that yielded maximum gain per hectare on cultivated pastures. This may not be true for rangeland. As selling price increased over purchase price, gross income increased at all stocking rates and remained maximum at or near the point of highest gain per hectare. If prices fell, high stocking rates tended to maximize financial loss. The least financial loss occurred with the greatest weight gain per animal at low stocking rates. Intermediate price reductions resulted in gross losses at high stocking rates and lowered returns at low stocking rates. Apparently high stocking rates produce high gross returns when price changes are favorable and produce the greatest financial losses when prices fall.

Analyses that only include changes in livestock prices tell little about net return or profit from changes in stocking rate. Production per unit of labor, per kilogram of fertilizer, per centimeter of rainfall; number of game animals harvested; and other factors may be as relevant to economic analysis as is production per hectare. These input and output factors vary widely in time and place. As costs increase and prices decrease, the economically optimum stocking rate appears to decrease. Lower stocking rate does not always yield lower net returns. If rapidly gaining animals develop a price differential in their favor, the manager may need to redress stocking rate toward lower levels and less gain per hectare to maintain high rates of weight gain and profit.

Other factors being equal, the curve of profit against stocking rate appears to be relatively flat (Hildreth and Riewe 1963). This relationship gives the manager considerable flexibility. The enterprise is not required to have the stocking rate at a fixed point to obtain near-maximum profit. As Mott (1960) wrote, optimum stocking is a range of rates rather than a single one. The manager should strive for stocking rates that maximize net profit, as continually modified by risk and ability to cope with changing factors. Torell and Hart (1988) said to maximize profits the last animal added to the herd must add as much return as it does cost, including in the cost any range deterioration that may occur.

Partially controlled game populations present stocking rate problems similar to those of livestock. For example, deer and elk fecundity rates change inversely with stocking density. Net production per breeding animal decreases as population size increases, and the stocking density at optimum yield of young animals uses less feed than the habitat supplies (Gross 1969). At maximum stocking density, the harvest is reduced for game as well as for livestock. Stocking rate determines animal performance, profitability under grazing, and rangeland condition (Hart 1986b).

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12

Utilization of Forage

UTILIZATION DEFINED

The chapters on Defoliation concentrated on experimental treatment effects on plants such as those due to clipping. The responses were largely from plots, potted plants, single plants, and single culms or parts of culms (phytomers). The results were expressed in weight per unit and chemical composition. This chapter emphasizes the effects of grazing on rangeland vegetation.

The amount of plant material consumed and otherwise caused to disappear by herbivores, expressed as a percentage of the current herbage crop, has been known as **range utilization, degree of use, percentage use, actual use, herbage use,** and **range use**. These terms apply to single species as well as to the pasture as a whole. **Actual use** may be an expression of the AUMs obtained in a grazing season and thereby may be confused with **stocking rate**.

In this book, **utilization** as the noun form of utilize, a specific concept in the dictionary, refers to disappearance of herbage. **Use** will refer to a product or service derived from rangeland, as in multiple-use. In the range profession these words are often synonyms, but they need to be specifically defined and applied.

A distinction is made here between **stocking**, which is a daily phenomenon; **range forage utilization**, which is seasonal; and **grazing**, which has a longer time reference. Thus, **overstocking** can be corrected in a day and **overutilization** in a growing season, but the results of **overgrazing** may take several years to eliminate with proper utilization each year.

Many comparative terms result from combining the prefixes **under, proper**, and **over** with **stocking, utilization**, and **grazing**. Definitions of these terms may be self-evident, but several are given here as follows: **Overstocking, if continued, results in overutilization, and if continued**

for years, will result in overgrazed or deteriorated range. In comparison, **proper stocking results in proper utilization at the end of the grazing period and promotes maintenance or improvement in range condition.** Other terms modifying **utilization** and suggesting different but seldom specifically defined conditions include **close, destructive, extreme, full, light, local, moderate, slight,** and **severe.**

DETERMINATION OF FORAGE UTILIZATION

Managers and range technicians estimate and measure forage utilization to determine when the correct degree of grazing has occurred, to indicate the amount of forage that remains to be harvested, and to ascertain the extent of livestock distribution problems. Utilization may be expressed in percentages of the herbage weight removed, of the number of plants grazed, and of the height removed. Tables of ungrazed height/weight relationships have been developed for this procedure (Heady 1949, McDougald and Platt 1976, Harshman and Forsman 1978).

Paired plots, one caged to protect it from grazing, give estimates of forage weight removed by herbivores and herbage remaining on the ground. The most accurate method compares the weight of herbage before and after short periods of grazing. Ocular estimates before clipping and weighing helps to standardize one's estimates of forage utilization. When extensive herbage growth occurs during the grazing period, the estimates of forage utilization are inaccurate. Before and after measurements of utilization may be made without cages with short rotation grazing periods and on both browse and grass types.

Another relatively accurate method but one that is time consuming to apply depends upon the relation of weight to height of grasses. It requires construction of standard tables or graphs (Heady 1950). Field application requires comparison of average ungrazed height and stubble height with the standards. Figure 12-1 illustrates the variation in height and growth form for *Agropyron spicatum* and *Koeleria cristata* for 1946 and 1947 in Montana.

If grazing is light or moderate, many individual plants or plant parts are ungrazed, and a random sample of the number of ungrazed and grazed plants and the weight of each permits measurement of utilization without protection of plots. Usually the key species are measured separately.

The percentage of ungrazed stems has been used to indicate utilization of rhizomatous species such as *Agropyron smithii.* The United States Department of Agriculture-Forest Service Range Analysis Field Guide for Region 5 of the national forests suggests that, for bunchgrasses, fewer than 53 percent grazed plants indicates less than 35 percent utilization and fewer than 5 percent ungrazed indicates more than 75 percent utilization.

12-1a 12-1b

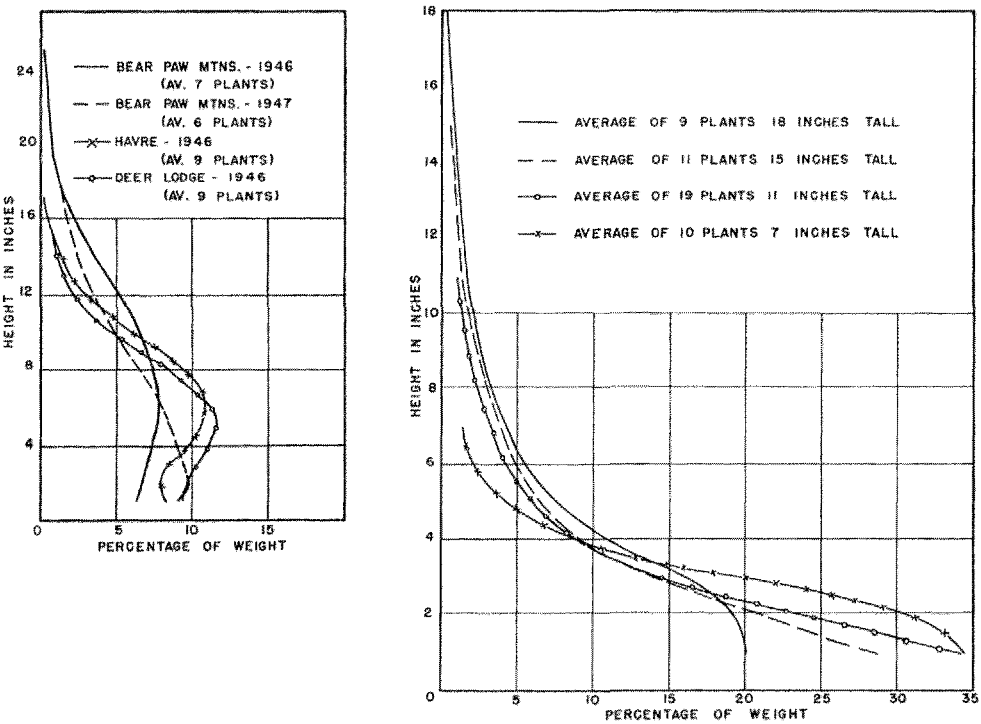

Figure 12-1 Percentage of weights according to height of *Agropyron spicatum* at four locations (12-1a) and *Koeleria cristata* (12-1b). Data collected in 1946 and 1947 in Montana (Heady 1950).

The methods available for measuring utilization of browse are mostly indirect and depend upon regression models. Tagged twigs may be measured for length before and after grazing and samples of grazed and ungrazed twigs of current growth may be taken for weighing. More commonly, utilization of browse is described in qualitative terms, which include percentage of plants browsed; hedging of key species ranked severe, moderate, or not evident; and categories that describe the browse line.

A review of the methods for determining rangeland forage utilization described numerous methods (Heady 1949). Each method gives a different answer, sometimes quite different with large Standard Errors, and all should be considered as indices to be tempered by reasonable management. Annual utilization inventory is a tool. It cannot be either the sole basis or objective for land management decisions.

Proper Utilization

Utilization measurements can indicate effects of different intensities of grazing. Plants have a tolerance to grazing, and many are stimulated by low levels of defoliation. Dyer et al (1982) called this reaction of grasses to grazing as the "Grazing Optimization Hypothesis." The relationship is best associated with the tallgrass areas, but there is little evidence to support it for arid and semiarid areas (Heitschmidt 1990). If herbage removal exceeds a certain critical point, however, most plants will lose vigor, produce less herbage, and eventually die. **Proper utilization is that maximum point of defoliation which continues to maintain desirable range productivity or to improve poor range.** Efficient utilization of range forages requires the right kind and class of animals, the best stocking rate, and the proper season of grazing. Any expression of proper utilization must be considered as a guide to be applied with care.

Many animals on rangeland, in addition to livestock, remove forage and all do mechanical damage to the standing crop. Pearson (1975) reported that 17 to 21 kilograms of herbage disappeared per animal unit day on southern pine range but cattle intake accounted for less than half of that amount. Estimates of production and utilization of actually grazed plants which are based on measurement of plants not grazed at all may be inaccurate. For example, expressions of forage removed by clipping of *Agropyron desertorum* varied from 54 to 82 percent depending upon the method of calculation (Cook and Stoddart 1953). Spring clipping resulted in 82 percent removal of mature herbage weight produced by the plant itself, but this amount was equivalent to only 54 percent removal from mature plants that were not spring-clipped.

In field studies, when the desert termite was controlled, the standing crop of grass increased by 22 percent and litter by 50 percent at the end of the second year. These results from Texas (Bodine and Ueckert 1975) are similar to those found in other termite studies throughout the tropical and subtropical world.

Hewitt et al (1976) reported that one grasshopper (*Aulocara elliotti*) per square meter near Three Forks, Montana removed 10.5 kilograms of forage per acre if it lived for 75 days. In a study of 26 grasshopper species, Hewitt and Onsager (1982) found an average disappearance of herbage amounting to 43 mg per grasshopper day. They have been estimated to destroy more than 20 percent of the annual herbage crop on rangelands in the United States (Hewitt and Onsager 1983). Often, more grasshoppers occur on heavily grazed areas than on lightly or moderately grazed ranges (Holmes et al 1979). The most harmful grasshopper species increase or are favored if the range is overgrazed (Hardman and Smoliak 1982). In epidemic numbers, they are known to have eaten all herbage in their path. It is accurate to say that extensive defoliation takes place without domestic animals and that all herbivores, large and small, cause herbage losses in addition to that eaten.

No two plant species in a vegetational type will be grazed to the same degree, and the degree of utilization will not be the same for a single species in different parts of a vegetational mosaic (Table 12-1). On a summer cattle range in the mountains of eastern Oregon, the grassland portion was 23 percent grazed when 60 percent of the herbage produced by *Agropyron spicatum* and 55 percent of the herbage produced by *Koeleria cristata* had been removed (Pickford and Reid 1948). Cattle in the Oregon study foraged on open grassland sites to a greater degree than they did on timbered range, although several of the major forage species occurred in both areas (Harris 1954, Johnson 1956, 1966, Smith 1967). Other factors such as botanical composition of the vegetation, season of grazing, kind of animal, and distribution of animals contribute to variation in range utilization. These factors are discussed in other chapters.

Although stocking rate may remain approximately the same from year to year, variation in forage production in response to climatic variations will cause large yearly differences in degree of forage utilization (Table 12-1). In only one year of ten was utilization considered proper by Harris (1954); and the variations in utilization were too great to justify yearly changes in stocking. As summarized by Hedrick (1958), an average utilization of the key species over a number of years which approximates 50 percent removal is a reasonable expression of proper utilization for most grassland ranges. Valentine (1970) agreed with the 50 percent guide for good condition *Bouteloua eriopoda* ranges but recommended 32 percent removal on ranges in poor condition.

Table 12-1 Ten-year fluctuations of actual forage utilization, in percentage of growth removed by cattle on mixed grassland and timbered range, Starkey Experimental Range in eastern Oregon (Harris 1954)

	Grassland	% removed	Timbered range	% removed
	Mean	Extremes	Mean	Extremes
Agropyron spicatum	52	38-69	41	30-60
Festuca idahoensis	41	26-67	32	15-48
Koeleria cristata	38	16-55	22	18-38
Danthonia unispicata	43	18-76		
Poa secunda	15	4-34		
Carex geyeri			28	18-40
Calamagrostis rubescens			10	4-12

What constitutes proper degree of herbage removal for most species at different times along the growth curve remains unclear. Here are examples: A 5-year simulation study indicated that a threshold of 2700 kilograms of above-ground biomass per hectare was needed to maintain *Spartina alterniflora* marsh on the Cumberland Island National Seashore. Grazing by the horse herd should leave that amount of biomass to prevent degradation (Turner 1988). *Bothriochloa caucasica* had greater loss of leaf mass than root mass under heavy relative to light grazing. This resulted in a better root surface to leaf surface ratio, thus the plant's high tolerance of heavy grazing (Svejcar and Christiansen 1987). Sauer (1978) reported that standing dead material had an apparently beneficial effect on *Agropyron spicatum*. As stocking rate was increased, animal production per hectare increased except at 4 times the moderate stocking rate. Weight gains per animal decreased in a 35-year study of *Festuca scabrella* grassland in Canada (Willms et al 1986). Underutilization may be as damaging as overutilization in *Lolium perenne/Trifolium subterraneum* pastures (Motazedian and Sharrow 1987).

Variability in Proper Utilization

Several types of grassland appear difficult to damage permanently by overgrazing. Among these are the shortgrass plains of central North America and the Mitchell grass downs in Australia. Severe droughts in these types cause extensive reduction of ground cover and herbage production irrespective of grazing pressure. As has been shown in the shortgrass plains, heavy grazing retards recovery in years of good rainfall. Stocking rate in these situations appears to be more important to the immediate welfare of the animals than to the health of the range vegetation. The northwestern bunchgrass type in the United States can be easily damaged by grazing. However the California annual type was grazed for 4 years at a stocking rate of 2.5 times moderate but after one year of no grazing little residual impact was found (Pitt and Heady 1979).

Variation over time, space, and method with respect to the determination and use of utilization in decision making casts doubt on the reliability of published "specifications and guidelines." The numbers in these specifications tend to become fixed. If used in that way, management is "cookbooked" and often fails.

Forage Taken or Residue Left?

Most forage utilization data emphasize the proportion of material that has been removed. Sixty percent utilization means that 40 percent of the herbage crop remains on the ground. The 60 percent that disappeared is only measurable by indirect methods because that part was eaten, scattered, decomposed, and trampled to the ground. The portions eaten by the different herbivores and destroyed by them are difficult to separate by cause. Sucking insects reduce plant vigor but reduction of biomass by them may not occur. The black grassbug lays its eggs in the stems of grasses and the larvae feed there which reduced the vigor of *Agropyron cristatum* (Ansley and McKell 1982).

Continuing the above example, the 40 percent that remains as organic residue can be measured directly. It is this portion that initiates future growth, protects the soil, and indicates the health of the range. Quantity of material rather than proportion of the crop is the better indicator of grazing effects. Standards of range utilization based on those amounts can indicate range condition and eliminate the inaccuracies of estimating the proportion of the herbage crop that has disappeared.

The physiological dependence of each plant on the ungrazed or remaining regenerative tissue makes reconstruction of the total crop of doubtful value in evaluating range responses. Therefore, amount of ungrazed herbage should be increasingly used to express proper utilization. A number of scientists have suggested that measurements of utilization and establishment of proper utilization standards should be based on herbage residue rather than on herbage removed.

Among the first to use this concept were those concerned with Mediterranean annual-type grassland in California (Hormay and Fausett 1942, Bentley and Talbot 1951). Their method required matching range appearance with a set of standard photographs. Under moderate utilization, the residue is patchy, reflecting a mosaic of lightly and heavily used areas. Vegetation in swales is used to an even stubble height of approximately 2.5 centimeters. Small objects on the ground are masked from view by plant residue at 6 to 9 meters from the viewer. The landscape has a yellowish cast of varying amounts of vegetation rather than a uniform gray or brown soil color. Both under- and overutilization give more uniform appearances than does moderate utilization.

In the southwestern United States comparison of the grazed perennial plants on the ground against photographic standards of key species (Schmutz et al 1963, Schmutz 1971) indicate utilization in one of five categories; slight, light, moderate, heavy, or severe.

Heady (1956, 1965) and Hooper and Heady (1970) showed that productivity and species composition in the California annual type are directly related to herbage residue on the ground at the beginning of the growing season. They recommended 560 kilograms of mulch per hectare for their study site when utilization was proper (Fig. 12-2). Later research showed that the amount would vary by site and rainfall (Bartolome et al 1980). Management based on residue is practiced in the California annual grassland.

In a summary of data from grazing trials over a 19-year period on the Central Plains Experimental Range in Colorado, Bement (1969) emphasized that the most satisfactory way to assess forage utilization on shortgrass rangeland was in kilograms of ungrazed herbage per hectare (Table 12-2). Analysis showed the greatest animal gains per hectare when the herbage residue was 280 kilograms per hectare, a plateau of greatest gains per animal when the residue was 390 kilograms and the highest net profit when the residue was 335 kilograms, equivalent to an average stocking rate of 1.06 hectares per heifer month. The net return column (Table 12-2), although calculated on the basis of 1964 to 1966 prices, recommended that proper use was achieved at 335 kilograms of plant residue per hectare (Bement 1971). This study indicated that shortgrass range is ready for grazing when the herbage supply reaches 335 kilograms per hectare. Animals should be removed from a pasture anytime during the grazing season when the residue becomes less than that amount. This amount is an optimum standard for livestock production because the vegetation will withstand heavier use (Hyder et al 1966).

12-2a

12-2b

Figure 12-2 Photo 12-2a shows mulch removal in the late summer and photo 12-2b the response the following spring in the California annual type. Absence of mulch promoted small broad-leaved plants (photo 12-2b right) while abundant mulch favored grasses (photo 12-2b left).

Table 12-2 Relation of animal gains to the amount of herbage residue at the end of summer grazing on *Bouteloua gracilis* [based on 19 years of grazing trials at the Central Plains Experimental Range (Bement 1969)]

Ungrazed herbage, kg/ha	Animal gains for 6 months		Net return per kg	Hectares per heifer month
	kg/ha	kg per animal		
168	14.67	57.2	$0.48	0.65
224	16.34	73.5	0.75	0.75
280	16.89	89.8	0.78	0.89
336	16.61	106.1	0.88	1.06
392	15.28	116.1	0.85	1.26
448	14.15	118.4	0.80	1.40
504	13.16	118.4	0.74	1.50
560	12.85	118.4	0.71	1.54

In Israel, Gutman and Seligman (1979) found that cattle began to lose weight when the plant biomass dropped below 700 kilograms per hectare. Hyder (1953) developed the residue approach for sagebrush/grass range in eastern Oregon and suggested that the proper amount is 270 kilograms per hectare. Bison feeding rates declined by 50 percent due to smaller bite size as forage biomass was reduced to 780 kilograms per hectare. Both number of bites per minute and hours of grazing increased (Hudson and Frank 1987).

Considerable information on proper use factors has accumulated through experience as part of range reconnaissance surveys and other types of range inventories. Some of the plant lists that are associated with those surveys mention stubble heights of individual species when they are properly utilized.

In general, these heights are estimates of the residue after grazing. The selected group of species and stubble heights for proper utilization in Table 12-3 has resulted from grazing trials and clipping studies. The stubble heights indicate that 40 to 60 percent of herbage crop remains. Utilization of browse usually is given in percent of current crop remaining.

The concept of proper range utilization on a residue basis applies to grazing in any rotation pasture during the growing season as well as all pastures at the end of the grazing season. At any time when the forage on-offer falls below certain critical points animal production also falls.

Consequences of Overutilization

The degree of herbage removal by the grazing animal has more influence on range vegetation than does any other grazing factor. Reduction in plant vigor results when too high a proportion of the photosynthetic tissue is removed. Experiments in which the treatments included a series of stocking rates, some too high and some too low, have characterized many pasture and range studies. Vegetational changes that resulted from the different stocking rates have permitted range managers to describe lightly-, moderately-, and overgrazed ranges for many different vegetational types.

Based on a summary of 14 research studies in 9 geographic areas, Van Poollen and Lacey (1979) found that herbage production under continuous grazing was increased by 35 percent when utilization was reduced from heavy to moderate. Herbage increased only 13 percent when moderate continuous grazing was changed to a grazing system. These same authors (Lacey and Van Poollen 1981) found 20 comparisons where annual herbage production averaged 68 to 46 percent higher when plots were protected from moderate livestock grazing. Likewise production of individual plants in 8 comparisons averaged 59 to 50 percent higher when protected. Data presented by Leege et al (1981) agree that no grazing resulted in more production than grazing. A stocking rate trial in *Festuca scabrella* grassland (Willms et al 1985) showed that very heavy stocking caused the replacement of *Festuca* with *Danthonia parryi*. Recovery of the grassland took more than 20 years.

Plant cover increased in all classes of vegetation in the *Quercus gambelii* type in Utah due to decreased grazing from 1935 to 1956 and no grazing 1957 to 1983. Grazing exclosures that began in 1905 showed little change in cover (Austin et al 1986). Moderate grazing in southwestern Utah for 29 years resulted in more desirable species (*Ceratoides lanata, Artemisia nova, Atriplex canescens*) and fewer *Chrysothamnus viscidiflorus*. It was just the reverse under heavy grazing (Blaisdell and Holmgren 1984). Defoliation by goats of the small tree, *Acacia karroo*, in South Africa resulted in stimulation of new branches. Branching was least in the spring flush and did not occur in the dormant season (Teague and Walker 1988).

Table 12-3 Proper utilization of selected grass and browse species expressed as stubble hieght or percent of current growth remaining on the plant.

Species	Stubble height cm	Location	Authority
Agropyron desertorum	5	Central Colorado	Johnson (1959)
Agropyron intermedium	10	Central Colorado	Johnson (1959)
Agropyron smithii	8.5	Arizona-New Mexico	Parker and Glendening (1942)
Agropyron smithii	7.5-10	Eastern Montana	Holscher and Woolfolk (1953)
Bouteloua eriopoda	7.5-10	Arizona-New Mexico	Parker and Glendening (1942)
Bouteloua gracilis	5-7.5	Arizona-New Mexico	Parker and Glendening (1942)
Bouteloua gracilis	2.5-5	Eastern Montana	Holscher and Woolfolk (1953)
Bromus inermis	10	Central Colorado	Johnson (1959)
Buchloe dactyloides	3	Central Colorado	Costello and Turner (1944)
Carex filifolia	2.5-5	Eastern Montana	Holscher and Woolfolk (1953)
Deschampsia caespitosa	7.5	Oregon-Washington	Reid and Pickford (1946)
Elymus junceus	7.5	Central Colorado	Currie and Smith (1970)
Festuca viridula	7.5	Eastern Oregon	Pickford and Reid (1942)
Hilaria belangeri	4	Arizona-New Mexico	Parker and Glendening (1942)
Koeleria cristata	5	Arizona-New Mexico	Parker and Glendening (1942)
Stipa comata	5	Eastern Montana	Holscher and Woolfolk (1953)
Amelanchier alnifolia	35*	Northern Idaho	Young and Payne (1948)
Ceanothus sanguineus	40*	Northern Idaho	Young and Payne (1948)
Fraxinus americana	75*	Southeast Texas	Lay (1965)
Ilex vomitoria	50*	Southeast Texas	Lay (1965)
Purshia tridentata	40*	California	Hormay (1943)

After 19 years of heavy, medium, and light stocking, Smoliak (1974) found that *Agropyron smithii* and *Stipa comata* had decreased and *Bouteloua gracilis* had increased in southern Canada. Under yearlong grazing on slash pine ranges in the southern United States *Andropogon divergens* decreases and *Axonopus affinis* increases (Pearson and Whitaker 1974). Browse was not greatly affected by intensity of grazing.

A common fallacy is that plants most palatable to animals on rangeland are selected for the first bite and perhaps selected again and again as grazing continues; preferred species, especially where they exist in preferred grazing areas, receive repeated defoliations, even if only one animal grazes. The individual plant responds with fewer and smaller leaves, stems, seed stalks, and roots. A gradual demise of plants and a gradual deterioration of the vegetation result. Energy capture and flow are interrupted, as is the accumulation of carbohydrates. Destruction of vegetation continues. For two reasons this line of argument is false. (1) Many examples of reduced, but not eliminated, grazing have resulted in increased vegetation and succession toward climax. (2) The vegetation and plants that compose it have coevolved with grazing animals through geologic time.

During the process of vegetational destruction, the soil surface becomes exposed to the beating action of raindrops and the scouring action of running water because its protection by mulch and live plants is reduced. The environment at the soil surface increases in variability, and extremes increase in severity. The soil may be puddled by rain and by stirring as animals walk over it. Infiltration is reduced, runoff increased, and the available water for plant growth diminished. A bare and eroded landscape ultimately occurs. Desert-like vegetation appears in regions where the amount of rainfall supports less xeric species. Many of the concepts regarding vegetational changes and plant succession have resulted from concern with destruction of vegetation by yearly overutilization (Fig. 12-3). However, rangeland vegetation in the United States as a whole is more complete and there is less erosion than any time in this century.

Techniques of evaluating rangeland forage utilization, finding standards for proper rangeland forage use, and techniques for obtaining proper grazing management constitute a large part of Range Management. Understanding the effects of space variables including topography, soil, and vegetation combined with weather changes over time require intelligent interpretation of facts and data on forage utilization that is unincumbered by regulation too broadly stipulated.

ADJUSTMENT OF ANIMAL NUMBERS TO FORAGE SUPPLY

Forage supply on all ranges varies from year to year in response to changes in weather (Table 12-4). A manager may use a number of procedures to adjust stocking rate to that wide variation and continue to maintain range condition. One procedure stipulates stocking rates that result in proper utilization of the average crop, or more conservatively, that result in proper utilization when only 65 to 80 percent of the average crop is produced. With this procedure stocking rates may remain about the same from year to year, as for example, permitted numbers on federal lands. Unless the grazing period is adjusted, the result can be one year in four when the range is overgrazed and another when it is undergrazed. The objective is to balance range improvement in the years of high production against damage during the years of low production. Any strategy that maintains constant livestock numbers on rangeland results in widely varying grazing pressure and large changes in gains per animal and per hectare from one year to the next. It is an easy plan to follow for a pasture but a difficult one for a ranch. On the other hand, changes in stocking rates also are difficult in practice because they often require sale or purchase of animals in unfavorable markets.

Table 12-4 A few examples that illustrate the magnitude of fluctuations in forage supply

Type of herbage	Location	Variation		Source
		kg/ha	yr	
Short grass	Southen Alberta Canada	100-925	1930-1953	Smoliak (1956)
Short grass	Eastern Montana	250-1,780	1927-1934	Campbell (1936)
Short grass	West Central Kansas	150-2,815	1940-1942	Weaver and Albertson (1944)
Bouteloua eriopoda	Southern New Mexico	0-990	1926-1934	Campbell (1936)
Mixed Perennial	Central Utah	505-1,425	1924-1935	Campbell (1936)
Annual	California	1,345-2,580	1935-1948	Bentley and Talbot (1951)

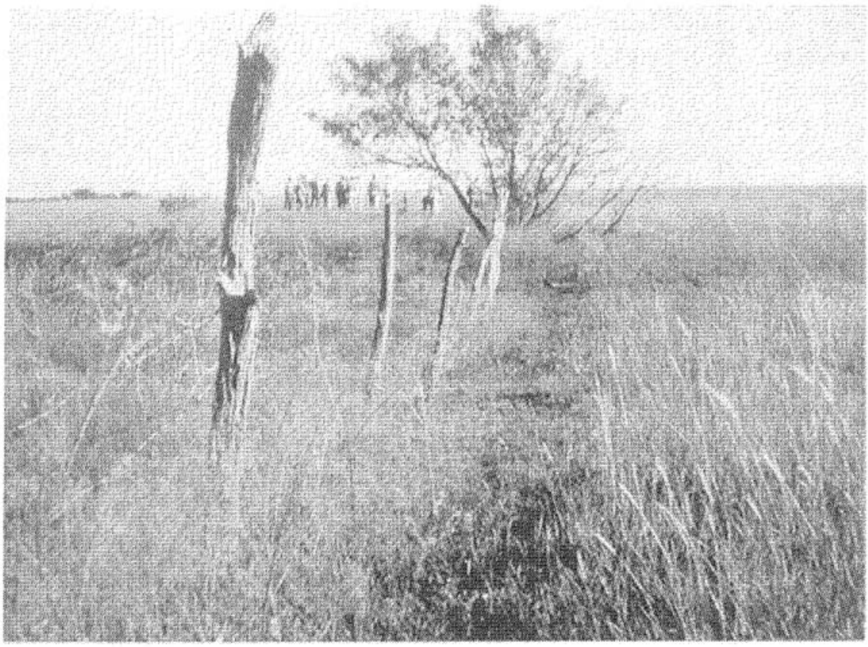

Figure 12-3 Annual broad-leaved plants within the fence on the left, a strip of short grasses where animals can reach through the fence, and tall grasses on the right constitute three successional stages due to degree of grazing in this true prairie type in Texas.

Secondly and as a managerial expediency, it probably is best to combine fixed stocking of a base herd of mother cows with flexible stocking of other animals to obtain the most rapid improvement possible during the favorable years and least damage in the poor years. The base herd including replacements should be approximately 75 percent of the average grazing capacity. Calves may be held over, stocker animals purchased, and grazing rights leased in the good years. In very bad years severe culling of the herd may be necessary. **In this plan, a certain amount of organic residue would remain on the soil surface after grazing each year, regardless of the amount of herbage grown. In the good years, the amount would be more than in poor years, but at no time would herbage utilization be excessive.**

Both plans require flexibility. As a strategist, the manager knows the important decision making factors available for manipulation. As a tactician, the need is to be certain that sufficient feed is available every day of the year. That requires skillfully adjusting when animals are put into pastures, the time when they are moved, and the place where they go next. **A key to these animal movements is the degree of forage utilization; another is accurate prediction of feed supplies in the future.**

Predicting Range Forage Production

A successful method for predicting range forage production could result in near-perfect forage utilization each year. However, success has escaped those searching for techniques that predict weather and forage in a manner useful for day-to-day management decisions. Clawson (1947) showed that consecutive years tend to be either below or above normal in precipitation in the northern Great Plains and Rocky Mountains. In the southwestern United States, the distribution is more random. Even at best, the prediction of forage production based on prediction of weather has no better chance than three years in four of being correct. Based upon 10 years of research in mountain grasslands Mueggler (1983) was able to predict that forage production was within 85 percent of the mean two-thirds of the years. Stocking adjustments can be accomplished by varying the grazing season to meet unexpected forage-growing situations.

Sneva and Hyder (1962) reviewed and agreed with a common belief that winter-spring precipitation correlates closely with subsequent herbage yields of bunchgrass in the intermountain region. By the time spring rainfall is known, the time to make effective changes in animal numbers is past. A decision on the number of animals to winter often determines the number of animals on spring range. An attempt at determining number of cattle to winter by applying Sneva and Hyder's procedures shows that half the calves should be sold in late fall if below-normal July through October precipitation occurs and all the calves should be kept until they are yearlings if rainfall is above normal (Rogers and Peacock 1968). This procedure needs more testing before it can be recommended. All methods that use weather records for predicting and adjusting stocking rates have shown only marginal success

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13

Animal Distribution

The ideal distribution of any use on rangeland reduces number and area of places damaged by congestion of animals and people, and extends the area of proper use as widely as possible. The objective of distribution management is uniform and moderate or maximum use that does not damage soil and vegetation.

Faulty livestock distribution caused widespread western rangeland degradation during the latter half of the 1800s and the early part of the 1900s. Early recommendations and requirements for improved range management on national forests included many suggestions for improving livestock distribution (Jardine and Anderson 1919). These recommendations need to be continuously updated and applied to all rangelands (Williams 1954).

Failure to correct uneven distribution of grazing pressure results in considerable damage to vegetation and soil. Livestock and wild animals cause damage for several reasons. They may be territorial, have memory for certain places, and prefer certain habitats; and they naturally congregate near water or in favorite resting places. Correction of distribution problems is often the first applied rangeland management practice.

In the initial steps of establishing a range program, livestock watering facilities usually receive first attention. During the free-range era in the western United States, control of water signified control of the land. Available water determined grazing capacity as well as animal distribution.

Fencing allowed control of land and water. At first, the purpose of fences was to prohibit abusive trespass and later to attain even forage utilization. Other grazing management practices, such as specialized grazing systems, facilitation of prescribed burning, fertilization, and seeding, required additional fencing and more water to be effective.

Division of large range units into small ones increases grazing capacity, often without other range management practices.

FACTORS INFLUENCING ANIMAL DISTRIBUTION

Geographical locations of vegetational types, soils, slopes, and weather influence animal distributions and management. Animal species have certain inherent reactions to these habitat characteristics. Informed management requires knowledge of the location of resources and the degree of utilization made of them. Grazing animals distribute themselves unevenly over the land. Irregular patterns of utilization result from the interaction of physical impacts, food selection, and intensity of eating.

Vegetational Types

All animal species prefer certain vegetational types to others. For example, domestic animals normally stay away from dense timber, except at the edge where they find shade. Regrowth of trees in a mosaic with grassland after logging and fire reduces the area available for grazing. Patches of thick trees restrict livestock movement, making uniform grazing difficult to achieve. Although forage quantities within a timber stand may be small, proper use of it takes special effort.

Mule deer in northern Montana consistently used the bunchgrass type more than any other in spring, willow/meadows in the summer, and alfalfa in the winter. Whitetailed deer in the same area used woody deciduous vegetation and alfalfa more than did mule deer (Martinka 1968). In another study in Utah, cattle, deer, and elk on summer range all used aspen and mixed shrub types. However, cattle grazed the grass/forb types continuously, elk used them in midsummer, and deer hardly used them (Julander and Jeffery 1964). Clearly, the distribution of animals correlates with vegetational type, because there they find food and cover.

The vegetational types of major concern include the mesic willow/shrubs, sedges, and moisture-loving grasslands commonly referred to as riparian. They furnish green feed and water at a time when they are not available on the uplands. The result has been congregation of animals and extensive degradation of riparian habitats. Fortunately, the accumulated water that makes an attractive riparian habitat also fosters quick repair under proper management.

Topography

The steepness and length of slope influence the use of forage by domestic and wild animals. In 1944, Glendening reported forage utilization of 80 percent on *Muhlenbergia montana* at the bottom of 20 percent slopes and zero use 1.6 kilometers higher on the same degree of slope. Those slopes greater than 40 percent had little value for cattle grazing. Mueggler (1965) found that as an average on 38 bunchgrass areas in southern Idaho, 75 percent utilization was attained for 32 meters above the foot of 60 percent slopes, while the same utilization occurred for 740 meters above the foot of 10 percent slopes (Fig. 13-1).

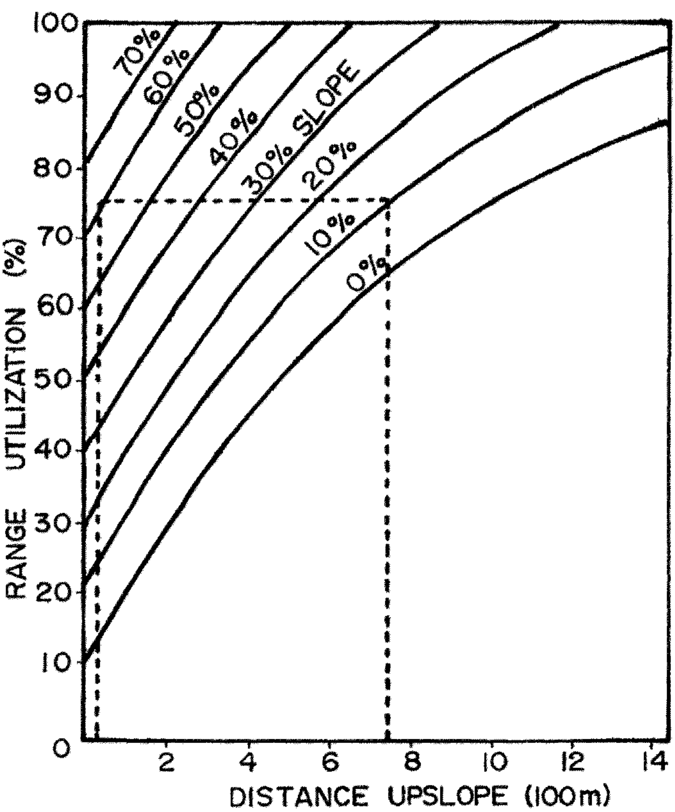


Figure 13-1 Influence of slope steepness and distance upslope on use of range by cattle (Mueggler 1965).

Steepness of slope significantly influences distribution of cattle, but this factor does not operate alone. Water usually occurs at the bottom of slopes, causing animals to congregate there. Plants near the streams stay green and palatable for a longer time than do those on slopes, especially those facing the sun. Cook (1966) in studying 21 factors, found significant correlations between herbage utilization and percentage of slope, distance to water, percentage of palatable plants, thickness of brush, and position of salt. Others (McDaniel and Tiedeman 1981, Gillen et al 1984) give data to show that slope gradient was the only physical factor consistently associated with cattle and sheep distribution.

Different species of animals prefer different positions on the topography. In Utah the greatest summer use by deer occurred on slopes between 30 and 40 percent and on major ridgetops; elk selected slopes less than 30 percent and cattle mostly used slopes of less than 10 percent (Julander and Jeffery 1964). Bighorn sheep were not impaired by slopes up to 80 percent. Cattle, feral horses, and deer began avoiding slopes in excess of 20 percent, 30 percent, and 40 percent respectively. If large areas of near-level topography were available, cattle and horses made still less use of moderately steep slopes (Ganskopp and Vavra 1986).

These variable data should not be generalized into statements that cattle, sheep, or any kind of animal be limited to certain slope percentages. In some areas sheep will use steeper slopes than cattle, but percentages attached to that statement and applied broadly are misleading.

Animal Behavior, Intelligence, and Memory

Animal behavior, inherent and learned, influences distribution patterns and forage preferences. Sheep graze into the wind, causing concentration and overuse in the southeastern corners of pastures near Broken Hill, Australia, where wind prevails from the southeast. When disturbed, as when being corralled, blesbok in South Africa run uphill, so the mustering point of their pastures should be at the highest place. Rambouillet traveled farther than did Targhee sheep when unherded on mountainous summer range (Bowns 1971). Santa Gertrudis cattle walk farther than Herefords, resulting in even use of a larger area (Herbel et al 1967). Many studies have shown that animals travel farther on poor than on good range and as percentage of forage utilization increases.

Seasonal grazing distribution of cattle on shortgrass ranges in Colorado correlated with proximity of water, nearness to fences, and measures of forage quality (crude protein) and quantity (Senft et al 1985a). Favored resting sites in summer were low-lying areas, fencelines, and near water, but in winter south facing slopes were favored (Senft et al 1985b).

A study in Norway of unherded sheep with radio collars found activity patterns similar to other studies of domestic and wild sheep. As the season progressed, use of meadows decreased in favor of more forest use and their selected night camp was always uphill from day use areas. Cold and wet weather reduced activity (Warren and Mysterud 1991).

After several generations, hill sheep in Scotland were found to gather in subflocks or family groups that restricted themselves to certain parts of the pasture. This segregation resulted in some groups being heavier than others and furnishing most of the replacement ewe lambs (Hunter 1964). The home ranges seemed to be related to soil and vegetational types, but crowding intensified peck-orders that forced some animals to establish new groups.

It is well known that the vegetational mosaic, physical improvements such as fences and water points, improvement of range condition, and changing livestock numbers in a pasture alter distribution of animals and their behavior (Hart et al 1991). Failure by the manager to consider animal habits reduces the effectiveness of other rangeland practices and may result in local overuse.

Animals may not travel significantly different distances in experimental pastures used to compare stocking rates and grazing systems (Hepworth et al 1991). Division of large pastures often increases the evenness of animal distribution and forage utilization. However, a pasture size exists whereby animals graze them evenly and further reduction in size is of no advantage. The smallness of separate pastures in experimental studies may or may not have confounded animal behavior, distribution, and travel relationships with treatment effects. **Pasture size is an important consideration in rangeland management.**

Apparently, cattle learn and can remember where they have foraged and if the forage resources warrant a return visit (Provenza and Balph 1988, Bailey et al 1989). Cattle and sheep learn to come when a vehicle with feed approaches. Animals learn to avoid places and feeds as well. Lane et al (1990) conditioned heifers to avoid the highly poisonous *Delphinium barbeyi* by intraruminal infusion of lithium chloride whenever they consumed the *Delphinium*. The chemical caused an illness. The animals evidently remembered the association and avoided the plant a year later.

Young animals learn locations and appropriate food items from their mothers and others in the herd. This leads to the belief that selection of replacement females from within the herd will result in fewer deaths from poisonous plants and more uniform forage utilization. Home grown means that the animals "know" the range. Feeds learned during preweaning commonly are preferred after weaning, at least for awhile. This can be used to reduce the transition time for weaned calves to full growth rate in the feedlot. In another example, lambs were fed two palatable shrubs and a bit of lithium chloride that made them ill. Later these lambs grazed the grass and avoided the shrubs, which could be a boost to shrub establishment (Burritt and Provenza 1990).

Another form of learning is **bonding**, as attachment of mother and newly born. Bonds have been developed between sheep and other animals including cattle, donkeys, llamas, and dogs for reduction of predation. Positive results in the training of domestic grazing animals as illustrated above is a new field of activity that warrants increasing effort.

CONSEQUENCES OF FAULTY ANIMAL DISTRIBUTION

Animal concentrations near water, shade, salt, and on relatively level areas within steep topography destroy vegetation. A permanent water source, such as a spring or well, serves as a focal point for grazing animals. They trail to and from water and repeatedly graze along the way. Lange (1969) showed that the concentration of their grazing varied as the square of the distance from water. Sheep trails radiated from water in the center of 260-hectare areas. Populations of *Atriplex* increased in density as distance increased from water (Barker and Lange 1970).

Measurements of forage utilization in several vegetational types illustrate the effects of animal concentrations. In eastern Montana, percentage utilization of *Agropyron smithii* on cattle winter range was 100 percent at water, 54 percent 180 meters away, and 28 percent 1,460 meters away. In the same study at the same distances from water, cattle used *Bouteloua gracilis* 100, 38, and 19 percent, respectively (Holscher and Woolfolk 1953). Cattle used 100 percent of the bunchgrasses at water, 78 percent 180 meters away and 32 percent 900 meters away in a southern Idaho study (Mueggler 1965). Semidesert grassland in southern New Mexico showed an average of 50 percent use within 0.8 kilometer of water but only 12 percent use between 3.2 and 4 kilometers distant (Valentine 1947). Use of *Festuca arizonica* and *Muhlenbergia montana* in Arizona decreased to zero at 5.6 to 8 kilometers from water and 0.4 to 0.8 kilometer from established trails (Glendening 1944). With heavy camel grazing in Saudi Arabia, no perennial vegetation occurred within 15 to 20 kilometers of water and occasionally the distance was over 50 kilometers (Heady 1963). Agnew (1966) suggested that the proportion of land in animal trails indicates the degree of overgrazing.

Degree of forage utilization and the composition of the vegetation can be the basis for mapping zones of deterioration or areas of differing condition class around a watering point. Five such rings or zones as defined by key species are sufficient for planning purposes. They define the distribution problem and indicate the locations needing corrective measures (Anderson and Currier 1973).

When development of water, fencing, prescribed burning, and other rangeland practices do not cover the whole pasture or grazing unit, they tend to concentrate animals. For example, the rangeland around a new watering point soon can become overgrazed and lose condition unless intensity and season of grazing are controlled. The improvements can be advantageous only in conjunction with careful management of animal numbers, seasonal grazing, and other aspects of a total range program.

PRACTICES TO LESSEN ANIMAL CONCENTRATIONS

Range management includes many practices to spread animals in accord with the herbage resources. Several such as development of water; construction of fences; and building of roads, trails, and windbreaks; and vegetational manipulations are applied to the rangeland. Other practices, including herding and spreading of salt, directly influence animal distribution. Each technique will be discussed as to its location and effectiveness, but for construction specifications refer to field manuals such as handbooks on fences, watering facilities, and livestock handling facilities by the United States Forest Service and available from the Society for Range Management. Another is Sanderson et al (1990). They have many tables of materials, specifications, and construction diagrams.

Development of Water

Development of water, especially new water, on rangeland has several purposes. For livestock, the aim may be better utilization of little-grazed land, or increased length of the grazing season through greater supply. For wildlife, the aim is essentially the same, uniform use and more available land for the ungulates. Birds and smaller animals use the water for drinking, and some for habitat. Riparian problems may be relieved if livestock are drawn elsewhere. Fundamentally the purpose is to improve rangeland condition for all the users.

Water for livestock and game has been developed with ditches, dams, earthen ponds or tanks, vertical wells, horizontal wells that open springs, pipelines, troughs, metal tanks, and guzzlers with sealed runoff aprons. The water has to be found, stored, and delivered in adequate amounts at the right times and places (Fig. 13-2). The problems of discovery, storage, and delivery of range water have been present since Bedouins started crossing the desert. Techniques using artesian water, wind turbines, gravity distribution, solar energy for pumping, solar units to prevent freezing, and submersed pumps are of recent application.

Considerations to enhance stock water for waterfowl habitat during the nesting and rearing of broods have added several specifications for construction. Mallard ducks and blue-winged teal prefer ponds larger than 0.6 hectare with shallow water areas that support submerged vegetation composed of *Polygonum* spp. and *Eleocharis* spp. and tall growing shoreline vegetation. Grazing should be restricted until after nesting and the broods are well along (Rumble and Flake 1983).

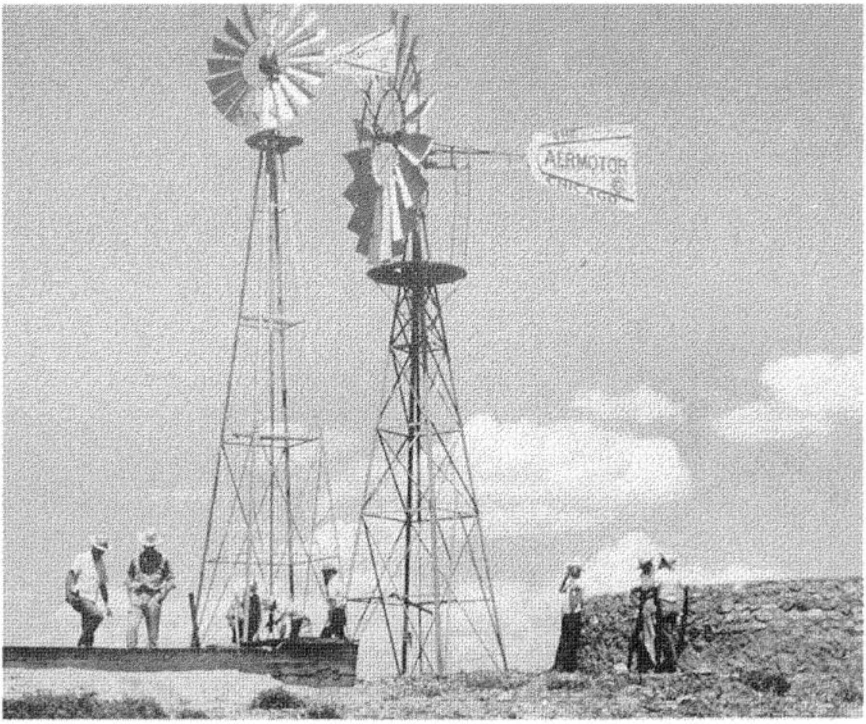
Wherever practical, new water facilities should be located where grazing has been lightest and where grazing capacities are high. Barnes (1914) recommended that cattle not be forced to go more than 3.2 kilometers to water in relatively flat country and 1.6 kilometers in rough topography. A better rule is to have livestock water no farther apart than 2 kilometers (1.3 miles) even on the driest of rangelands.

From work on the Starkey Experimental Range in eastern Oregon, Goebel (1956) claimed that 0.8 to 1.2 kilometers is an ideal distance. Between 1949 and 1953, the number of watering places on the Range was increased from 9 to 52. In planning for that development, it took several years to coordinate water with cattle behavior. Water was used to attract cattle to little used forage resources, to divide large herds into smaller ones, and to reduce trailing. No more than 50 animal units per watering facility is a commonly used rule of thumb. Matching requirements with site feasibility for reservoir development takes close study of animal movements, soil, topography, and geology.

Herded sheep can make even use of rangeland with water at greater distances than the maximum distance for cattle. They can obtain needed water from snow in winter while cattle do poorly using snow. Thus, cold desert areas are wintering pastures for sheep.

Where sheep are pastured without herding, as in Australia and parts of the United States, they need water as close as cattle do if efficient range use is to be attained. Lange (1969) claimed that number of animals on a watering point has more importance in proper management than does number of points per pasture. Longer distances between water means less live weight gains and less uniform utilization.

13-2a



13-2b

Figure 13-2 Photo 13-2a: The large windmill pumps water from a deep well and the smaller one lifts it to a storage tank from which gravity flow supplies watering points. Photo 13-2b: A guzzler for quail is shown with its protective fence and brush covering the water.

Discovery of water depends on interpretation of the geology. Dug wells in sandy stream bottoms have served the Bedouins of Arabia for many centuries and were an early form of water development on rangeland. These wells are limited to relatively shallow water tables. Drilled wells and windmills facilitated livestock expansion into the American West and many semiarid and arid parts of the world. Welchert and Freeman (1973) reported the use of horizontal wells to tap seepages and small flows of water on the San Carlos Apache Indian Reservation. A liter per minute was enough flow for a single water point, and 20 to 25 liters per minute supported storage and pipeline development for several troughs. The wells were cased and capped for water control because most flowed by gravity. Advantages of horizontal wells include storage of water in the soil with a minimum of loss, sanitary water, usually low-cost development since the wells are shallow, and high success rate in construction. Larger, naturally flowing springs have similar advantages when they are boxed and fenced and the water is piped to troughs (Hendricks 1938).

Storage of water in open dirt tanks has developed into a pond hydrology with specifications for construction under varying situations of runoff, soil, geology, vegetation, land use, size, sedimentation, water quality, evaporation, and seepage; and use for fisheries, waterfowl, and recreational purposes. These small stockwater structures duplicate in miniature many values, such as gully control, recreation, and garden irrigation; and problems such as control of streamflow, water right regulations, downstream values, and environmental regulations for clean water.

Much water is lost by evaporation from dirt tanks, 3 meters or more a year in hot, dry climates. Deep reservoirs with little surface area in relation to depth reduce but do not eliminate evaporation losses. A rule of thumb on depth is to have storage for 2 meters of water plus the annual losses. A desilting basin above the water storage traps the silt. Covering the water surface with a monomolecular film of alcohol reduces evaporation, but wind, which breaks the film and piles the material to the lee side of the ponds, makes it of questionable value. Foam rubber 2 centimeters thick may be floated on water in metal tanks.

Water harvesting is the gathering of runoff water from aprons that have been treated to reduce water infiltration into the soil. Runoff of 10 centimeters from an apron 10 x 10 meters provides enough water for 100 cows for three weeks and minor losses. There are five basic methods of increasing runoff: reduction of vegetation; use of naturally impervious surfaces such as roads and rock; land alteration; chemical soil treatment such as with salt and wax; and ground covers with concrete, fiberglass, plastics, and asphalt roofing. The ground covers with membranes commonly yield over 90 percent of the precipitation (Frasier et al 1979).

A common formula is to make the apron a size that half the average rainfall fills the storage tank. Efficient use of water requires covered storage, a trough, and float valve to control the flow. The seal on the drainage apron and the water trap may last only a few years. Water harvesting may be as small as a meter square basin to provide extra water for establishing a planted shrub.

Any facility must provide sufficient water for animals after losses. Louw (1970) summarized information on minimum water requirements (in liters per 100 kilograms of body weight) of several animal species when they were subjected to temperatures of 40 degrees centigrade during the day and 22 degrees at night. These following data do not cover variations due to feeding habit, use of water in the feed, and species differences in extracting water from the feed. They do show that the domestic cow of the European type requires more water than other ungulates and that wild animals need to be taken into account when planning water developments:

Animal Species	liters/100 kilograms/day
Hereford	6.42
Eland	5.49
Cape buffalo	4.58
Zebu cattle	3.22
Thomson's gazelle	2.74

Varying with rangeland location, season, and breed, a reasonable rule is to supply 10-12 gallons per day (38-46 liters) for a cow and calf, 12-15 gallons per day (46-57 liters) for a horse, and 1-1.5 gallons per day (3.8-5.7 liters) for a ewe and lamb. Most of the animals in a pasture will seek water at the same time; therefore, the water delivering device should be large enough to supply the daily needs of the herd in an hour or two.

Sand trapped above a dam holds water in the voids among the sand grains. In coarse sand, water space amounts to 25 to 30 percent of the volume. Evaporation proceeds at a slow rate after the top 2 or 3 decimeters of sand have become dry. No plants of any kind should be allowed to grow on the sand because transpiration uses water. Water in the sand tank may be obtained from a well on the upstream side of the dam or from a pipe through the dam. Sand tanks have been developed and used for a century or more in the southwestern United States, Mexico, and longer in desert areas.

Plastic pipe has facilitated extensive range pipeline systems for watering livestock. Commonly, the system begins with a well and pump to lift the water into a storage tank located on a high point where gravity flow may be utilized. For safety, the storage capacity should be at least a 7-day supply for motor-driven systems or a 14-day supply for wind systems (Patterson 1967).

Pipeline routing and placement of drinking facilities depend upon number of animals and topography. Troughs placed at 800- meter intervals along the line tend to spread cattle into small bunches. Troughs may be opened or closed to attain rotational grazing and to relieve heavy utilization near water. Martin and Ward (1970) claimed that water points must be separated by the maximum daily cattle travel distance for water to serve as a device to keep them away from certain areas.

The hauling of water for livestock on rangeland began with the wagon trains across the plains. The practice has continued as need has arisen and changed as the hauling equipment has improved. The necessity of hauling water follows the drought and the wet weather patterns.

Fencing

Efficient use of fences requires an initial concept of the different uses of the landscape on either side of the proposed boundary. Well-defined property boundaries make good neighbors and their purpose hardly needs describing. Internal division fences having different purposes than the boundary fences are discussed here.

Obviously, cropland and hayland must be separated from grazing resources. Different classes of livestock sometimes may require separate pastures for animal management. Fences confine animals to certain areas and exclude them from others. However, the number of pastures and location of fences often depend upon availability of water and other facilities. Regulation of access to areas by animals and people requires fencing.

Fences should be located on ridges, perpendicular to the contours, angling across steep slopes where animals naturally avoid the steepness, and should be placed where they serve their purposes with the least upkeep. Fences will aid management if they can be placed between different range condition classes and where high- and low-value vegetational types can be separated. Before any fence is constructed, the need for that fence, in terms of conserving soil and added use of forage to repay the cost of the fence, should be determined. Roughly, 1.6 kilometers of new fence should add the equivalent of 1 AU in grazing capacity or like value in reducing management costs.

Fences that cross drainages often cause concentration of animals on one side and damage to riparian resources. If fences must be located near reservoirs on rough cattle range, they should cross below the water because cattle usually graze outward and upward. Narrow corners tend to create ungrazed areas on cattle range, but on sheep range they may be overgrazed if they point toward the prevailing wind.

Permanent fence varies in design as much as the builders. Designs are available from the dealers of fencing materials and most range management manuals in the federal agencies also show fencing specifications.

Electric fences have many advantages on rangeland. Capture of solar energy, plastic posts and special conducting wire makes possible their use almost anywhere. They can be used as temporary barriers to eroded places, new seedings, stands of poisonous plants, newly burned areas, fertilized areas, riparian zones, and new water facilities. A single wire about 1 meter above the ground holds mature cattle and permits calves to cross underneath to better feed. Electric fences cost relatively little, since posts are widely spaced and one wire strings easily. Juniper or local woods may be used for fence posts. The lay-down fences, put on the ground before winter, avoid damage by snow and reduce problems with game. White posts and glitter strips on the wire help animals see the single-wire fence.

Fencing where wild animals need to be permitted full movement or prevented from entering presents special problems. Deer control requires straight, vertical fences about 2.5 to 3 meters in height. Slanting, overhanging, and outrigger types of construction, which prevent deer from approaching the fence base, discourage them from jumping. Pronghorn will not jump a fence much over 80 centimeters in height unless they are pursued or stressed. They tend to go under rather than over most fences so the lowest wire should be smooth and at least 41 centimeters (16 inches) above the soil. Short cattle-guards may be used as pass structures for pronghorn. One-way off-ramps over highway game fences permit deer, elk, and antelope a one-way passage away from auto traffic.

Fencing for seasonal grazing plans on relatively level country with high grazing capacity presents special problems because the pastures may need to be divided a second time as the plans develop. Water courses can be blocked into small pastures on each side and larger units located toward the hills. Triangular shapes that extend from a central watering point divide efficiently.

Roads and Trails

Construction of livestock trails and roads over rough, rocky areas, through dense timber, and across other barriers increases efficiency in use of rangeland. Grazing ceases away from trails in dense timber and shrub stands. Livestock distribution in large areas of marsh and overflow land, as near the Gulf of Mexico, improves with the construction of earthen dikes for walkways and windbreaks. When water covers the land, cattle graze near firm ground. The dike should be at least 2 meters above high water at settled heights, 2 meters across the top, and should have slopes of 1.5:1. The paths may be graveled to reduce trampling damage and to serve foot travel by hunters and birders. The barrow pit furnishes a permanent aquatic habitat for waterfowl and stock water through the dry season. Rather than always being on one side of the dike, the barrow pit should be staggered on alternate sides at about 100-meter intervals.

Range roads have many values for the landowner, livestock, recreationists, and wildlife. Pioneer plants and insects along the track furnish food, and the culverts become warrens for wild species. Roads, as open strips through the vegetation, are lines of sight for predators and people, fuel breaks, and escape routes.

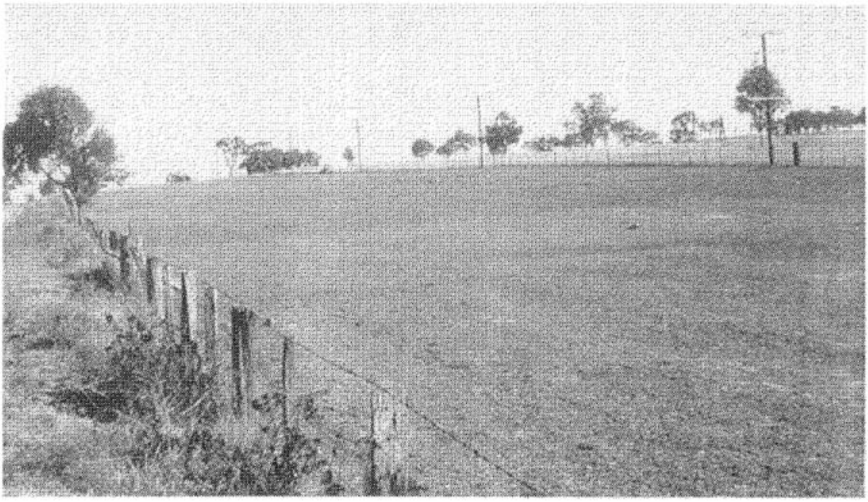
The trailing of large herds has largely disappeared, except for the Bedouin movements in some parts of the world. Stock routes still exist in Australia, but their use has decreased as trucking has increased (Fig. 13-3). Trailing reduces weight gains in livestock, increases death loss, and causes considerable damage to vegetation and soil. However, within management units trails are opened through timber, over cliff barriers, etc. to permit even utilization of range forage.

Herding

Herding of cattle is necessary in large unfenced pastures in order that they use the forage evenly. One rider or a person on a wheeled vehicle can take care of approximately 500 head or 125 square kilometers of land, in favorable topography. The rider needs to know range condition, effects of grazing, and animal habits. Cattle can be trained to use certain areas and will repeat that use year after year. Duties of the range rider include repairing fences, maintaining adequate water and salt, caring for sick animals, preventing death losses, keeping bulls distributed, and assuring proper forage utilization.

Herding sheep in bands of 1,000 ewes plus lambs in the summer and roughly double that number of ewes in winter remains a common practice in the western United States. Even use of a range by sheep depends almost wholly upon the herder and the routes that are followed.

13-3a



13-3b

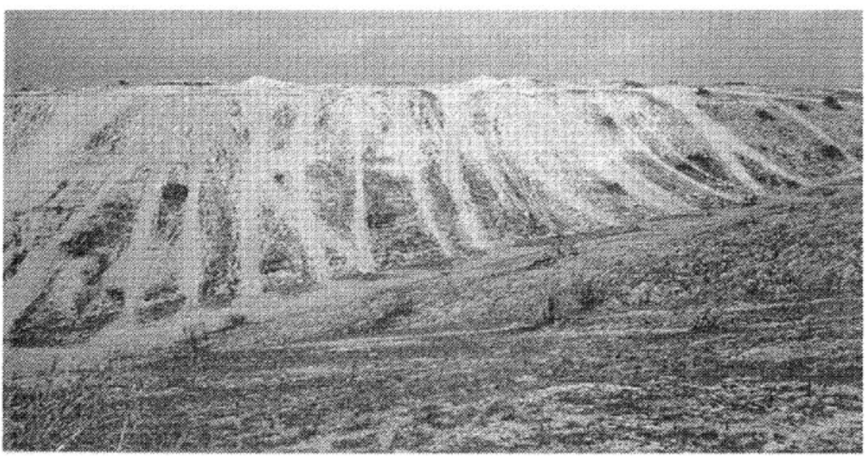


Figure 13-3 Photo 13-3a shows a stock route between a highway and private land in Australia badly abused by trailing sheep. Photo 13-3b shows damage by motorcycles in California.

Such practices as open herding, one-night bedgrounds, planned routes, and proper use of mixed timber and grass types are at the option of the herder. The sheep should be allowed to graze in open formation, with only their direction determined. This type of grazing means little use of dogs and quiet handling so that the band will spread over the area to be grazed. Herding in this manner increases weight gains over those attained with close herding.

Bedding bands of sheep on national forests in a new place each night increased weight gains, decreased damage to bedgrounds, wasted little forage, and resulted in uniform forage use. During the free-range era, bands of sheep stayed in the same location every night for three or four weeks. The new practice of moving every day became regulation in the use of national forests by sheep and were shown to be a means of range improvement (Heady et al 1947). Herding of sheep offers closer control of forage use than does herding of cattle.

On ranges where tree and meadow types of vegetation exist in a mosaic, each type of vegetation should be used by sheep in proportion to the forage produced. Usually the open areas are grazed early and late in the day and the forested areas in late morning and again in early afternoon after the midday resting period. Thus the sheep are kept in open country during the times of greatest danger from predators and in shade during the hottest part of the day.

In Australia, where sheep are pastured within fences and not herded, distribution problems become similar to those of cattle. Large pastures with few watering points leave many parts of the pastures essentially unused. In much of Africa and the Middle East, small groups of domestic animals are herded into the bush each morning and returned to a central corral at night. Using wide-spaced corrals for a day or so at a time in rotation reduces trailing of animals and permits range improvement.

Light aircraft, aerial photos, and helicopters are aids to checking water supplies and the welfare of domestic animals. Counting, capturing, and gathering many wild animal species depends upon aircraft. Australian sheep ranchers use light fixed-wing aircraft to find sheep in bushy areas and in large pastures and to herd them toward the ground crew.

Salting

Salting is the planned distribution of the amount of salt required by livestock for the grazing period. Cattle movement can be altered effectively by proper placement of salt grounds. Locations should be selected so that animals will move to them and are drawn away from overgrazed or heavily trampled areas. Likely, these salt grounds will be on flat places, near shade, on accessible ridges, on level spots on slopes, in lightly used openings in forests, in patches of vegetation with low palatability, and in accessible corners of ranges where animals seldom graze. In forested areas, salt should be placed so as to attract cattle away from the meadows and onto the dry slopes. As slope and distance from water increase, more salting locations should be used.

Where abundant dissolved salts exist in soil, water, and vegetation, free salt may have little attractive value for animals. Ordinarily one salt ground should be established for each 30 to 40 head of cattle in flat country and for each 25 head on rough range. Enough salt should be placed in each bunker to last until proper forage utilization is attained or until ten days before animals are moved. Salt-hungry cattle readily will accept new locations at moving time if shown the locations. Common mistakes in salting include placing too much salt in one place, locating salt grounds over 1.6 kilometers apart, salting in the same location year after year, placing salt closer than 400 meters from water, and not showing animals salt at new locations. The necessity for placing salt near water has not been demonstrated.

Herded sheep in bands on open rangeland should be salted at or near their bed-grounds in the evening, away from overused sites near water. If this is done, the band will settle for the night and stay on the bed-ground, with less tendency to leave than when salting occurs in the morning.

Salt (20 percent) and cottonseed meal (80 percent) distributed on rangeland in self-feeders serve to maintain livestock condition as well as to improve the utilization of forage. If needed, minerals such as phosphorus in the form of dicalcium phosphate may be added to the mixture. Movable self-feeders, bunkers and troughs, permit flexibility in attaining an effective proper-use plan for the entire range. Ares (1953) after several years of study of forage use attained with different distribution patterns of a 4:1 meal-salt mixture, reported that the area of proper use increased from 32 to 59 percent of the pasture when no feeding site was closer than 800 meters from water. Feeding near water resulted in more supplement and less grass consumption than feeding away from water (Martin and Ward 1973).

Elk in northern Idaho consumed salt distributed for cattle, especially after two to three weeks on succulent spring feed. However, elk did not change their movements from winter range to summer range in response to salting that aimed to retard their trek to high elevations (Dalke et al 1965).

Vegetation Practices

Seeding highly palatable species away from water and less palatable ones near water has been suggested as a means of improving animal distribution. Suitable species and sites limit the usefulness of this scheme. However, seeding of plants with low palatability or high resilience to defoliation near areas of livestock concentration has value in soil conservation and range rehabilitation.

Fertilization and prescribed burning away from water may serve the same purpose as seeding. Livestock are known to be attracted to both treatments. Smith and Lang (1958) fertilized a strip 100 meters wide and 1.6 kilometers long going outward from a watering point. Forage utilization adjacent to the strip increased from 15 percent before fertilization to 55 percent afterward. Hooper et al (1969) claimed that increased utilization and better livestock distribution are as valuable as the added forage from fertilization and that profitability comes from the combined results.

Fires in the California chaparral, dense sagebrush, slash after logging, and in cacti increase forage supplies and facilitate use of the land by livestock and game animals. Fires in dry grasslands and marshlands make available new green growth, which soon attracts both livestock and game.

Combination of Practices

Fencing requires assurance of adequate water. Conversely, water developments can improve the uniformity of forage use without fencing. Half a dozen or more practices give numerous alternative combinations. The amount of money that can be expended for range improvements to increase livestock distribution depends upon increased production from the land. Increased grazing capacity stems from newly available range, even use, and a longer grazing season. They are expressed through increased weight of animal products, reduced labor and machinery, and a decrease of the nonrange feed requirements (Roberts and Wennergren 1965). Economic evaluation of cattle distribution on mountain rangelands for one location suggested that water development, trail construction, salting, and herding were more profitable than was fencing (Workman and Hooper 1968). It is well to keep in mind that increased livestock production ascribed to seasonal grazing may be in part due to decreased pasture size and even distribution of animals.

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14

Mixed Species Grazing

DEFINITION

Grazing two or more species of domestic animals together or separately on the same range in a single growing season has long been known as *common use* or *dual use*. The main principle supporting common use was that differences in forage preferences or lack of dietary overlap required two or more species for uniform use of mixed vegetation. However, as forage utilization increases dietary overlap decreases.

During the early decades of the Range Management Profession, common use only referred to domestic species and was discouraged because it often resulted in double use and severe overgrazing. It carried the connotation that grazing by more than one species was undesirable. However, old systems in Africa and the Middle East were known to enhance human food supply when cattle, sheep, and goats were grazed together (Wilson 1986).

The advantages of mixed species grazing are complementary food habits, improved distribution of grazing, diversification of income, parasite and disease management, and fewer losses due to predation. Disadvantages include increased costs due to loss of feeds, breakage of fences, trampling damage, damage by hunters, increased facilities, reduced efficiency within each species, labor conflicts, and need for increased management skills (Baker and Jones 1985). Optimum conditions for one species is usually a tradeoff and poorer conditions for another; yet the production of two is usually more than either alone.

Demands for Mixed Species

Research and experience have favored common use in many instances, and management of several species, especially livestock and game, has increased. Experience with using cattle and sheep, sheep and goats, or all three together proved more profitable on ranges with mixed vegetation than did the grazing of any one animal species alone (Cook 1954, Merrill and Miller 1961). Perhaps even more influential in changing people's attitude toward mixed-species grazing has been the growing interest in preservation of wild animals; game farming for hunting, viewing, and meat products; and recreational services for wildlife and other rangeland resources. Because of changes in public demand, research and experience with mixtures of animal species, some of them wild, have accumulated a body of information on effects of mixed-species grazing. That knowledge, attitudes toward rangeland animals, and the context of mixed- species grazing in rangeland management are explored in this chapter.

ATTITUDES TOWARD ANIMALS

Perhaps a starting point for this discussion is a viewpoint expressed by Aldo Leopold (1936) that livestock grazing is one of the tools that can improve cover and food for wildlife. The use of that tool remains a controversy between those who espouse sustained consumptive use and nonconsumptive use, that is, between prescribed grazing and no grazing by livestock. Mixed wild and domestic species needs to be economically rewarding for the landowner, ecologically sound for the ecosystems, and environmentally acceptable by all.

Beginning with the passage of the National Environmental Policy Act (Public Law 91-190) in 1969 the objectives for wildlife changed from a focus on species that were hunted, trapped, and caused nuisance damage to a focus on all species as having value in themselves. The public demanded more attention for threatened and endangered species of plants and animals than those found in abundance. Species diversity became as important as single or featured species management. Habitat management became a subject of concern through environmental impact analysis. The system approach used inventory and planning before landuse and management to do the best for rangeland ecosystems. Afterward monitoring checked to see if objectives were being achieved.

In national parks, national forests, and other public lands, people, hunters, conservationists, and recreationists have become parts of the producing system as well as harvesters of the products. If one person reaps the beautiful view but in so doing blocks the view of another, that person becomes a part, in this example a negative part, of the producing system. Therefore the original range concept of "common use" is extended from its early reference to livestock alone to include wild animals and people. This is multiple-use. All rangeland has and will continue to be the home of many animal species, threatened and endangered, and humans. A mixture is assumed to be inevitable and desirable.

Attitudes of the public toward domestic and wild animals determine the use and management of rangeland, especially the public rangeland. Individual viewpoints vary from **protect and save** everything to **complete use** and few people have exactly the same attitude.

A highly held view is one favoring the protection of all wild animals, but it is often restricted to natives. That is accomplished in many different ways: by preservation in game preserves, parks, and zoos; by laws against cruel treatment and killing of animals; by regulation including international trade against the importation of skins, meat, hair, horn, ivory, and feathers; by preservation of habitat; by religious beliefs and taboos; and by eliminating animals from medical experiments. Removal of all domestic animal grazing on public land is often advocated, except for some of the feral species.

One protectionist view regards wild animals as pets, and no pet should be eaten. They are to be enjoyed and protected as living creatures, as part of the family of mankind, perhaps as valuable as people. If killing is necessary, it is to be done mercifully and only after all efforts to save them have failed. One hears the term **animal rights** in this context. Animal rights pose threats to management of wild and domestic animals on rangeland.

Included in the animal-rights approach is the idea that if a wild animal population goes through a buildup and crash cycle during which it has major detrimental effects on its habitat and on other species, so be it. Catastrophe due to drought and disease is natural and expected. Any effort of management must aim at improving the habitat and minimizing such problems as disease transfer to humans and domestic animals, while not disturbing the animals themselves. Included here are such beliefs as not to cull a herd, kill or experiment with animals for any purpose, and the refusal to eat game meat, to use leather, or to admire mounted trophies. Individual nuisance animals may be excepted.

The ultimate goals of people who have this attitude are to prevent extinction of endangered species of plants and animals, keep other species from becoming endangered, and to maintain balanced and diverse biological systems. Carried to extremes, this attitude suggests attainment and maintenance of the animals and their environment as they were at some past time. An immediate purpose of preservation activities is maintenance of animal populations for sightseeing, avoiding extinction, and photography. Taxonomy as a science is reduced or even eliminated because the long-accepted principles of extinction and evolution of new species are no longer acceptable.

The concept expressed in "**animal welfare**" permits management and use of animals to attain such goals as production of edibles, increased biodiversity, protection of endangered species, and control of individual predators. It requires minimum pain and suffering by the animals. Range Management must recognize animal welfare.

Another attitude toward animals is **game ranching** and still another is **game cropping**. The ranching approach raises and sells animals, while the cropping approach is exemplified by the hunting of animals under state regulations. Although no person exclusively accepts any of these attitudes, most people favor one of them and agree about saving certain species. For example, few have argued against efforts to save the mountain zebra in South Africa and the California condor. Laws, attitudes, and management procedures do not match the requirements for longterm preservation of many species. "How to do it" does not as yet equal the change in public attitude from conservation based on sustained yield to preservation by nonconsumptive use.

Domestic or Wild Animals or Both

While proponents of either game or domestic animals usually agree that mixtures of species are more productive than single species, they disagree as to whether game and domestic species should be mixed. Claim and counterclaim are largely based on overgrazing and other faulty range management practices that the Range profession does not condone. Enough positive wildlife/livestock information exists to warrant developing the viewpoint that in some situations wild and domestic animals can be grazed together.

MIXED GAME ANIMALS

Skyrocketing tourism, based largely on the hunting, viewing, and photographing of wild animals, and predictions of high production of game meat, skins, horn, and hair, increasingly support contentions that large areas of rangeland should be devoted to raising a mixture of wild animals. Worldwide, the biomass of game animals, including a variety of species filling a wide array of ecological niches, has been locally estimated as high as 18,000 kilograms per square kilometer. Implied is high efficiency in the conversion of a large spectrum of forage plants into animal products without damage to soil and vegetation.

Ignored is the fact that wild animals can cause damage to soil and vegetation. Reproductive and growth rates of many game species are high, killing-out percentages are good, and little wasteful fat is mixed with the lean meat. Some wild species do not need frequent access to water, so trailing and trampling are less than with domestic animals. Game can use areas in Africa where tsetse flies carrying trypanosomiasis prevent livestock grazing. Wild species are resistant to many other diseases that plague livestock (Talbot 1966).

Conversely, it can be argued that several species and breeds of domestic animals contribute variety to the appearance of the countryside, consume most of the available forage species, and contribute the principal support to many pastoral peoples. Where pastoralism is important, as in parts of Africa, Asia, South America, and the Near East, incomes from wild animals usually accrue to the nation as a whole and to industries other than pastoralism. Furthermore, in these areas, production from viable herds of game often is compared with that from poorly managed livestock. Biomass and intensively managed livestock can be as high as or much higher than that of game. As long as livestock provide the daily food and secure the pastoralists place in the social structure, livestock should be improved to meet the need. Many pastoral peoples do not interfere with wild populations that have shared their lands for centuries.

Subsistence pastoralism evolved using mixed herds. Market pastoralism is rapidly learning how to use mixtures of animal populations. The mix of species that the land manager selects for any given situation results from the interplay of many constraints such as tradition or custom, laws, market demands, handling facilities, food habits of different animals, and biological relationships among species. Other people with a sincere interest in animals, as well as those with direct land management responsibility, approach these constraints in different ways.

INTRODUCTION OF EXOTIC RANGE ANIMALS

Grazing animals have been transplanted both intentionally and unintentionally to new lands. Fourteen species of large herbivores were liberated in New Zealand, beginning with release of goats and pigs by Captain Cook in the eighteenth century (Wodzicki 1950). Horses became a wild animal of central North America following Coronado's expedition in the sixteenth century. By accident or carelessness of the keeper, any enclosed animal may escape. Importing a new species, even if it is enclosed in a small pen, adds a potentially wild species to the rangelands of the region. Exotic plants that have become new natives number in the thousands in the United States.

All domestic grazing animals in the United States have become feral on rangelands. Wild horses are the best known. At their peak they numbered many thousands. Wild burros are problem animals in parts of Arizona, California, Nevada, and New Mexico and exist in small groups in several other states. Feral cattle are not so persistent. Feral goats and sheep have caused extensive damage to range vegetation of several islands along the California coast. Feral pigs have become established as the second (after deer) most important big game species in California (Craighead and Dasmann 1966), and they are common in other parts of the United States. Managers have crossed it with the European wild boar to enhance its trophy value. Castration of the male pigs may improve the mature barrows for human food and not reduce trophy value.

President Carter's Executive Order 11987 in 1977 restricted introduction of exotic plants and animals into any natural ecosystem in the United States. Secretaries of Agriculture and Interior were given authority for exemptions. An introduction must satisfy a specific need, be ecologically suitable, will not damage other species, and satisfy quarantine requirements.

Importation and maintenance of exotic herbivores on private lands have been permitted. State laws on feral and exotic animals vary from complete protection, as the burro is protected in California, to stipulation in Texas that a game species must be an indigenous species. In the latter state, no exotic grazing species, birds excepted, are subject to game laws and regulatory responsibility by a state agency. In 1988, Texas was reported to have 67 species of large exotic herbivores on private land. Estimated numbers of the three most numerous species and the next three species in importance were as follows (Demarais et al 1990):

Animal Species	Number of Animals
Axis deer	39,000
Nilgai antelope	36,700
Blackbuck antelope	21,200
Aoudad	
Fallow deer	
Sika deer	

These numbers can be only approximate because some animals escape reporting. The interbreeding of mouflon sheep with domestic sheep further complicates censusing. Most of the buildup in numbers has occurred since 1950.

Only a few herbivorous species have become successful and beneficial immigrants to any country. Most either have been unsuccessful or have expanded to nuisance levels, as have the red deer, chamois, thar, rabbits and others in New Zealand. The successful species would appear to be the opportunist animals that can take advantage of widely varying habitat conditions and fill open niches. Specialized species transplant with difficulty and are unlikely to become pests. Disease, poor physical condition of animals at release time, lack of adaptation to new habitats, too few numbers, and shock from handling cause failures. Diseases can spread to the native species.

High hunting fees from guests who want "something different" encourage importation of game species. Some advocates of importation claim that more meat, better hunting, and higher profits can be obtained with additional species that fill vacant niches. Other advocates claim that newcomers improve upon the complexity of nature and help to prevent extinctions of rare species. However, exotics may replace native species through uncontrolled spread and competition. Faunas should not be mixed because genetic changes soon take place in imported animals. Undesirable consequences of introducing animals cannot be predicted at reasonable risk levels (Decker 1978).

Alternative regulations for exotics include declaring them private rather than public property, exterminating them altogether, giving them protection, placing them in sanctuaries, and including them as game animals. None of these can be a final answer to importation and management of all species or even one species in all places. A species imported, raised, and managed on a ranch should be private property, as many species are in Texas or as ringneck pheasants are on shooting reserves. In different situations, regulations may be required, but they seldom can be stated in advance of importation.

Without brands or other ownership markings, escaped individuals on public land traditionally become public property and subject to regulation by public agencies, as have wild horses. Private regulation of game animals can be successful on private lands, but public rangelands will continue to require public regulation of exotics as publicly owned animals. Those species (horse, burro, goat) that have little value for hunting should not be declared to be game.

Several points concerning exotic and feral animals seem clear. Many foreign species have made permanent homes in new areas, and more are likely to be added to the list. Exotic game birds and exotic forage plants have been highly beneficial on rangelands. New game animals also can be beneficial, but problems will develop. Their control and even elimination will be needed where habitats are required for other purposes.

Each introduction brings a need to determine the ecology and management of the species in its new situations. Mixtures of exotic species and domestic species on rangeland have been profitable in Texas, largely because of careful management by all interests and consideration of all animals in harvest and production. Further development of exotic range animals, especially on public lands, requires careful consideration of policy matters, statutory regulations, and biological relationships.

EXCHANGE RATIOS AMONG ANIMAL SPECIES

If management requires a switch from one kind of animal to another, addition of a new species, or change in proportions of animal types, the concept of equivalent grazing pressure among species is useful. Thus, "How many sheep equal one cow in grazing impact?" **The cow is taken as the standard and called an animal-unit (AU).**

Various methods of obtaining exchange ratios among species have been used, but none has been completely satisfactory. If the feed eaten is reasonably the same for both species being compared, the ratio of metabolic weights, gives the exchange. Although variation exists among individuals and species, the 3/4 power of weight in kilograms defines the metabolic size of an animal (Kleiber 1961). It expresses the fact that smaller animals produce more heat and consume more food per unit of body size than do larger animals. For example, a 500-kilogram cow and a 50-kilogram sheep have metabolic sizes of 105.74 and 18.8, respectively. The ratio of live weights is 1:10 but the ratio of metabolic weights is approximately 1 cow to 5.6 sheep, which is a better expression of the relationship of their feed needs. A cow:sheep ratio of 1:5 has been used on rangeland more than any other and appears to be a reasonable expression of the relative impact of the two upon the range. Table 14-1 gives animal unit equivalents for a number of species and for animals of different sizes, e.g., 1.5 animals weighing 272 kilograms equal 1 animal unit. These are approximations; Forero et al (1989) claimed that weight for weight is a workable cow/calf to yearling substitution ratio for the shortgrass steppe.

Food habits, ages of animals, cover, and differences among species alter exchange ratios. For example, little competition and, therefore, little basis for exchange exists between moose and cattle in southwestern Montana, where the former has a diet of 98 percent browse and the latter mainly grass (Dorn 1970). Giraffe and cattle in the same African pasture exert little competition with each other because one feeds on browse and the other on grass and forbs. The proper number of each in a pasture depends upon the amount of grass and browse available, not upon the notion that it takes 3 cows to weigh as much a 1 giraffe or that their ratio of metabolic size in approximately 1:2. In fact, the manager may desire to use excess giraffe to overbrowse the woody plants; so the start may be 1 giraffe to 2 cows. As the brush disappears so must the giraffe, until the final result is grassland with cattle alone.

Any use of exchange ratios among range animals should be limited to those with similar diets and to the initial exchange. Table 14-1 is only a guide, since wide dietary differences exist among the animals included. Manipulations in proportion of species should depend upon changes in range condition which are caused by each species.

Table 14-1 Approximate number of individuals per animal unit based on ratios of metobolic weights (wt. $kg^{0.75}$) for mature animals.

	Approximate wt.				
	lb	kg	$kg^{0.75}$	Ratio, 98/x	No. per animal unit
Cape buffalo	1,200	545	112	0.87	0.9
Bison, cow, eland, horse	1,000	455	98	1.00	1.0
Elk, zebra	600	272	67	1.46	1.5
Waterbuck, wildebeest	400	182	50	1.96	2.0
Hartebeest, topi	300	136	40	2.45	2.5
Mule deer	150	68	24	4.08	4.0
Sheep, impala	120	55	20	4.9	5.0
Pronghorn, goat	100	45	17	5.76	6.0
Thomson's gazelle	50	23	10	9.8	10.0
Dikdik	12	5	3	32.00	33.0
Blacktailed jackrabbit	5	2.8	2	49.00	50.0

FORAGE AND ANIMAL COMBINATIONS

In a general way the proportions of grasses, forbs, and browse determine the desirable kinds of animals on a given range. Cattle and horses, among the domestic animals, prefer grass to a greater extent than do sheep and goats. Goats are known for their browsing habits, and to a lesser extent so are sheep, but both eat grass and do well without browse. Neither cattle nor horses thrive on strictly browse feed. Most foraging and browsing animals exhibit a wide range of preferred dietary plants and shift from one or a few species to others as forages change in their availability and growth stage. The larger grasses should be used by cattle; fine grasses make excellent sheep feed; browse is used mainly by certain game, cattle on forest range, sheep, and goats; and sheep do well on many weedy, broadleaved plants.

Some examples of minimal dietary overlap are: Deer had a forb dominated diet in meadows in central Oregon while cattle selected grasses and grass-like plants. Only 6 forb species of the 34 common ones in meadows constituted any degree of overlap (Stuth and Winward 1977). In Colorado, the dietary overlap between horses and deer was 1 percent, cattle and deer 4 percent, and for wild horses and cattle it was 77 percent (Hansen et al 1977). Ruyle and Bowns (1985) found that common use by cattle and sheep on mountain summer range in Utah distributed the grazing pressure more evenly over grasses, forbs, and browse than either animal species alone. The grazing capacity on 120-acre pastures in Wyoming was 8 antelope and 7.2 sheep for each species alone but 6 of each in dual use (Severson et al 1980). These results, while only from a few areas, suggest that common use more efficiently utilizes the range than a single species.

Exceptions to these generalizations occur in specific locations. For example, food habits of deer in northwestern California indicated high dependence on acorns in the fall and grass in the winter/early spring period but not at other times of the year. Kufeld et al (1973) in a review of 99 studies found 788 plant species listed in deer food habits. Deer on the Welder Wildlife Refuge in southern Texas are grazers with about 3 percent browse in their diets, while Spanish goats selected more brush species (Warren et al 1984).

Habitat Selection

The fact that several kinds of animals occupy the same region, pasture, or even vegetational type does not indicate that they occupy the same niche and are in direct competition with each other. More likely they do not completely overlap on the food and cover parts of the habitats.

Lamprey (1963), after lengthy study of numerous grazing and browsing animals in north central Tanzania, suggested that the separation is accomplished in six different ways:

- Species concentrate in different parts of a vegetational mosaic.
- Species select different types of food.
- Species separate topographically on a seasonal basis.
- Species select the same area but at different seasons.
- Species select different feeding levels in the vegetation.
- Species separate on a vegetational basis according to season of food stress.

The first two of these principles are illustrated in Figure 14-1, which shows that occupied habitat is not the same as food selection. The third principle, topographic separation, is accomplished in the dry season, when impala and Grant's gazelle use upland areas because they can live without free drinking water while other species move to lower areas near water. Elephants illustrate the fourth principle by their ability to range more than 40 kilometers from water in the dry season, placing them on forages that are used by other species only in the wet season. Black rhino, dikdik, and giraffe illustrate the fifth principle because they browse, but they feed at different levels in the woody vegetation. The sixth type of separation is illustrated by zebra and wildebeest, which live closer together and near water in the dry season but separate to different parts of the grassland in the wet season. These separations illustrate types of horizontal and vertical stratification among animals.

Separations of animals into horizontal and vertical strata is further illustrated by mule deer, elk, and cattle on a section of the Missouri River Breaks in central Montana. Minimal interspecific competition existed, although the three species occupied the same general area (Mackie 1970). In the summer, deer concentrated in ponderosa pine/juniper, elk selected *Sarcobatus/Agropyron smithii* in the bottom lands, and cattle grazed the sagebrush/grass type. During winter and spring, all three species occupied the sagebrush/grass type. Deer preferred steep southerly slopes all year; elk moved from southerly exposures in the winter to northerly slopes in the summer; and cattle spent at least 80 percent of their time in all seasons on slopes of less than 10 percent. Deer and elk overlapped in their preference for forbs in the summer. Deer and cattle separated completely, since they concentrated in different parts of the vegetational mosaic, grazed on slopes of different steepness, and preferred different foods. Elk and cattle were more competitive, since both ate grass, but they still selected different winter habitats.

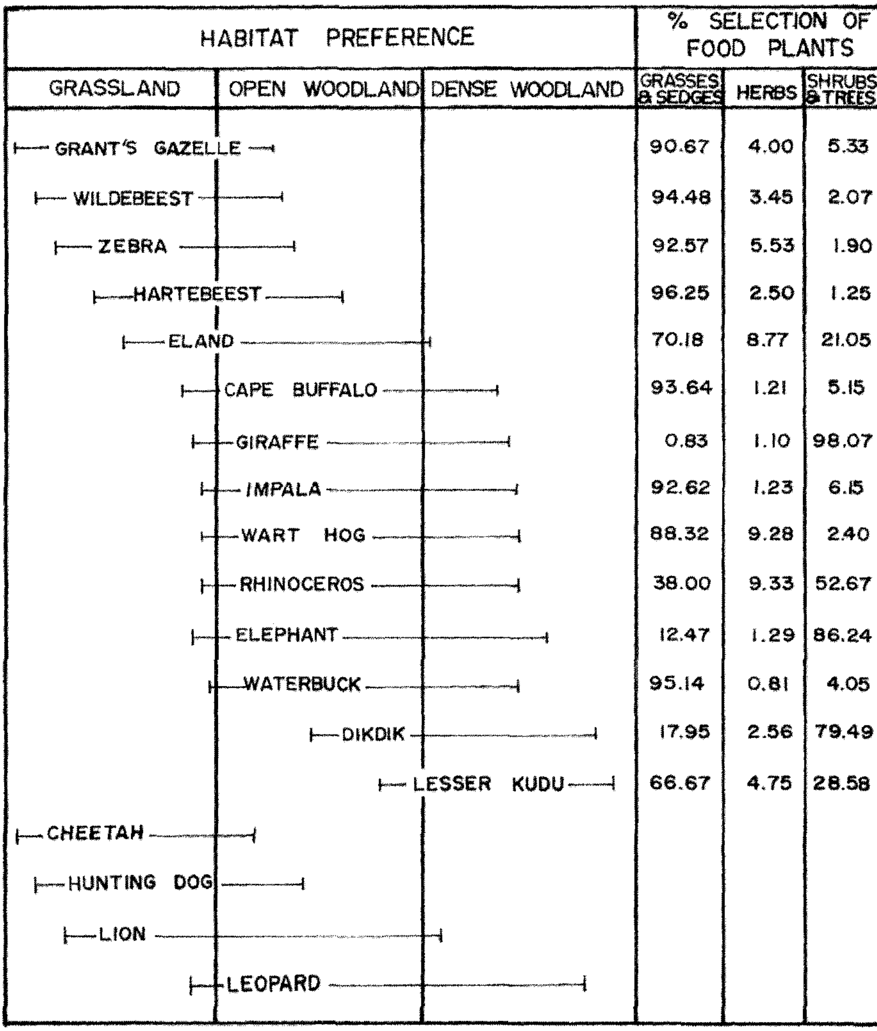

Figure 14-1 Habitat preference and food preference based on frequency observations along transects in two areas of Tanzania (adapted from Lamprey 1963). Recordings were made almost daily for four years.

Species may be antagonistic. Moderate sheep use during the plant's dormant period discouraged use by pronghorn until spring regrowth (Clary and Beale 1983). Elk shifted away but deer did not when cattle were introduced (Wallace and Krausman 1987), and it is widely accepted that elk move away from human activities such as logging and roads.

Banff and Jasper National Parks in the Canadian Rocky Mountains had abundant elk in 1880, but very few in 1915 when bighorn sheep, deer, and moose were common. In the 1950s, abundance, from highest to lowest, was elk, bighorn sheep, moose, and deer. These population changes related to changing food supplies due to fires and to the elk overgrazing their habitats (Flook 1964).

Work with cattle, sheep, and goats at three stocking rates on the Sonora Experiment Station and adjacent ranches in Texas indicated that raising the species in combination yields more profit than does raising any of them singly (Merrill and Miller 1961). Other benefits of species in combination included fewer poison plant problems and uniform utilization of available forage. Whitetailed deer constituted a fourth species of value on many ranches in the area.

Livestock grazing improves quality of forage for wildlife, prevention of wolfplants, reduction of excessive leached residue, and higher nutritive quality at plant maturity (Anderson and Scherzinger 1975). Feral horses by grazing grasses and forbs increased twig production of *Purshia tridentata*, thereby improving deer winter range (Reiner and Urness 1982).

Grazing also affects the smaller animals. Mearns' quail populations were reduced when cattle grazing exceeded 55 percent utilization in southeastern Arizona (Brown 1982). Blacktailed jackrabbits concentrated on summer light and moderate grazing treatments. Cottontails were most abundant on moderate summer and winter grazing. Whitetailed jackrabbits did not respond to any treatment (Flinders and Hansen 1975). Grasshoppers eat all species of herbage available (Joern 1983).

Maintenance of Forage and Animal Combinations

Other factors being equal, an animal species with specific food habits finds its best habitat to be the one furnishing those foods to the greatest degree. As the number of grazing species increases, the spectrum of consumed forage broadens and increasingly overlaps. By the same reasoning, multiple species utilization theory becomes untenable where there is high dietary and habitat overlap. Combinations of animal species need mixed forage resources, and a mixture of grazers and browsers probably are best.

A change in the numbers of one animal species influences the population numbers of other species because it changes habitat. These relationships may be used for managerial purposes. However, widely varying cause and effect responses must be recognized. Herein lies a major problem in the ranching of mixed animal populations. All the species must be managed. For too long, the general question in common use management has been, "What can a second animal do for the first?" The view developed here emphasizes that each species of animal should be managed for what it can produce and how it can influence total production. Succinctly, goats should be raised for goat products and vegetational management, not just to control brush.

Several examples that illustrate the close relationship between changing habitat and changing animal populations are described below. They illustrate situations where, for the most part, the changes were remembered or recorded in hindsight. The ultimate objective in management is to predict changes in vegetation and animals and to plan for their best use.

That vegetation and animal populations change as a result of management is illustrated by experiences in Kruger National Park in South Africa. From 1902 to 1947, an area near Numbi Gate was burned annually and became open grassland with numerous wildebeest and zebra as dominant grazers. Fire was eliminated from 1947 to 1954, during which time bush increased, as did impala and greater kudu, but wildebeest, sable and roan antelope, and zebra decreased (Pienaar et al 1966). This example illustrates an effect of fire on vegetation and the close relationship between kinds of animals and habitats. Animal populations were left to adjust naturally with the habitat changes. Undoubtedly impala and koedoe tended to improve the habitat for wildebeest and zebra by eating the bush. The latter two species, preferring grass, had the reverse effect.

In a research study in South Africa, goats used browse that tended to be avoided by cattle and both together controlled the woody plants to some extent, thereby increasing the herbaceous vegetation (Donaldson 1979, Aucamp and Barnard 1980). In another study Aucamp et al (1983) found that grass production was greatest with a tree (*Acacia karroo)* density of 297 per hectare but maximum red meat was produced by Boer goats and cattle with 2600 trees per hectare.

For at least two decades, winter deer range condition in northeastern California had been declining. Elimination of cattle from the area of winter deer range aimed to improve the browse (mainly *Purshia tridentata*) supply for deer. However, few browse plants regenerated and grasses increased considerably. When heavy early-spring cattle use of grass in experimental areas was followed by no summer grazing, stands of grass were reduced and bitterbrush increased. Apparently this range needs grazing that reduces grass to remain in acceptable condition for deer (United States Forest Service 1970). Careful management serves both cattle and deer.

Following exceptionally widespread wildfires in 1910, elk and deer populations in northern Idaho and western Montana increased rapidly in the developing shrub stands. Elk reached an estimated 11,000 head in the Selway River drainage alone by 1935. As coniferous trees replaced the shrubs and as shrubs produced less browse in their older growth stages, elk feed lessened and elk populations decreased. If the elk herds are to be maintained or increased, timber management must maintain elk habitat, including shrubs producing abundant browse (Mueggler 1967). Also, a decrease in mule deer in western Montana occurred as the tree canopy continued to increase (Klebenow 1965).

Increasingly, management of national forest lands aims for less timber harvest, less use of forage by domestic animals, and more attention to the needs of wildlife and people. Practices that promote understory vegetation usable by deer are favored (Reynolds 1969), such as forest openings that can be rotated by patch clearcutting. Openings can be seeded to browse and grass and used efficiently by deer and livestock. Thinning, which enhances timber yields, also favors deer food. Leaving slash as it falls promotes a better habitat for deer than does slash piles. Cattle and sheep favor grass, gentle slopes, and areas where the slash is cleared.

CYCLES OF ANIMALS AND HABITATS

Wild animal populations change in response to changing habitat conditions. These give opportunity for vegetational management to favor desired species. Forty-nine species of mammals regularly occur in California chaparral, seven are found in mature chaparral and nine in young chaparral. The others occur in riparian vegetation and in many habitats. The most favorable habitat is a mixture of chaparral that is maintained by small prescribed fires (Quinn 1990).

Changes in animal populations and habitats may be naturally cyclic. In 1900, during the building of the railroad through the area that now includes Tsavo National Park in Kenya few elephants were seen. Grassland dominated the landscape. Brush increased in density for several decades. Elephant population increased even faster than the supply of browse and went beyond it, causing destruction of trees and shrubs. Grasses increased as the *Commiphora/Acacia* cover thinned, first near water and later at considerable distance from water, in response to the browsing and playfulness of the elephants. Fires speeded the change toward more grassland (Napier-Bax and Sheldrick 1963). The decreasing browse discouraged rhinoceros, which suffered heavily during drought (Goddard 1970), but elephants, being taller than rhinoceros, could reach sufficient browse to remain alive when the grass was gone. Less and less browse indicated that the dry season quality of diet was lowered and less feed was available. The next drought caused the death of many elephants, and afterward, a rapid increase in grazing species of the open grassland (Laws and Parker 1968). As plains animals increase and overgraze the grassland, woody plants were encouraged. And so the cycle, partly observed in several African sanctuaries, and partly measured in research, continues over centuries.

People, continually increasing their influence, are unlikely to permit the full elephant cycle. For example, with continued heavy grazing and reduced fire, the *Commiphora* woodland will regenerate rapidly (Agnew 1968). With light grazing and frequent burning, the grasses will dominate for decades. Thus, the manager can combine the use of animals and fire to produce the desired plant species.

In the future, people will exert influence on these cycles by farming the land, poaching and hunting the animals, by hampering migrations and lesser movements, by prescribed fire, and by grazing domestic animals on the vegetation. However, the choice of techniques to control the cycles presents a question secondary to the choice of objectives. Are changes caused by elephants and other animals to be considered destructive or desirable according to today's and future values? Is the aim to stop thê cycle and to maintain a certain combination of animals and plants? Choice among the alternatives determines if steps should be taken to control the animal populations or if nothing should be done so one can marvel as the system changes. If the manager selects animal control at a certain level as the objective, it should be done on the basis that a stipulated mixture of animals and combination of vegetational types also will be maintained.

Additional information, if only anecdotal in nature, on the relative influence of many wild species on their habitats is needed. Opportunities are available for gathering knowledge in parks, nature reserves, and extensive pastures where large numbers of wild animals can be managed in grazing experiments. For example, at Percy Fyfe Nature Reserve in the Transvaal, South Africa, 500 blesbok, 41 tsessebe, and 18 roan antelope grazed in separate pastures. A fourth pasture contained greater kudu, zebra, impala, eland, waterbuck, sable antelope, black wildebeest, and a number of smaller species. These pastures gave the opportunity for determining the separate influences of several animal species on their feed supply, the effects of grazing systems in which one species follows another on a seasonal basis, and the techniques for handling or semi-domesticating each kind of animal.

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15

Mixed Species Management

Management of rangelands, the vegetation and animals, is the subject matter in other chapters. The reader is reminded that the cardinal principles are proper number of animals or degree of forage utilization, uniform forage utilization over the land, manipulation of season of grazing, and the mixture of herbivorous species according to rangeland resources. These resources in themselves are subject to manipulations by prescribed fire, mechanical and chemical noxious plant control, seeding, fertilization, biological and chemical control of insects, and unusual natural events. **Understanding of the processes, interactions, and resource changes operating within and without the manager's control is the substance of rangeland ecosystem ecology.**

The management of mixed wild species, mixtures of wild and domestic species, and of different domestic species are subject to the same animal and vegetational management techniques mentioned above. However, the manner of off-take, numbers to be harvested, and needed facilities for management widely differ among the domestic and wild species. Eltringham (1984) reviewed most of the world's case studies of wildlife cropping and wildlife ranching, but included little on common use management. Whether domestic or game animals, the demand for each of the mixed species is social and recreational, as well as economic. The demands, hence objectives of rangeland management for mixed species, differ greatly among people's interests and is especially controversial between public and private ownership of resources. So many references have been made to the damaging effects of livestock overgrazing on wildlife that the positive effects of proper grazing on vegetation and grazing for the specific purposes of wildlife habitat restoration have been overshadowed and often claimed as untrue. The ultimate effort in habitat restoration makes use of every tool available including management of the wildlife, management of domestic animals, and numerous types of vegetational manipulations without animals.

OBJECTIVES OF HABITAT MANAGEMENT

There are four objectives in habitat management for animal production. Severson (1990) gave these for wildlife as (1) alter the composition of the vegetation, (2) increase the productivity of selected forage species, (3) alter the structure of the habitat, and (4) increase the nutritive quality of the forage. While these were given in the context of habitat alteration by domestic animals for improved wildlife habitat, they apply when the objectives are only wildlife or only domestic species. In most situations, when the above objectives are attained other results such as erosion control and high diversity will also be gained.

HARVESTABLE NUMBERS

Determination of a percentage off-take or harvest that will maintain a maximum productive herd without destructive changes in soil and vegetational resources constitutes a major problem in multi-species domestic and game management. Theoretically, each species in the herd has a density at which all its environmental needs are met to the fullest and increase in annual biomass is the greatest. Fortunately, the abundance of each species has some leeway in the mix. The optimum species mix, stocking rate of each, and management system are problems of economics, sociology, as well as biology; not just one of maximizing biological output per hectare. However, off-take should balance the increase whether it be numbers of animals or biomass; otherwise the species will diminish.

A few guidelines, based on experiments and experience, exist for intensity of wild-animal harvest. After many years of study and control, an annual off-take of 40 percent of the autumn herd has been recommended for the saiga antelope in Russia. The species has a high twinning rate and a relatively low rate of loss in the young (Bannikov et al 1961).

From studies beginning in 1928 on the George Reserve in Michigan, McCullough (1984) calculated that the maximum annual harvest of whitetailed deer should be 47 bucks and 44 does from a maximum herd of 180 animals. Average annual decrease of a different whitetailed deer herd in northern Michigan amounted to 32 percent of the fall herd. This decrease was composed of 12 percent through natural losses and 20 percent through hunting (Arnold and Verme 1963). Mule deer on the National Bison Range in western Montana sustained an annual removal of a third of the herd; fawn and predator losses were light (Nellis 1968).

Although the herds are small, game ranching in Western Canada is increasing and is primarily concerned with breeding stock of bison, moose, and wapiti. The main problem is poaching for velvet antlers. Commercial meat production by a community of game ranchers is unlikely on a sustained yearlong basis until the numbers reach a million head (Renecker and Kozak 1987). Nine species of antelope were harvested mostly for meat on farms in the Cape Province of South Africa (Jooste 1983). Hunting is recreation so first provision in the harvesting of game is a pleasant experience, whether the purchase by the hunter is for trophy or meat.

Game eradication in Africa for the purpose of removing the food of tsetse flies and thereby eradicating the fly and the disease, trypanosomiasis, has special reference to the problem of determining harvestable numbers of game animals. Game removal first became a national program in South Africa in 1929. The suggestion that game elimination would reduce tsetse infested areas originated from the fact that fly areas diminished after the rinderpest epidemic of 1896, which decimated both game and livestock populations. Estimates based on recorded kills in the Umfolozi area of South Africa suggest biomass of game animals at about 280 kilograms per hectare before the first eradication program in 1929, and 244 kilograms per hectare in 1944 and 1950 (Mentis 1970). Species such as eland, wildebeest, and zebra were easily eliminated or reduced to near zero, and others, such as cape buffalo, greater koedoe, and waterbuck, were greatly decimated, but some survived. Smaller antelope and nocturnal animals such as bushbuck, duiker, and bushpig were curtailed but perhaps for only a brief time.

Problems of reducing or maintaining each animal population at a certain level are illustrated in all tsetse control hunting operations. In eastern Zambia two years of hunting duiker were insufficient to change age composition in the herd. Feeding habits were changed, and the animals became more difficult to find (Wilson and Roth 1967). In Zimbabwe after killing 10,838 duiker over 310,000 hectares in a 29-month period, hunters were shooting as many as at the beginning (Lovemore 1963). After 23 years of organized game shooting to control tsetse in a 775-square kilometer area of Botswana, only one of a dozen hunted species was reduced in numbers (Child et al 1970).

These failures to eliminate species support the proposition that wild animal populations can produce considerable meat. Although many approximations went into the estimate, the 1942 to 1950 program in South Africa produced about 1.2 kilograms of meat per hectare per year in an overkill situation. Development of resistant livestock strains and prophylactic treatments appear to be the best available approach to control of trypanosomiasis.

Whether the determination of off-take numbers is approached on a basis of herd increase or maintenance of a specified herd size, the actual harvest will vary from year to year. It must be sensitive to annual climatic changes and to annual variation in reproductive rates. Above all, off-take of females is as important as the taking of trophy males and the landowners must be compensated for raising the wild animals.

Harvesting in Parks and Reserves

Harvesting or removal of animals from parks and reserves necessitates careful attention to public opinion. The public permits reduction of animal populations only after long and careful enunciation of reasons. Less public opposition to reduction is often associated with concern for increased water and feed to support more animals and to prevent the ravages of droughts. Successful examples of animal population controls in parks are the management of bison in west central Montana, the continuous reduction programs in Kruger Park in South Africa, among elk in or near Yellowstone Park in Wyoming and Montana, and among hippopotamus in Uganda parks. In the last example, 1.4 million kilograms of undressed carcasses were taken and used for food during a 10-year period.

Generally, killing and capturing should be done by park personnel or under their close supervision (Leopold et al 1963). Tourists have not been allowed to witness the taking and processing of animals in most parks. An exception was the reduction of hippopotamus numbers in Queen Elizabeth Park in Uganda, which continued for approximately 10 years in full view of many tourists.

ANIMAL CAPTURE AND HANDLING

When wild animal populations need to be reduced, capture and transport of live animals to a new area is a viable, although usually temporary, alternative to killing. Capturing of various species requires a variety of equipment and techniques; just as the facilities differ for handling of cattle and sheep.

Domestic animals normally are dehorned, castrated, branded, checked for health, and sorted in a set of corrals. Cattle and sheep, being different sizes and behavior, require handling facilities of different designs. Permanent structures for shearing sheep have minimum usefulness for other purposes. However designs for handling wildlife and domestic animals have some common attributes. A large pen usually leads to a smaller one and that to a holding pen, a squeeze circle, and with gates along the way (Fig. 15-1). The large animals (elephant, rhinoceros, giraffe, etc.) are nearly always captured with drugs as are many of the smaller species. Driving into nets and corrals and trapping are other methods of capture.

All commercial animal industries require facilities for the holding and transportation of live animals. Otherwise new herds cannot be established, crossbreeding or other herd improvements cannot be obtained, and conveyance of animals to market restricted. Some of the requirements in facilities designed for wild animals are darkened crates for individual animals and for two to five of the smaller species, which have highly developed herding instincts. Jumping animals are usually restrained by covers on the crates or pens. A horse trailer with high sides and a tall windbreaker front serves for giraffe. These are illustrations that facilities for capture, handling, and transport fit the animal; otherwise injury and escape will occur.

Additional information on wildlife capture, handling, holding, and transport facilities may be found in White (1987).

GAME CROPPING

Game cropping is maintaining animals in a wild state but harvesting or cropping of the principal species; thereby keeping populations in check, and reducing cyclic extremes in numbers. It is game hunting as controlled by landowner, state, and federal regulations and it may include cropping of several species at the same time and place. Sale of all types of wild animal products is usually prohibited, but on private land hunters customarily pay a fee. The manager controls populations only after disease, natural predators, and stress do not exert sufficient pressure. Ideally, populations continue with diverse herd composition and at densities that prevent overgrazing of food supplies. Wild animals exercise full competition with each other, have freedom of movement, and follow natural behavioral patterns. The ultimate management objectives are to protect the species and their habitats by taking over formerly natural controls and at the same time, but secondarily, to produce as many products and services as possible. Game cropping requires more than simply allowing hunting.

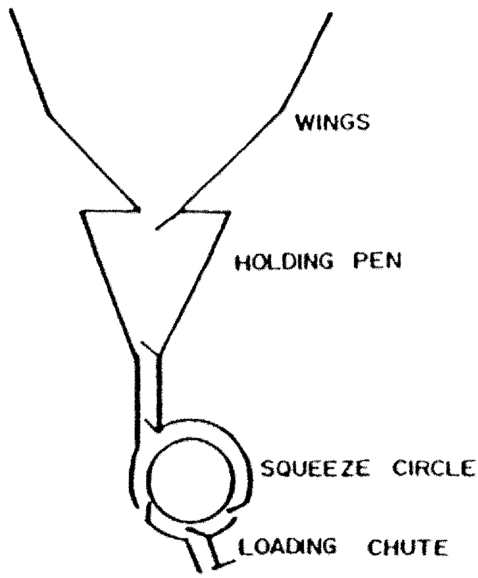

Figure 15-1 Design of a portable corral for catching springbok, blesbok, zebra, and wildebeest, animals that are not high jumpers (adapted from Riney and Kettlitz 1964). The wings are dark plastic and at least 1.5 meters high. The chute into the squeeze circle and the squeeze itself are wood or wire panals as needed to hold the animals, but they are open so that the herd leaders (blesbok) can be seen through the material or solid so that horns will not tangle in them (springbok). The inside circle gives capacity to the chute and at the same time keeps the animals milling rather than bunching them into a corner. The circle has gates or baffles at two or three points so that only a few animals can be caught at once and all can be handled easily. Blesbok will not jump a 1.5 meter fence. They are caught by the horns by a person reaching over the fence, then led through the gates into shipping gates. A straight chute is used for wildebeest. All pens should have rounded corners and posts on the outside so animals will not be injured in handling. A helicopter has been effective in driving animals into the first compartment.

Hunter harvest of game on private land is an increasing means of deriving income from the public-owned but privately raised species. Trophy animals are sold at a price as high as the market will accept, for example, several thousand dollars for a trophy elk, but meat animals to keep the herd in check may be sold for only a few hundred dollars each. These prices may or may not include guide services, camp or lodge-type living, and handling of such items as license, meat handling, and taxidermy. Other state aids to private landowners for raising the public-owned game include direct subsidy, issuance of kill permits, increased bag limits, payment for damages by wild animals, tax incentives, and technical assistance (Dumke et al 1981). These benefits are usually in exchange for habitat management and to encourage stewardship of the resources. Fee hunting on public land could foster rangeland improvements and be beneficial to both livestock and game (Thomas 1984).

Game cropping usually involves hunters leasing private land for the privilege to hunt. The types of hunting leases are (1) The seasonlong type is usually the state hunting license season for wild animals and birds or one set by state or owner for exotic animals and released birds. Other types are (2) day hunting, (3) hiring of a hunter broker or outfitter, and (4) a charge made per animal taken.

GAME RANCHING

Game ranching is more complete control of animals and the hunters by the private landowner and may or may not be regulated by state laws. Native and exotic species are raised for trophy hunting, meat, and miscellaneous other products under semidomestication types of control. Game ranching also includes raising or release of birds and mammals for hunters.

For several thousand years, few serious attempts were made to domesticate new wild species. Within the last 100 years, eland have been domesticated in Russia and Africa and bison raised as ranch animals in the United States. Genetic stock from ancestral and closely related species has been moved around the world. In the last 50 years, interest surged in ranching many kinds of game animals and birds, principally in parts of Northern Europe, Africa, Australia, New Zealand, and the United States. This interest is based on the proposition that through genetic manipulation and management, valuable and profitable species can be improved for meat production and other purposes.

Domestication aims at complete control of breeding, health, nutrition, herd composition, and production. When applied to game animals, it requires elimination of population cycles caused by fluctuations of food supplies, disease, and wild predators. Domestication substitutes a highly developed predator/prey relationship in which humans are the "predators" for natural population controls. However, society applies strict controls to management of native game. Thus far, the marketplace has favored the person with camera or the one with a rifle for trophy and home meat.

A longterm result of wild animal domestication may be private ownership of game and fewer truly wild, but conversely, efficient production at the level of profits. Since the wise manager uses both wild and domestic animals as tools in the management of range vegetation, regulation of the whole vegetation/animal system becomes easier as the domestication process becomes more complete.

GAME AND LIVESTOCK RANCHING

Managing wildlife and livestock together requires decisions as to which species and how many of each. The key factor in these decisions is the objective of the landowner or manager, either for personal preference or profit. Because all species have certain requirements for food, water, cover, and space, there is little room in one area for a wide selection of species. The selection might be one to three domestic species and about that many wild species unless intensive management with exotic species is included. An extensive review symposium of wildlife/domestic animal relations in Africa summarized many results of research and experience on wildlife/livestock interfaces (MacMillan 1986).

Ranching of several species is widely practiced on a completely business basis for profit and ranchers are venturing into planned combinations of wildlife and livestock. Others are moving completely into game ranching. During the last two decades, many have forsaken sheep for cattle. Farming of native and exotic species for meat, skins, trophies, and other products is increasing. Many motives are followed in raising livestock and wildlife together or each separately.

Ranching of mixed species occurs in numerous locations around the world and ranchers have changed from emphasis on one species to another. Frequently the management emphasizes one or two species and others receive little attention.

In summary several aspects of mixing wild and domestic species are well established (Heady 1986). (1) The most likely reason for farming and cropping of several animal species together is for profit and personal preference. (2) The off-take that maximizes production and income follows the same principles for wild as for domestic animals. (3) A management principle for wildlife is harvest females to adjust herd size to grazing capacity and to produce trophy males. (4) High off-take requires low natural or unplanned mortality and a high rate of survival and growth, which in turn requires ample feed. (5) Select species based on their ability to utilize and alter their habitat in favor of other species. (6) In selecting species, take advantage of such species characteristics as differences in parasites, disease, susceptibility to poaching, and predation. (7) Common use management is attractive to some people but it is not a system for all. (8) Improvement of wildlife habitat by prescribed livestock grazing has been successful, but not universally so. (9) Facilities for managing multi-species increases fixed and operating costs. (10) Above all, **manage habitats**.

MANAGEMENT OF MIXED SPECIES

Many species, wild and domestic, can be managed together but not without many of the problems associated with rangeland use by livestock alone. This section expands on parts of the above paragraph. The maximum production of either livestock or wildlife may not always be the best strategy. Benefits of one species on another are becoming known. For example, Bryant (1982) in a review of 214 studies of the relationships between livestock and wildlife found that, excluding waterfowl, more species of wildlife benefitted from grazing than were adversely affected. Dabbling ducks needed cover for nesting in the early part of the growing season. Overutilization or even grazing by domestic animals at that time was detrimental to nesting success. Proper utilization and seasonal grazing plans solved that problem. The following are other problems and solutions:

Seasonal Restrictions Related to Kind of Animal

If a breeding herd of one species, say sheep, obtains efficient use of range during the winter season, the rancher must also provide feed during spring, summer, and fall. The manager may be obliged to graze the sheep during the summer months on coarse grass or other ranges that are better suited to cattle. If a change is made to cattle, the summer range may be more efficiently used than is the winter range, but little is gained. Usually, developing appropriate year-around feeds is preferable to combining species of animals in situations of widely different seasonal restrictions on efficient range use.

Grazing influences in one season carry over to grazing by other animals at a different time. This fact was illustrated by a situation in the Blue Mountains of Oregon. Cattle used the range from June 15 to

October 15; mule deer, for 8 or 9 months in spring, summer, and fall; and elk, in spring (May and June) and early winter (November to January). Cattle influenced elk more than deer (Fig. 15-2) because there is a greater overlap of selected foods between cattle and elk than between cattle and deer. Moderate cattle grazing affected deer use minimally but discouraged elk use. Sustained maximum use by the three kinds of animals required light cattle and elk stocking. It mattered little that the animals were using the range at different times (Skovlin et al 1968).

Bryant et al (1979) found that deer were favorably affected by management that led to excellent range conditions on the Experiment Station at Sonora, Texas. Ample grass reduced livestock pressure on the forbs and increased availability of green grass. In northern Utah, regrowth of *Agropyron cristatum* was higher and winter deer use greater where cattle had not grazed the previous spring (Austin et al 1983). At the Welder Wildlife Refuge deer under short-duration grazing avoided cattle concentrations by alternating between preferred habitats, especially in spring and early summer (Cohen et al 1989). Deer and elk use varied seasonally between and within plant communities in northeastern Oregon (Miller et al 1981). A study in southern Texas indicated that whitetailed deer densities were greatest in the summer where the brush cover was above 60 percent and least in areas with less than 43 percent cover (Steuter and Wright 1980).

In mountainous regions where deer migrate, their winter range at low altitudes coincides with spring and fall livestock ranges. Either species can overgraze the range, but usually damage results from one or the other. Since parts of the winter deer range may be owned privately, and the deer are public property, many controversies arise over the cause and solution to overuse. As food habits, behavioral characteristics of animals, and responses of vegetation to different influences become better known, the many patterns of seasonal use by different animals can be made to complement each other.

Diseases and Parasites

Deer and sheep in northwestern California are known to have at least 45 species of internal and external parasites of which 21 occur in both host animals (Longhurst et al 1954). This large number of parasitic species suggests that either deer or sheep may harbor parasites that do little damage to themselves but great damage to the other species. However, less than half a dozen species caused major damage to either host. Physiological differences seem to restrict or even prevent actual transfer of several gastro-intestinal nematodes from one host species to the other (Baker et al 1957).

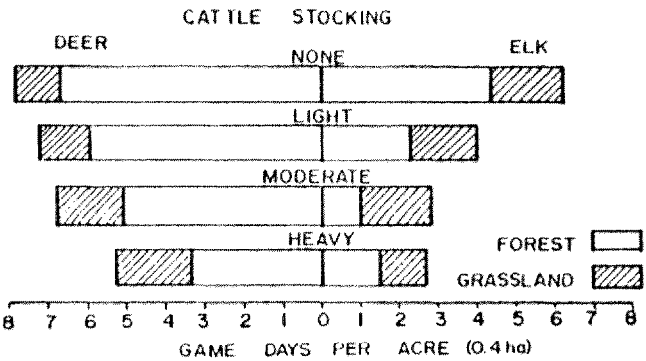

Figure 15-2 Effect of summer forage utilization by cattle on use by deer and elk grazing during different seasons (Skovlin et al 1968).

Brucellosis, or contagious abortion, may be one of the more troublesome diseases that appear when wild and domestic species graze together. This disease occurs in wildebeest, zebra, giraffe, hartebeest, and eland in Africa; and in bison and elk in North America. Neither the seriousness of the disease to each wild species nor its transferability to other species, including domestic animals, is well known. For example, the bison herd in Yellowstone Park has brucellosis (Tunnicliff and Marsh 1935), but the herd almost never contacts domestic animals because fall and spring migration patterns keep the bison away from livestock. Other bacterial diseases common to wild and domestic animals include anthrax, hemorrhagic septicemia, tuberculosis, and tularemia.

Anaplasmosis, a widespread protozoan parasite of red blood cells, occurs in cattle and deer in warm climates of the United States (Stiles 1942). Under natural conditions, external parasites, mainly ticks, transfer it from infected or carrier animals to healthy ones. Deer, at least the Colombian black-tailed, constitute a reservoir of the disease. Values of deer for hunting and viewing preclude reductions to achieve anaplasmosis control, especially since the danger of transferring the disease to cattle cannot be assessed with accuracy.

Four viral diseases of game and domestic animals in East Africa are relevant to the proposals for ranching mixtures of species (Plowright 1968). Rinderpest, more or less continuously present in the tropics and subtropics, potentially is the greatest killer of cloven-hoofed animals. Domestic animals can be immunized against rinderpest, but in wild animals the disease remains uncontrolled. Quarantine against this widespread and widely feared disease and foot-and-mouth disease prevents import of uncooked meats and other animal products from entering many countries. Signs of these two viral diseases appear in a wide spectrum of domestic and wild species.

Two other viral diseases, African swine fever in the giant forest hog, bush pig, and warthog and malignant catarrahal fever in wildebeest, cause no visible symptoms in those animals. However, domestic pigs and cattle are highly susceptible, having mortality rates as high as 95 percent. Transfer of the viruses from wild to domestic animals can be prevented through isolation of the domestic from the wild species.

Trypanosomiasis control in Africa illustrates the complicated nature of disease problems on extensive rangeland. Techniques of control have included removal of the game reservoir; removal of humans until the infecting trypanosomes disappeared; removal of tsetse flies through trapping, insecticides, and habitat manipulations; treatment of infected animals; and development of resistant animals. None of these have been completely successful.

Changing from sheep to Indian cattle may eliminate problems of foot rot, certain ticks, and blow flies. Since Indian cattle are more resistant to tropical parasites and diseases than are temperate breeds, much effort in the tropics aims at establishing hardier cattle breeds by combinations of various Bos indicus blood lines. While the presence of disease in any animal or species is potentially dangerous and must be of concern to game and livestock managers alike, evidence suggests that the threat of transfer of most diseases between domestic and wild animals is not great. Transfer has become less prevalent since the advent of vaccines such as those for trypanosomiasis, brucellosis, and rinderpest, and effective tick control. Management of mixed species requires continuous attention to disease problems.

Poaching

Managed production of any animal is always subject to thievery, whether the situation is one of snaring a wild animal in violation of game laws, cattle rustling, or taking of a pet in a metropolitan area. Both wild and domestic animals remain tempting and frequent targets for poachers, who take animals for their own food, for profit, for spite, and for sport.

Poaching seriously restricts the management of wild species for two reasons. Because the number of poached animals is unknown, poaching prevents accurate determination of population sizes, increase rates, and harvestable off-take. Also, poaching loss decreases profit by increasing costs and decreasing returns. Preservation of diminishing species, game ranching, and cropping of wild animals require prevention of poaching.

Predation

Losses to predation in the 17 western states in 1977 were estimated at 4 to 8 percent of the lambs, 1.5 to 2.5 percent of the ewes, and less than half a percent of the calves (Wade 1982). These numbers translate into losses of many millions of dollars to the producers. The principal predators are domestic dogs, coyotes, black bears, mountain lions, bobcats, foxes, golden eagles, and vultures. Toxic chemical control methods were prohibited by EPA and Presidential orders in 1972.

Predation on grazing animals is a part of the natural system, whether the predator is a human or an animal of the range. For people to profit most from their husbandry, they must eliminate or reduce competition from the wild harvesters. They are subject to elimination through diminishing habitat, fewer prey, and direct human efforts. Species differ in their ability to meet these increasing pressures. The coyote, for example, does well in close proximity to population centers, but the wolf and grizzly bear have been eliminated from most of North America. Mountain lions in the western United States will take pet dogs from the homestead. Losses of sheep by an individual rancher to uncontrolled predators may be over 10 percent of the herd.

General attitudes toward predators resemble those toward other wild animals: They are protected by law and preserved in parks and reserves. Game ranching may be allowed to take certain nuisance individuals but other animals are not the be touched. The problem animals are the ones to be eliminated (Leopold et al 1964). Even the widespread taking of sheep by coyotes (as much as 90 percent of the total losses) may be reduced by repellents and other protective techniques without overall coyote extermination. Extensive control of all predators increased fawn production of whitetailed deer by 70 percent and 43 percent in two consecutive years but had no discernible effect on quail, rodents, and lagomorphs in south Texas (Guthery and Beasom 1977).

Intensive livestock/game programs cannot tolerate much loss to predators. However, livestock raisers have been prone to condemn all animals when only a few individuals prey on their livestock. Most individuals feed on competing herbivores such as rabbits, rodents, and other native animals. Coyote control in cattle country is seldom needed, and, if trouble develops, it is likely to be with one or a few individuals. Sheep, are much more susceptible than are cattle to predation by coyotes. Government and conservationist support for selected control in problem situations could maintain both predatory species and profitable husbandry.

The domestic dog is one of the most troublesome predators on rangeland animals including livestock. Many people in the world make little effort to control their dogs, with the result that some become hunters. One grazing experiment in Israel which used sheep in small flocks also had dogs in one or more of the adjacent ungrazed pastures. These animals, known as **anti-dog dogs**, were trained to bark as a warning to the shepherd when other dogs approached. The Great Pyrennes and Komondor dogs appear to be the best breeds for protection of sheep, but many individual dogs of numerous breeds including mongrels have given rise to anecdotal success accounts (Green and Woodruff 1987).

An interesting experiment was the bonding of sheep to cattle by placing young lambs in close association with heifers. As the sheep grew older, they grazed close to cattle, even in large pastures. The presence of the cattle reduced sheep loss to coyotes (Hulet et al 1987).

Although expensive, fencing against predators of the dog family provides effective longterm control. Predator fences must have the lower wire buried in the ground and carefully maintained to prevent burrowing beneath the wire, but need not be stronger than fences to keep out deer and rabbits. Fences against cats must be higher than those for dogs and must have a device to prevent climbing.

Electric fences have had mixed success in controlling coyotes. Fences against them need aprons and overhangs to prevent crawling under and climbing over (Thompson 1979). However, Dorrance and Bourne (1980) claim reduced predation with alternating plus and minus wires 15 cm apart. Gates et al (1978) gives a design and evaluation of an anticoyote electric fence. It took 12 wires (alternated charged and ground) 168 cm high and 13 to 15 cm spacing or 4 to 5 strands offset 13 cm from existing woven wire fence to stop coyotes (Linhart et al 1982). This is high cost so the need is for application on land with a high stocking rate.

Australia has a number of barrier fences to protect sheep from dingo predation and to prevent emus from grazing range forage and planted crops. The longest of these "dog" fences is some 8,500 kilometers. This fence forms a major boundary between the dingo area used for raising cattle and the sheep region (McKnight 1970).

A fencing program to exclude predators often inadvertently includes a number of them within the enclosure, especially nocturnal species such as coyotes, jackals, and hyenas. Quick elimination of enclosed predators prevents large losses. Enclosed prey species become highly vulnerable because fences restrict their movements. For example, jackals and hyenas killed several fully grown Thomson's gazelle in the beginning of fenced experiments in Kenya. Survival of blesbok young near Pretoria, South Africa, increased from 37 to 85 percent when blackbacked jackals were removed from their pastures (du Plessis 1970).

Predation of duck nests in grasslands is very high. The worst predators are red fox, skunk, raccoon, badgers, and coyotes. Others are crows, raptors, and snakes; however most destructive of all is the reduction of nesting habitat and protective cover by farming practices and overutilization of forage in the nesting season.

Observations of predator behavior and analysis of recorded kills by predators in Kruger Park, South Africa, suggest that populations of predators are controlled by intraspecific densities that affect reproductive rates and survival of young (Pienaar 1969). Other controlling factors include cannibalism, flood, fire, army ants, disease, injuries inflicted by the prey, and parasites, much the same factors that control numbers of prey animals.

The need for a program to cull herbivorous animals in Kruger and other parks indicates that predators alone cannot maintain a balance between the prey species and their habitat. Much predation has little depressing influence on the prey populations, since losses from different causes tend to compensate each other and to increase reproductive rates. In parks and game reserves, the herbivores are more likely to reach overpopulation levels than are the carnivores. Except for elimination of troublesome individuals, carnivore control should be avoided.

Poisonous and Injurious Plants

Losses from poisonous plants occur in addition to death through birth defects, decreased weight gains, and debilitation. Some of these losses are obvious but others are difficult to detect and evaluate (Nielsen 1978).

If rangeland is properly maintained in excellent condition and not overutilized, losses from poisonous plants are usually light. An exception is the danger to cattle from *Delphinium* on good condition high mountain meadows. Heavy utilization rates increased incidence of poisoning regardless of the grazing system (Merrill and Schuster 1978, Quinton et al 1989). Poisonous plants are mostly unpalatable, the toxin decreases with plant maturity, and many grow in the early spring. Exceptions occur to all three generalities. Potential trouble for cattle always exists where poisonous varieties of *Delphinium* occur, but sheep can safely graze there. In contrast, sheep are more susceptible than are cattle to some species of *Lupinus*. *Oxytropis sericea* seedpods were found to be selected at the immature stage by cattle (Ralphs et al 1987). Two grazing strategies are suggested: Restrict access at that time or use many animals so that none gets a lethal dose (Ralphs 1987). Losses of sheep to *Halogeton* are heavy and widespread. Published accounts of plant poisoning of wildlife are rare. Wolfe and Lance (1984) reported locoweed (*Oxytropis sericea*) poisoning of elk and pronghorn.

James and Johnson (1976) described the major plant toxicities and gave a few examples as follows:

Major Plant Toxicity	Examples
Teratogenic effects	*Veratrum californicum* *Lupinus sericeus* *Lupinus caudatus* *Astragalus* spp.
Loco symptoms	*Astragalus* about 13 species
Selenium poisoning	*Astragalus* about 21 species
Larkspur alkaloids	*Delphinium* tall and low species
Cicutoxin and coniine	*Cicuta* spp.
Pyrrolizidine alkaloids	*Senecio* 3 species *Crotalaria* *Heliotropium*
Sesquiterpene lactone	*Helenium hoopesii* (Sneezeweed) *Hymenoxys odorata* (Bitterweed)
Cyanide	*Prunus virginiana*
Oxalate	*Halogeton glomeratus*
Nitrates and nitrites	*Amaranthus* spp.
Photosensitization	*Hypericum perforatum* *Tetradymia glabrata*
Abortion	*Pinus ponderosa*

Bailey (1978) gives lists of range plants that affect several body systems including cardio-pulmonary, nervous, gastro-intestinal, renal, hepatic, musculo-skeletal, and reproductive. Adequate examinations of these systems are best accomplished at the time of death.

Mechanically injurious plants cause shifts in animal species grazing certain ranges. *Erodium* seed in California fouls the wool and burrows through the skin of sheep. *Heteropogon contortus* and some species of *Stipa* are especially bad in that respect. Large increases in *Heteropogon* following thinning of *Eucalyptus* forests in east central Queensland, Australia, forced many ranchers to change from sheep to cattle. Noxious plants which have properties more damaging to one kind of animal than to another determine, or at least influence, the mix of species.

To reduce animal losses from poisonous plants, the manager needs to know the plants and the symptoms caused by each, avoid placing hungry animals where the plants are abundant, eradicate or reduce the abundance of poisonous plants, provide adequate water, salt and supplements, and keep the vegetation in excellent condition by avoiding overutilization. **In some situations, changing the kind of animal is the best control of losses.**

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16

Seasonal Management

Seasonal management implies that whether a range is being used by livestock, wild animals, or people, the use is restricted to a specified time. However, the emphasis of this chapter is on seasonal grazing which restricts that concept to grazing and browsing animals, either domestic or wild. The principle applied is that forage plants respond differently to defoliation during different parts of the forage year, the subject of an earlier chapter; and its corollary: A vegetational type is best suited for grazing during a certain season. **The seasonal grazing technique applies grazing and nongrazing or use and nonuse in some type of rotation.**

SEASONAL SUITABILITY

As defined in Jacoby (1989), terms like "seasonal distribution" and "seasonal zone" seem to apply primarily to range animals or areas. For example, modifiers of the word "range," such as **spring, spring and fall, summer, winter,** and **yearlong**, define areas that are grazed primarily during those seasons. **Summer range** may be in mountains at high elevations or in climates where grazing is restricted to summer. The sagebrush/grass type is frequently called a **spring and fall range,** because animals used it before they were moved to summer range in the mountains and during their return to lower elevations in the fall. Many sagebrush/grass ranges are used efficiently and safely in both summer and winter by application of grazing systems or schedules and other management practices.

These rangeland suitability terms imply that an optimal grazing season exists for many range types, although grazing often was not completely restricted to the named season. As fewer livestock use public summer and winter ranges, experience has indicated that many vegetational types can be grazed safely during more seasons than seasonal suitability terms labeled them. The labels of seasonal distribution and zones convey a combined vegetative suitability for grazing and for ranch operations.

Two synonymous terms in Jacoby (1989) are **seasonal grazing** and **seasonal use**. As therein defined they confuse the land-characteristic concept as given above and the grazing system concept that is accomplished through the use of rotating grazing and nongrazing. This chapter emphasizes the type-of-rangeland application of both terms. The two following chapters are about the management of grazing systems, plans, or schedules of pasture use. Seasonal kinds of range vegetation should not be confused with grazing systems. Nor should seasonal use be given a utilization or a meaning of "how much." Most grazing systems are broader than vegetation. They must also include economic, sociological, and political considerations of ranch and allotment management.

Variations in Growing Period

An earlier chapter described plant responses to defoliation at different points in the growth cycle. Some plant species, and hence some range types are damaged more by grazing at certain times of the year than by grazing at other times. Conversely, other species show little differential response in herbage growth to moderately intensive defoliations throughout their growing season. Therefore, seasonal grazing may foster range improvement in one range type but change another hardly at all.

Grasses respond to defoliation by changing proportion and biomass of leaves, stems, and seeds. Generally, herbage removal within the rapid-growth periods reduces total growth more than at other times. Single, early defoliation does little damage to plant vigor if sufficient soil moisture is available for regrowth. Repeated early defoliations are destructive. The opportunity to improve range by correlating grazing use with vegetational phenology varies from one vegetational type to another.

In temperate regions with dry summers, the rapid-growth period occurs in spring after temperatures become warm. In semidesert grasslands of the southwestern United States, late-summer rainfall results in rapid late-summer growth. A mixture of species maturing in cool and warm seasons grow in the true prairie of central North America, where a combination of spring soil moisture and summer rainfall fosters a long growth period and a wide range of plant maturity dates.

In annual grasslands of the Mediterranean climatic type, growth begins at the start of winter rains and ends when summer arrives. Since there is a new generation of annual plants from seed each year, no possibility exists for plants to develop vigor that carries from one year to the next. Maintaining a desirable botanical composition in the annual grasslands depends almost entirely upon intensity of utilization and very little upon season of grazing.

Since seasonal differences in plant development vary by location, seasonal grazing schedules must be correlated with the growth characteristics of the particular species and vegetation at hand. No grazing plan is likely to have worldwide application. The expected vegetational composition as well as animal production from a specialized grazing plan must be carefully determined for each region or even for each ranch. For example, one grazing plan may be used to increase cool-season grasses over warm-season species in the true prairie, while a second plan does the opposite and the third favors both plant growth patterns but in different pastures.

RANGE READINESS

Range readiness defines that point in the plant growth cycle at which grazing may begin without permanent damage to vegetation and soil. It implies that earlier grazing will cause range deterioration and that little feed will be available. During the early history of rangeland grazing in the United States, severe vegetational destruction resulted from intense, continuous, and often-repeated early grazing when green growth first appeared and from trampling damage. To counter that situation, guidelines to range readiness were developed for much of the forested rangeland in the Western States (Table 16-1). These standards indicate that grazing without damage to the range may begin (1) when certain showy spring flowers are fading; (2) when growth by key perennial grasses has reached a stipulated height or number of leaves; and (3) when a standard proportion of full growth has been reached. Normally, these phenological stages indicate soil moisture sufficiently low to prevent large animals from making deep tracks.

Movement of animals from one pasture to another, time of fertilizer applications, haying operations, and other events in the annual livestock management operation are dependent upon vegetational conditions. Whether it is called **range readiness** or by some other name, the concept of starting management practices at the right time is desirable.

Only a few countries other than the United States have made use of the range readiness concept. Native pastures in Switzerland are ready to graze when *Taraxacum officinale* begins to flower, and hay is ready to cut when *Chrysanthemum leucanthemum* flowers (Caputa 1968). Where domestic animals graze yearlong, the question of range readiness in the sense of a beginning time or turnout date for grazing does not arise.

Therefore range readiness has received little attention in the subtropical and tropical rangeland regions.

Table 16-1 Selected examples of range readiness for national forests in California (Wood et al 1960).

Achillea lanulosa	Leaves 5-10 cm; flowers in bud
Agropyron spicatum	Leaves 10-20 cm
Amelanchier alnifolia	Current twigs 5-10 cm; leaves 50% developed; buds opening
Balsamorhiza sagittata	Leaves 3/4 developed; buds opening
Cercocarpus betuloides	Twigs 5-10 cm; leaves 50% developed; flowers in bud
Erodium cicutarium	Plants 5-10 cm tall; flowers in bud
Festuca idahoensis	Leaves 7.5-10 cm; flowers in boot
Koeleria cristata	Leaves 12 cm; panicles mostly emerged
Poa secunda	Leaves 5-7.5 cm; heads all emerged
Prunus emarginata	In partial leaf and flowering
Purshia tridentata	Full leaf; twigs 7.5-15 cm; flowers opening to full
Ranunculus occidentalis	Plants 30-40 cm; flowers faded
Symphoricarpos albus	Leaf buds opening; flowers in bud

Range readiness guides are useful where the beginning of range grazing is completely controlled, as on public lands of the western United States, where severe weather prevents winter grazing. Federal lands grazed according to a permit have a turnout date stipulated in each lease. This date represents an average of yearly variations in range readiness dates. The practice is for lessor and lessee to decide each year upon the actual opening date of grazing according to vegetational development.

Ranch managers often are impatient with range readiness dates on Federal land, claiming that the ranges should be grazed earlier. Clipping studies have tended to support the contention that early grazing is not damaging if perennial grasses are given relief from grazing during culm elongation and maturation. Beginning use at the earliest time that will not damage the range relieves dependence on costly conserved feeds, grain crops, and planted pastures. Minor damage from early grazing that cannot be avoided usually can be corrected with grazing plans, adjustments in stocking rates, or other management practices, not the least of which is seeding of early-growing species to be used only for early grazing. With the advent of sophisticated grazing management, attention to range readiness has become less important.

Plant species vary greatly in their ability to withstand early grazing. *Agropyron desertorum* is much less sensitive to early use than is *Agropyron spicatum* (Caldwell and Richards 1986). Spring grazing of the former should be set by animal welfare or when livestock can get a full feed each day. Sharp (1970) suggested that *A. desertorum* seedings had reached that point when the standing crop amounted to 225 kilograms dry matter per hectare and the daily increment had reached approximately 11 kilograms. Before that time, animals will have difficulty obtaining a full feed from young grass. The suggested daily increment is approximately the daily intake per animal unit.

YEARLY CYCLES

As indicated above, range vegetation presents a wide variety of growing periods from place to place and of optimal times when the range can be used. Production and development vary in response to climate, but regardless of these perturbations, a number of annual cycles occur. All mature grazing animals must eat about the same amount every day for efficient growth but the total herd requirements are greater at certain times than at others. Rangeland does not always supply that amount; nor is the feed of the same quality throughout the year. Within a year, the manager is faced with making the best of cyclic situations in the daily increment or loss of forage, the quality of forage available, and the demand for feed. These cycles overlap.

Forage Supply Cycle

Daily increments of herbage on rangeland are small at the beginning of plant growth. They increase rapidly during a short period of flush growth and cease at plant maturity, when the standing crop is usually near its peak. Upon maturity, there begins a period of decrease in herbage supply, whether or not the range is grazed (Fig. 11-1). This decrease is the result of shattering of seeds; leaching by rain and snow; breakage of leaves and stems by wind; grazing and breakage by insects, rodents, and birds; and decomposition. In many vegetational types, the whole herbage crop disappears in a year because of these factors. In others, a mulch will accumulate, but in all grassland and forb types the turnover of organic matter is rapid. The rate of disappearance increases with moisture supply and temperature. **This cycle goes on whether or not the manager allows animals to harvest some of the feed; it is harvest the feed or lose it.** Except for some meadows, irrigation on rangeland is not possible and forage cannot be conserved by mowing. The manager of grazing is very much at the mercy of this natural cycle.

Forage Quality Cycle

A second cycle of major concern to management is the nutrient quality of the feed. **New growth is high in percentages of crude proteins, carbohydrates, vitamins, and water on a dry-matter basis, so it must be low in fiber, lignin, and those items that generally suggest low nutritional quality. As the growing season progresses, these two groups of substances gradually reverse their positions.** Poor-quality feed results after plant maturity. Fine grasses and short species often retain greater nutritional quality when cured than do tall, coarse grasses. In all range types, the quality of feed after plant maturity decreases for larger herbivores as the available quantity of forage decreases.

During the early part of the growing period, especially in mornings with heavy dew and after rain, the water content of young forage may be so high that an animal cannot consume enough dry matter to be properly nourished. At these times, the highly favorable content of crude protein, as determined on a dry-matter basis, may not accurately measure feeding values. Usually the weight of desirable nutrients per hectare reaches its peak near the time of plant maturity, but percentages in the feed have decreased by that time. Conversely, the amount of nutrients per hectare is low during the early growth period when dry-weight percentages of nutrients are high. Both amounts and percentages are low after leaves have matured and shattered or have been leached by rain.

Forage Demand Cycle

A third cycle of concern to range managers is the amount of needed forage (Fig. 11-1). An operation that runs cows and calves or maintains a breeding herd of any species must provide feed yearlong. The amount needed for each mature animal changes only slightly from day to day as requirements vary for pregnancy, lactation, growth, fattening and general good health. Normally, as young animals grow, the demand for high-quality feed increases, thus there are peak needs at or near sale time. When animals are sold, the total demand for feed in the operation takes a corresponding drop. Other types of producing systems, steer production for example, need larger quantities of feed for shorter periods and may not require feed for certain parts of the year when no animals are present.

MANAGING WITHIN THE CYCLES

The grazing management aim is to combine the cycles of forage supply, quality, and demand to obtain the highest profit from the livestock operation and greatest good from other uses, all consistent with maintaining excellent condition range. Although the cycles describe continuously changing situations, their union is divided into four periods for the matching of periods of grazing and nograzing with the forage resources and the forage requirements.

Period 1

This period begins with the start of plant growth. The vegetation produces inadequate green forage to meet all the demands of grazing animals. It is a time of slow herbage increment per day. Animals avidly seek the new green material, but its low availability forces heavy grazing use of old growth. Much care should be taken to prevent overuse and trampling of wet soil during this period because new growth can be reduced rapidly and the capacity of the plants to recuperate may be endangered. The concept of range readiness resulted from concern with too early grazing that also was too intense.

Specialized grazing plans that concentrate livestock in a few areas and rotates them among pastures tend to foster overuse or at least heavy grazing pressure during Period 1. The manager must redress the balance between green-forage supply and animal needs on a daily basis to avoid damaging the range more in this period than can be repaired in later ungrazed periods. Bunching of animals provides less available green feed per animal during this period of scanty supply. Widely spaced animals often show more weight gains in the early growing season than those in rotations. They have more feed available and more chance to select quality feed without so much competition from other animals.

Research support for this hypothesis is found in several studies that indicate highest animal gains when a certain amount of feed is available per unit area.

Period 1 is a time when the manager often pushes his interlocking cycles to the limit. The need is for less expensive range forage as a relief from winter feeding of hays and concentrates. Young animals and lactating mothers need high-quality green feeds for rapid production. Bunching of animals may accentuate the possibility for stress on both the livestock and the range. So that possible damage can be relieved, the grazing time in the rotations should be shortened or the animals distributed in several pastures. In yearlong grazing situations, the beginning of Period 1 is a time to start rotations and to move animals rapidly. Often, a rainfall that wets the soil several inches and a rise in temperature signal that time.

Period 2

Period 2 is the span of time when demand for and growth increment of forage are about equal. It is often referred to as the fast growing season or optimum grazing season. This period is short, perhaps no longer than a week or two, on most rangeland. In contrast, on improved pastures, where the manager has more control over daily herbage production by using planted species, fertilization, and irrigation, there is a long period when increment and demand are similar. If forage production on irrigated pastures becomes too rapid, the manager harvests and conserves quality forage as hay; a practice not available to rangeland grazing.

Period 2 is difficult to define, but it appears to begin with the start of rapid growth of range vegetation. It is a key time for moving of animals in specialized grazing plans. The pasture that animals leave must have time for plant regrowth and maintenance of vigor. The plants in the receiving pasture are past range readiness and they are beginning to grow faster than they are being grazed. Moderate defoliation is of little consequence to their vigor.

Period 3

Period 3 is that part of the growth cycle when daily increment of new herbage exceeds demand. It is the flush growth period. Many rangelands with low rainfall have short and rapid growth periods. With high rainfall rapid growth may occur over a long period of time as in tropical areas. Period 3 is the span of time when ungrazed forage is accumulated for later use, either as cured standing feed on the ground or as hay. This is a period when grazing time is increased in some pastures, and other pastures go ungrazed for one or more rotations.

Rangelands receive little overuse during this period unless too many animals are concentrated in a pasture and left there too long. If herbage is accumulating, grazing pressure is light and the possibilities of range damage slight, in contrast with Period 1.

Clipping treatments in Period 3 that remove herbage to a low stubble height too late for regrowth have shown that vegetation can be damaged by defoliation at that time. Such a situation can be duplicated in grazing systems. When large numbers of animals are kept in a small area, other pastures are ungrazed. Without extremes of animal concentration and forage utilization during Period 3, it would seem that the schedule of grazing would make little difference to either plant vigor or animal production. Probably the favorable responses of animals to season-long grazing results from low grazing pressure during Periods 2 and 3.

Period 4

This is a time without forage increment and with considerable natural herbage losses, including gradual loss of nutrients. It is the dormant season for plant growth. Demand for forage by domestic animals is ordinarily reduced at this time by sale, but needs of wild herds remain high and may increase. Before the end of Period 4, hunting, losses to predators, disease, and lack of feed normally will have reduced the wild animal populations to their annual low. Period 4 ends when Period 1 begins a new cycle.

Grazing consequences on mature vegetation generally are considered minimal. However, trampling, reduction of stubble heights, changes in litter amounts, and laying of standing dead material may profoundly influence the next crop through altering the environment near the soil surface. Effects from the absence of grazing, overgrazing, and rotation of grazing during Period 4 are unclear. Much research testing is needed on this point.

Comparisons Among Periods

The highest animal production probably comes from complete utilization of forage during Period 3. With this plan forage would be used when it was palatable and when it had the highest yield per hectare of dry matter with adequate nutrient content. Summer ranges in mountainous areas frequently are harvested in Period 3, and livestock on any ranch may graze all the feed from a pasture or two at this ideal time.

However, ranches that maintain breeding herds normally graze the range during all four periods. Any problem of maintaining a yearlong balance between feed supply and needs must be met. An important aspect of good management is that numbers of animals and the time they are allowed in each pasture are such that overgrazing is minimized at all times. If overgrazing cannot be avoided, the overused areas should be allowed periods of recovery without grazing. Grazing systems or schedules based on the four seasonal periods constitute a tool for rangeland and range livestock management.

NEEDED INFORMATION

If one accepts the proposition of Periods, whether four as used here or a different set, they can be used as hypotheses to test the effects of grazing at certain times in the forage year. These would be the effects of **repeated seasonal grazing**. Few field or practical answers to the relative damage by grazing and improvement by nograzing during different parts of the forage year have been evident in the traditional testing of grazing systems. The vegetational response of each pasture treatment needs to be made.

MANIPULATION OF GRAZING PERIOD

The manager of livestock in a grazing system has several ways to manipulate the interrelations between vegetation and animals. The response of each is in part a function of the other. Decisions should consider all the possibilities, as follows:

- To graze a pasture or not to graze it is one decision. This entails evaluation of forage supplies in the occupied pastures as well as those in the pastures to be occupied, which in turn requires analysis of forage and livestock decisions through the periods ahead. Reduction of animal losses and range condition in dry years, forage losses in wet years, and improvement of range condition are major considerations.
- The parts of the forage year or when to graze is the second item of manipulation. For example, should a particular pasture be grazed in the early or late part of the growing season.

- Consideration for the length of the grazing period follows those mentioned in the two preceeding paragraphs. This decision often depends upon the amount of forage available, the time in the forage growth cycle, and the number of pastures available. A part of this decision is based on the time required for nograzing to be effective in vegetational improvement.
- The density of animals or the number at any time per land unit is largely a function of the number of pastures. The effects of high and low density on vegetation and animals are mostly determined by the time in the pasture or degree of forage utilization. Claims have been made concerning social needs and stresses among the animals at different densities.
- Adjustment in kinds, classes, and number of herds is another factor in the management of seasonal grazing. Kinds of animals are seldom changed but classes and herds frequently vary. These adjustments are due to changes in numbers to meet market conditions, problems of cash flow, and other needs in the ranch business.

Although each vegetational type may have an optimum time for grazing, many factors necessitate use at other times. Seldom can an optimum green-feed supply grow in concert with the daily need for feed. Therefore, every grazing schedule that takes advantage of an optimal grazing season in one place normally includes less than ideal seasonal grazing in another. In practice, "optimal grazing" is rotated with grazing at less than optimal times. In order to minimize grazing damage as well as maximize range improvement over the rangeland as a whole, care must be given to the balance between vegetational improvement during nongrazing and damage to the grazed pastures.

The need to keep specialized seasonal grazing plans coordinated with the cycles of forage demand, supply, and quality is obvious. Dates of grazing and stocking rates should be planned to meet expected needs and emergencies that may arise. The manager should not hesitate to combine different grazing plans to take advantage of all kinds of available feed. Grazing systems and schedules improve effectiveness of these changes, but flexibility in their application is crucial.

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17

Grazing Plans

The objectives of this chapter are to define terms used in seasonal grazing management, and to present the objectives and design of selected grazing plans. Responses of animals and vegetation to those plans are in the next chapter. Each term is limited to a single concept and designed for broad rather than for local or regional application. For these reasons. the definitions differ from those in the Jacoby (1989), Trollope et al (1990), and Allen (1991).

OBJECTIVES OF SEASONAL GRAZING PLANS

The objective of seasonal grazing plans may be any one or combination of the following:

- To improve range condition including attainment of less erosion, to increase soil cover, to provide fuel for prescribed fire, to maintain and increase plant vigor, to obtain seed and seedling establishment, to promote vegetational succession, and others associated with proper stewardship of the rangeland resources.
- To achieve regular distribution of grazing animals through careful attention to pasture size and shape.
- To promote uniform forage utilization by reducing selectivity of forage.
- To coordinate domestic animal grazing with habitat needs of wildlife and other uses of the land.
- To increase animal performance either individually or in terms of production per land unit, thereby increasing ranch income and decreasing costs of pest control, supplemental feeding, and labor.
- To increase flexibility and decrease risk in the ranch operation.
- To improve quality and quantity of forage and provide reserve feed for emergencies.

HISTORY OF GRAZING PLANS

The **Hema System**, gradually regaining support in the Middle East, predates the Islamic era and has been in use for centuries. The system protects and harvests the rangeland resources in five ways as follows (Draz 1978):

- During drought times, animal grazing was prohibited but cutting of grasses was permitted by certain people.
- Grazing and/or cutting were restricted to certain seasons.
- Grazing was allowed yearlong but the kind and number of animals were specified.
- A reserve was held for bee-keeping but grazing was permitted after flowering.
- Forest trees were protected.

Active ahemia (plural) occur in Saudi Arabia, Syria, Lebanon, Tunisia, and other Middle East countries. They are commonly recognized as grazing cooperatives.

Rotational grazing has been advocated in Europe for over 200 years and in southern Africa since 1887, but not widely accepted in Australia (Roberts 1986). However, Peter Waite in Australia divided his 260 square kilometer area into 16 paddocks following importation of almost 300 tons of wire in 1869. Included in the ADELAIDE OBSERVER description of his management in 1896 was the phrase "for resting of pastures in rotation" (Lange et al 1984). Mathews (1956) described the beginning in 1927 and many revisions of a holistic range improvement plan on his ranch in South Africa. This ranch, "Tukulu," became a much publicized show piece of excellent range management as a total ranch system.

Jared Smith (1895) first suggested seasonal grazing plans on rangelands in the United States, when he advocated rotation grazing as one means of improving range conditions in the southern Great Plains. Sampson (1913, 1914) after considerable ecological research in the Wallowa Mountains of Oregon, recommended deferred-rotation grazing as a general practice. Shortly thereafter, Jardine (1915) and Jardine and Anderson (1919) presented that schedule in diagram form and suggested it for use on national forests. Since that early beginning, evolution in design of plans and seasonal grazing effects have been the subject of considerable discussion, research, and argument, with gradually increasing acceptance.

A rationale for seasonal grazing is that many grasslands in the world evolved under intermittent grazing pressure from migrating herbivores, for example, bison in North America and wildebeest in East Africa. These animals used a given range during a short period, perhaps overused it, then moved to a new range in patterns that were more or less repeated yearly. Migrations became fixed in the behavior of many species and, consequently, exerted seasonal grazing pressures to which vegetation became adapted through natural selection.

Not all animals migrated, or if they did, in an irregular pattern. Some species moved at random, others remained in a location to graze yearlong; hence examples of repeated seasonal grazing, rotational grazing, and yearlong grazing in wild animal populations. Many designs of seasonal grazing plans developed as land managers attempted to fit their domestic animal species into naturally evolved plant and animal systems. A long-held and questionable belief is that grazing patterns should be as near as possible to those under which the vegetation evolved.

TERMINOLOGY OF SEASONAL GRAZING TREATMENTS

Terms dealing with seasonal grazing plans have been loosely defined and irregularly used. "**Treatments**" in the sense used here are the **types of grazing** applied to a pasture; thus a simple rotation plan may contain two treatments, grazed and ungrazed with calendar days defining each and the rotation.

Confusion About Deferment, Rest, and Ungrazed

"Deferment" in the Glossary of Terms (Jacoby 1989) can mean no grazing until "plant reproduction is complete, establishment of new plants, or restoration of vigor." Allen (1991) gives the definition as "delay of grazing to achieve a specific management objective," which includes Jacoby's (1989) three items and adds "return of environmental conditions and accumulation of forage for later use."

"Rest" in Jacoby (1989) "implies absence of grazing for a full growing season or during a critical portion of plant development such as seed development." Allen (1991) gives the definition as "ungrazed for a specific time such as a year, a growing season, or a specified period within a particular management practice."

These definitions completely overlap and they are used by many persons as synonyms for any ungrazed period from a day to more than a year as long as it is a part of a management practice. One does not know the meaning from the use of either term without further definition. Each written paper and conversation must define the terms as therein used. The South Africans call any time span without grazing "period of rest" if the purpose is vegetational improvement or "period of absence" if the purpose is for growth of another forage crop in the rotation (Trollope et al 1990). "Spelling" is used in other parts of the world to mean no grazing, sometimes for a year. "Controlled, delayed," and "strategic" also have been used as labels for the ungrazed treatments.

This book uses **deferment in the traditional sense of no grazing until reproduction is completed by the key plants and the pasture is grazed thereafter**. "Rest" in seasonal grazing management first received major attention as a full year of no grazing. The current usage is less restrictive and **rest will be used here to apply to any ungrazed period, except the specifically named deferred treatment. Therefore, "rest" and "ungrazed" are synonyms and should always be given with stipulations of calendar dates.** The terms "no grazing" or "not grazed" may be used.

The two terms, **deferred and rested (not a deferment),** stipulate different periods of no grazing on the proposition that vegetation responds differently to grazing and the absence of grazing at different stages in the growth cycle.

Deferment permits gain in plant vigor, increased seed production, storage of food materials in roots and herbage, and generally improved health of the range. A second consecutive year of deferment permits additional gain in vigor and, presumably, establishment of seedlings from the first seed crop. Improvement of good condition or better perennial grass range by reproduction from seed happens irregularly and is poorly documented. In semiarid and arid regions, gain in vigor may require a number of years of deferment or no grazing at all.

Grazing Season and Grazing Period

The **grazing season is that portion of the year when grazing is feasible and can be accomplished without damage on a specific area.** Throughout the Mediterranean climates, tropics, and subtropics, the grazing season is the whole year; but in cold climates or at high elevations, grazing may be possible for only a portion of each year. The length of the grazing season is controlled by environmental influences on the animals and normally is longer than the plant growing season. Yearlong range has a 12-month grazing season. On public lands, the established time for which grazing permits are issued is the grazing season by regulation or by permit.

The **grazing period for a specific area is the time span of a portion of the grazing season within which grazing actually occurs.** Yearlong range may have several grazing periods. The beginning and ending dates of one or more grazing periods on each land unit are stipulated in grazing plans and they may not be the same from year to year. The term **grazing period** makes no distinction between grazing by different groups or kinds of animals at different times. Modifiers, such as "for cows and calves," can be used to make the meaning more specific.

Continuous and Repeated Seasonal Grazing

Continuous grazing is unrestricted grazing through the whole of the grazing season, i.e. grazing in which the grazing season and the grazing period are the same. Grazing occurs during the whole period that plants are growing as well as during part or all of the dormancy period. In warm climates continuous grazing is yearlong grazing. **Set stocking** is the term employed outside North America.

Repeated seasonal grazing defines grazing a pasture at the same time each year. Migratory game animals usually follow repeated seasonal grazing on a yearlong basis. Ranchers who save pastures for grazing during a certain season each year are using repeated seasonal grazing.

Grazing Plan, System, or Schedule

The above describes the grazing treatments that a pasture may receive. They are continuous, repeated seasonal, deferred, and rested or ungrazed. The ungrazed treatments are many in length and are in addition to the specially named one, deferred. **Grazing plan or grazing schedule stipulates the order in which the pastures are grazed.** Either of these terms is preferred to "grazing system," which has long been in spoken and written usage. A schedule for moving grazing animals from one pasture to another is more appropriately a plan than a system. If **grazing schedule is used the reference is strictly to the time schedule of livestock movement among pastures; otherwise grazing plan is preferred.**

The concepts of **grazing management system** and **rangeland management plan,** as employed here, **encompass the day-to-day seasonal grazing plan and the holistic placement of that plan into a larger context, for example into a whole ranch plan. A grazing management system** might include grazing of improved pastures and crop aftermath, feeding of hay and concentrates, health precautions, vegetational improvements, multiple-use considerations, and ranch finances. **A rangeland management plan** must include resource inventory, planning for range improvements, and scheduling. The planning of allotment management of federal lands, farm and ranch management by the Soil Conservation Service, and of ranches as advocated by Savory (1988) are examples.

Planning and establishment of range improvements are usually needed before a schedule for grazing pastures can be accomplished. Improvements such as water developments and smaller pastures have value in themselves without seasonal grazing schedules. Favorable results from seasonal grazing plans may be from other practices, such as smaller pastures, more water, and better husbandry rather than from the schedule itself. Research has not separated the results of these practices and often favorable results have been attributed to the schedule of grazing alone.

TYPES OF GRAZING PLANS

Nearly all grazing plans that have had extensive use on rangeland in North America have been called "continuous, repeated seasonal, rotation, deferred-rotation, rest-rotation," or "short-duration grazing," almost without regard to their actual design. The types of plans are different mixtures of individual pasture grazing treatments. It is nearly impossible from the published description of most specialized seasonal grazing plans to correlate animal production with forage production and changes in range condition on the separate pastures. Too many factors are unmeasured and uncontrolled.

An example of a grazing plan that combines several pasture treatments is one that contains five pastures and is grazed by two herds. One pasture is rested yearlong, another deferred, a third continuously grazed, and two pastures are in a short grazed/ungrazed spring rotation. Treatments of all pastures change on a yearly basis resulting in all pastures receiving all treatments in a five-year cycle. Such a plan as this might be called either "rest-rotation" or "deferred-rotation." Neither name is adequate, so the plan is commonly called five pasture/two herd plan.

Obviously, one name for all plans is not desirable, nor is a separate name for each of the hundreds of plans that now exist. The 1989 glossary of terms (Jacoby 1989) suggests a uniform format in which every author describes the **grazing plan with at least number of pastures, number of herds, and lengths of both grazed and ungrazed periods. To this should be added number of animals in each herd, size and shape of pastures, and a word on intended degree of forage utilization.** By defining the plan this way, its name becomes less important and confusion is reduced.

Continuous Grazing Plan

Perhaps the simplest of all plans is continuous grazing. it might be called a single-pasture plan. Grazing occurs during all four of the periods described in Chapter 16. Grazing after the growing season depends upon forage accumulated during Period 3, the time of rapid growth. Therefore, pressure on the vegetation must be light in Period 3, and it can be heavy when growth begins in Period 1, as demonstrated by winter use in Mediterranean-type annual grasslands.

Continuous grazing is a pasture treatment that is often included in rotation schedules. Its use has been criticized because grazing occurs throughout the growing season, and it is argued that even light grazing during the growing season encourages repeated defoliation and overuse of the selected species and patches, while others are underused. This uneven distribution can be modified by techniques mentioned in Chapter 13.

The criticism that continuous grazing means complete defoliation is fallacious. It results in any desired degree of forage utilization depending upon stocking rate and stock density. Many areas have been continuously grazed for long periods without permanent damage to the resource.

In tests in which degree of range use has been controlled and proper distribution attained, continuous grazing has shown excellent results. Short grasses, annual grasses, sod grasses, and grasslands with few species of extreme palatability have responded favorably. Unless vegetation and livestock are under stress due to overgrazing, continuous grazing produces as well as any other plan in most situations.

Repeated Seasonal Plans

Seasonal variations in forage resources and animal husbandry may require repeated seasonal use. Vegetational types with coarse, unpalatable herbage and seeded stands of one or two species often are grazed on a repeated period basis. Early growing season or Period 1 grazing of *Agropyron cristatum* and *Agropyron desertorum* is an example of repeated seasonal grazing. Each year, *Distichlis* should be grazed in Periods 1 and 2 because those are the only times it is palatable. Because of differences in palatability and response, *Hilaria mutica* repeatedly is grazed in summer and *Bouteloua eriopoda* in the fall. Still another example is the marsh vegetation along the Louisiana coast, which is winter-grazed each year after fall burning.

Migratory game often graze the same area at the same time each year. Winter deer ranges in the western United States repeatedly are grazed in the same season. Caribou, with their linear routes in Alaska, and wildebeest, with their circular routes in East Africa, follow more or less the same yearly pattern in their migrations, but with some unexplained variations. For example, caribou in Alaska migrate with long treks to their summer range and return to winter range each year. They may follow the same route for ten years, more or less, but change to another route for several years.

Much has been said about rotational grazing of herds of bison in the United States and their tendency to follow circular migratory routes (Matthews 1954). One suspects that they, too, might have followed certain regular routes, perhaps in response to available water and feed, and **might have grazed in about the same place at the same time year after year. This is repeated seasonal grazing** in the sense used here.

Wild animals in natural settings do not follow yearlong rest or deferred-rotational treatments in most instances. Their plan is repeated seasonal grazing. This plan has resulted in excellent range that still supports abundant wild and domestic animals. Overgrazing by wild animals occurs where high animal density persists too long.

Ranchers throughout the world save certain pastures for grazing during the same season every year. They do this because they need to have animals close to headquarters during winter weather, near roads in the spring when the young are born, accessible to water in dry seasons, and feeding on high-quality forage when animals are being readied for market. Some seasonal grazing plans are at variance with the proposition that a range should be ungrazed in Period 3 so that plant regeneration and high forage production can occur. This would suggest that **degree of utilization is more important than seasonal grazing as a range management practice.**

Unrotated deferred grazing on a pasture is a type of repeated period grazing. Common practice in the northern Great Plains is to have animals on the same summer and winter ranges every year. Another excellent example of this type of grazing occurs on the steep slopes and benches in Hell's Canyon of Snake River in eastern Oregon. The canyon furnishes protection from winter storms because it is at a lower elevation than are surrounding ranges and has less snow cover. The result is deferred grazing until late fall or winter every year. There may be grazing in early spring, but none is allowed during Periods 2 and 3.

On mountainous ranges in western Montana, a once-over grazing that followed seasonal vegetational development resulted in more range improvement than did an early, light grazing followed by a second grazing in late summer from low to high elevations (Heady et al 1947).

Generally, repeated seasonal use has not been a treatment included in experiments with grazing schedules. It is a widely used practice that needs measurement. Varying responses to seasonal use could indicate when grazing is damaging to the vegetation and when it is not. Repeated period use could be the control against which other treatments are measured. These kinds of comparisons are needed to furnish the building blocks in designing grazing plans.

Rotation Plans for Specific Conditions

Rotational grazing plans are used in specific rangeland situations, especially in the early growing season, when forage supplies and growth rates are low. Types of rotational grazing plans include daily strip grazing in pastures, short rotations with two or three pastures, and complementary rotations with different species. These short rotations on rangeland usually span growth Period 1 in one cycle. An example of a short-duration plan is a two-pasture switchback arrangement on *Agropyron desertorum* in which each pasture is grazed in early and late spring in alternate years. If three or four pastures are available, the plan employed with this species may be strict rotation of short grazing periods in each pasture (Fig. 17-1). To best use native and seeded ranges, Smoliak (1968) suggested for southern Alberta, Canada, that 20 to 50 percent of the land should be in one or more seeded species and the remainder in native range.

These short rotations with few pastures are often used in situations of repeated spring grazing on turnout pastures before another type of rotation is applied to native vegetation. The yearly rotation of turnout pastures gives each a time without the earliest grazing, thus reducing the chance of damage through overutilization.

Deferred-Rotation Plans

Deferred-rotation grazing signifies that at least one pasture is not grazed until after seed production and another pasture receives the deferred treatment the next year. Thus, three years are needed for a three-pasture arrangement or six years if a pasture receives deferment in two consecutive years. These are long rotations with long grazed and ungrazed periods.

	Range Units		
First Rotation	A	B	C
April 20-30	G	U	U
May 1-10	U	G	U
May 11-20	U	U	G
Second Rotation			
May 21-31	G	U	U
June 1-10	U	G	U
June 11-20	U	U	G

Figure 17-1 A short-term rotation plan on *Agropyron desertorum*, showing each unit grazed twice during the 60-day spring period (Frischknecht and Harris 1968). Abbreviations are G = grazed, U = ungrazed.

Designs for deferred-rotation plans are numerous, and seldom are two alike. Hugo (1968) gave designs for 18 different rotational plans for various combinations of vegetational types and use objectives in South Africa. The simplest deferred-rotation plan employs one herd of animals. The number of pasture units equals the number of grazing periods and the number of years required to complete a rotation cycle. It is normally five or less.

An excellent example of the deferred-rotation plan is the one for yearlong grazing by bison on the National Bison Range in western

Montana (Fig. 17-2). The bunchgrasses, *Festuca scabrella, Festuca idahoensis,* and *Agropyron spicatum,* usually are in flower by the first of June and mature in July. Two pastures, ungrazed until fall and winter (October through March), are deferred each year. The pasture grazed early is ungrazed from July until the next January, a period of 18 months that includes the end of one growing season and all of the next. This is both a deferred and a yearlong rested treatment. The fourth pasture, which is grazed from July through September, may or may not be deferred, depending on the earliness of the growing season. Even in late growing seasons, grazing in this pasture does not damage plant vigor.

The plan tested by Herbel and Anderson (1959) on tallgrass vegetation dominated by *Andropogon scoparius* in the Kansas Flint Hills illustrates the use of ungrazed periods for cool- and warm-season plants (Fig. 17-3). The absence of grazing during May and June and intensive stocking thereafter (unit C, first year) defers use and favors desirable cool-season species that are a part of this grassland. Intensive use in the first half of the growing season followed by no grazing (unit B, first year) favors the warm-season species (Launchbaugh and Owensby 1978).

Opening of all pastures to free-choice grazing in the fall provides livestock full selection of highest quality herbage in the final harvesting and use of regrowth (Auen and Owensby 1988). Fall grazing favors the cool-season species which are more difficult to maintain than the warm-season grasses. Grazing spread over two pastures in May and June is enough to prevent concentrated early use due to high livestock density.

A plan that is called **deferred-rotation grazing** by its author (Merrill 1954) has shown impressive results in Texas and in East Africa. **It employs three herds and four pastures, each grazed continuously for 12 months and ungrazed for 4 months** (unit A, first cycle, Fig. 17-4). The 16-month cycle result is a deferment plus two other ungrazed periods of four months for every pasture during a 4-year period. The grazing is continuous for a year, and only one herd is moved at the end of each period. The rainfall, hence forage growth, is variable but it occurs in each of the 4-month periods. This plan emphasizes an occasional deferment and continuous grazing. Moderate grazing permits litter accumulation and increase of desirable plants (Reardon and Merrill 1976).

Different native species, seeded stands, and range sites have characteristics that require combinations of grazing treatments. A plan for seeded *Agropyron desertorum* and the native bunchgrass type on public domain land in southeastern Oregon illustrates a combination of repeated period grazing and rotation of deferred grazing (Fig. 17-5). Two pastures of *Agropyron* are grazed in a rotation plan during April and May.

	Range Units			
First Year	A	B	C	D
April - June	G	U	D	D
July - September	U	G	D	D
October - December	U	U	G	D
January - March	U	U	U	G
Second Year				
April - June	D	G	U	D
July - September	D	U	G	D
October - December	D	U	U	G
January - March	G	U	U	U

Figure 17-2 A deferred-rotation plan of grazing by bison on *Festuca scabrella* grassland at the National Bison Range in Montana. Abbreviations are G = grazed, U = ungrazed, and D = deferred.

First Year	Range Units A	B	C
May 1 - June 30	G	G	D
July 1 - Late Summer	D	D	G
Late Summer - Oct. 31	G	G	G
Second Year			
May 1 - June 30	D	G	G
July 1 - Late Summer	G	D	D
Late Summer - Oct. 31	G	G	G

Figure 17-3 Two years of application of a deferred-rotation plan for tall-grass prairie in Flint Hills of Kansas (Herbel and Anderson 1959). Abbreviations are G = grazed, U = ungrazed, and D = deferred.

The April grazing begins as soon as feed is available and ends when sufficient soil moisture remains for regrowth of new seed stalks. As a rule of thumb, **sufficient moisture** means at least 30 centimeters of moist soil, which might be as deep as 30 to 60 centimeters. This grazing treatment tends to result in heavy utilization, but it has the advantage of reducing or preventing wolfplants. Reserve feed produced on this pasture can be used in the autumn or in times of late-summer emergency.

The second *Agropyron* pasture is grazed until the utilization is 50 to 60 percent. Then for about a month and a half, the animals are on two native bunchgrass pastures while one pasture is deferred. From July 15 until September 1, all three of the native pastures are grazed. Although dates are shown in Figure 17-5, they are only approximate since the animals are moved on the basis of soil moisture, growth stage, and degree of forage utilization.

Grazing treatments in this plan include repeated seasonal use without deferment of *Agropyron desertorum*, continuous grazing after a delayed spring beginning, and rotation of deferment on native range dominated by *Agropyron spicatum*. This plan takes advantage of early growth and resistance to grazing of *Agropyron desertorum*, prevents all early use of *Agropyron spicatum*, and gives it a further opportunity to gain in vigor with a deferment once in every three years. In practice, the native bunchgrasses have responded rapidly, especially where *Artemisia tridentata* has been reduced.

Rest-Rotation Plans

The original rest-rotation grazing plan (Hormay 1970) had wide acceptance on both public and private land. Of great importance, it is the first plan widely used on western United States public rangelands. Not only did it raise the usage of rotational grazing; it showed that many variations were equally effective.

The plan called for five pasture treatments, or a five-year sequence of treatments on one pasture. The rationale for a single pasture dominated by *Festuca idahoensis* follows: During the first year, close grazing makes full use of all herbage, and standing dead material, if any exists, is trampled. The second year is one of no grazing to restore vigor and litter supply. Deferred treatment in the third year promotes and protects the new seedlings, enhances plant vigor, and grazing animals trample the second seed crop into the soil. No grazing during the fourth year benefits seedling establishment, further promotes vigor, and adds greatly to the litter cover. The absence of grazing until the key grass species have flowered in the fifth year ensures seedling establishment. Afterward the whole forage crop is harvested.

This plan is extreme in that 40 percent of the available land and perhaps 40 to 50 percent of the usable forage are ungrazed every year. It requires a cut in stocking rate because increased grazing pressure on the 60 percent that has to carry the grazing load may do harm that will exceed the benefit that can be gained during the three-year sequence of rest-deferred-rest. In this plan, animals are forced to use forage on two pastures after it has lost quality. If *Agropyron desertorum* occurs in the pastures grazed according to this plan, it tends to form dense clumps of straw called wolfplants during the years of rest. Although the original test of this plan was designed with five pastures, few if any such plans are still in operation.

First Cycle	A	B	C	D
March - June, Year 1	D	G	G	G
July - October, Year 1	G	U	G	G
November - February, Year 1	G	G	U	G
March - June, Year 2	G	G	G	D
Second Cycle				
July - October, Year 2	U	G	G	G
November - February, Year 2	G	U	G	G
March - June, Year 3	G	G	D	G
July - October, Year 3	G	G	G	U

Range Units

Figure 17-4 Two grazing periods per pasture in three years of the three-herd and four-pasture plan used in Texas (Merrill 1954; Keng and Merrill 1960; and Waldrip and Parker 1967) Abbreviations are G = grazed, U = ungrazed, and D = deferred.

	Agropyron desertorum		Native Bunchgrass		
First Year	A	B	C	D	E
April 1 - May 5	G	U	U	U	U
May 6 - June 5	U	G	U	U	U
June 6 - July 15	U	U	D	G	G
July 16 - Sept. 1	U	U	G	G	G
Second Year					
April 1 - May 5	U	G	U	U	U
May 6 - June 5	G	U	U	U	U
June 6 - July 15	U	U	G	D	G
July 16 - Sept. 1	U	U	G	G	G

Figure 17-5 A switchback or two-pasture annual rotation constituting repeated spring grazing of *Agropyron desertorum* combined with rotation of deferred grazing on native range, principally *Agropyron spicatum*, in southeastern Oregon. Abbreviations are G = grazed, U = ungrazed, and D = deferred.

They have been replaced with 3- and 4-pasture plans that rotate early growing season use and deferred treatment among the pastures. Figures 17-2 and 17-3 show two of the possible variations. Occasionally, a full season of no grazing may be included. A survey of the Vale, Oregon, Bureau of Land Management District found that seasonal schedules of livestock grazing were too varied for meaningful comparisons of whole systems. Between 1966 and 1986 the systems had became less complicated with fewer grazing treatments. Nearly all of 144 pastures had improved regardless of grazing schedule (Bartolome and Heady 1988). Flexible deferred-rotation with many variations appears to work best with moderate stocking rates on western bunchgrasses. Semidesert grasslands and shrublands may require consecutive years without grazing to show vegetational improvement.

High-Intensity/Low-Frequency Plans

Other types of rotations on rangeland have been tested in Southern Africa. One such plan was known first as nonselective grazing or the Acocks-Howell plan, in which intensive grazing for two weeks or less was followed by ungrazed periods of six weeks to five months (Acocks 1966). It later became known as high-intensity and low-frequency grazing.

The objective was heavy grazing pressure on a pasture for a short time to reduce the unpalatable species, to reduce competition against the better species, and to prevent grazing on the first regrowth. Long ungrazed periods were to provide ample time for recovery of the desirable species before the pasture was grazed again. In the dry season, the aims were to reduce standing dead material, loosen the soil surface by hoof action, and prevent the development of large ungrazed bunches of grass filled with dead stems. Seed production and seedling establishment were emphasized objectives.

The actual result was extremely heavy utilization of the desirable species and their demise, which was increasingly severe as droughts became more severe. The plan failed and is little used (Howell 1978). The result graphically demonstrated the importance of not overutilizing the desirable species. **Light grazing use is usually selective and heavy utilization is nonselective.** No grazing plan succeeds in eliminating selective grazing (Tainton 1991). Those that do so soon destroy the vegetation.

Short-Duration Grazing (SDG) Plans

About the time of nonselective grazing, a similar plan in Southern Rhodesia was labeled "short-duration grazing" (Goodloe 1969). It has been called the multicamp plan in southern Africa, "camp" meaning "pasture" (Roux and Skinner 1970).

Allan Savory is the principal proponent of SDG and it has come to be known as the Savory Grazing Method (Savory 1988). Commonly Savory recommends a grazing period 1 to 5 days, an ungrazed period 30 to 60 days, and both longer during vegetational dormancy. The layout of pastures, 4 to 40, is termed a "cell." Grazing by the whole herd in one pasture for 2 days provides an ungrazed period of 78 days in a 40-pasture cell. The high densities of animals were claimed to exert favorable effects of even distribution, trampling unused herbage, chipping of soil, and distribution of dung and urine. Increased stocking rates, sometimes more than 50 percent, have been recommended for the cell. The cell and its operation are parts of holistic ranch planning (Savory 1988).

The SGM has several basic tenets: (1) High livestock density results in utilization of plants often grazed lightly or not at all. (2) Livestock distribution and forage utilization are uniform. (3) Regrowth is not grazed. (4) Long ungrazed periods are provided during the growing season. (5) Numerous pastures provide managerial control over livestock handling, energy cycling, water infiltration, and other factors for range improvement. Numerous small pastures are needed to increase density of livestock in a practical way. The long, narrow V-shaped pastures in the wheel-design results in heavy trampling near water. Most grazing plans provide for these five tenets.

Short-duration grazing is highly flexible. Table 17-1 shows that by increasing the number of pastures, or changing the number used in any cycle, the manager can change livestock density, length of grazing period, days grazed per season, and percentage of the land ungrazed. Movement of livestock to another pasture can be controlled on the basis of forage utilization. Selective grazing of part of the vegetation where wide differences in palatability occur will not be eliminated. The system increases the manager's control and husbandry of animals and spatial uniformity of forage utilization. Preference can be given to different herds such as fattening animals, lactating mothers, and others. SDG requires daily care and that increases safety of operation.

Table 17-1 Relationships between pasture size and grazing schedules; assume 1,000 acres, 200 animal units, a grazing season of 150 days, and a constant ungrazed period of 50 days.

Pastures (No.)	Size of Pasture (Acres)	Livestock Density (AU/A)	Grazing Period (Days)	Grazings per Season (No.)	Total Seasonal Grazing (Days/Sea)	Ungr-azed/ Season (%)
4	250	0.8	17	2.24	38	75
8	125	1.6	7	2.63	18	88
12	83	2.4	4	2.78	11	93
16	62	3.2	3	2.83	8	95

A 16-pasture system illustrates some of the possibilities. At the beginning of plant growth, the herd can be divided for handling ease during calving or lambing. Each herd may be moved every day or two through four pastures and in two weeks to another set of four pastures. After the young no longer need daily care, the herds can be combined into the full 16-pasture plan. As the growing season progresses, grazing time in each pasture should increase until, by late growing season, it is ten days to two weeks. Plant maturity will find some pastures ungrazed or not grazed since early spring. These pastures should furnish feed until the next growing season starts.

In years of high production, some pastures may go ungrazed and excess feed is trampled down so that soil improvement is promoted. In drought times, the rotation must be more rapid by grazing pastures for fewer days. Unused pastures in droughts are wasteful of high-quality forage.

OPERATION OF GRAZING PLANS WITHIN THE ANNUAL FORAGE CYCLES

Management to accomplish seasonal grazing is evolving. It has moved through deferred-rotation, rest-rotation, high-density/low-frequency, and is struggling with short-duration grazing. The amount of time without grazing, when it occurs in the growing season, the degree of utilization, and when it occurs are the principal components of grazing plans. These factors must be fitted to the range resources and the ranch or public land system of the user. No plan is universal, and generalizing the best is impossible. Most plans are successful if carefully implemented and continuously maintained. **The major operational points to be followed in seasonal grazing schedules are:**

- The forage plants must accumulate energy reserves and produce a vigorous growth between successive defoliations; therefore, the period without grazing varies with climate, season, vegetation, and range condition. A moderate degree of forage utilization is the first requisite.
- The grazing period should be short to prevent grazing on regrowth, but should vary during the growing season.
- Numerous pastures give opportunity for several herds to favor animals with the greatest need.
- Grazing that follows the seasonal growth of forage plants requires flexibility in numbers of animals and dates of moving from one pasture to another. A strict time schedule of grazing days for each pasture and a constant sequence of pastures should not always be followed.
- Decisions on moving animals out of a pasture should be based on distribution of forage use, degree of selective grazing, intensity of utilization, expected growth, as well as how the moving fits into the overall cycles of ranch supply and demand for forage.
- Decisions on the pasture to receive the animals require consideration of the overall grazing schedule, the amount of forage in the pasture, water supply, the amount of time without grazing needed to promote improvement of range condition, supplemental forages, and the future demands for forage.
- Grazing schedules should fit the need for other range management practices such as burning, alternate grazing of forested and nonforested vegetation, and repeated seasonal grazing.
- Attention should be given to the annual supply cycle of forages by complementing rangeland grazing at certain seasons with planted, fertilized, irrigated pastures, crop aftermath, or conserved feeds.

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18

Responses to Seasonal Grazing Plans

If all parts of a range are to be grazed for production and ungrazed for improvement over a period of years, there must be some sort of planned grazing rotation. Actual benefits from rotations have varied, and objectives have not always been attained. **Few studies and experiments have quantified the chain of events from deteriorated conditions to higher range condition and increased profits; yet considerable experience has established that scheduled rotational grazing benefits the range and can be profitable, when livestock travel distance is decreased and uniformity of forage utilization is increased.**

Driscoll (1967) reviewed 50 studies of grazing plans. Other reviewers include Shiflet and Heady (1971) and Heady (1975). Most of the cited papers in the following discussions were published after 1974. For sake of brevity the expression **rotational grazing** is used in this chapter as a generic term including any or all of the actual rotational grazing plans. However, much of the research since 1975 has been testing the assumptions espoused about short-duration grazing (SDG) and the Savory Grazing Method (SGM) (Savory 1988).

VEGETATIONAL RESPONSES

The most commonly stated benefit of rotated grazing is improved range condition. As nearly all rangeland needs reclamation to some degree, few grazing plans have been tried solely on excellent condition ranges. Therefore, rotational grazing is thought of as a tool for improving range condition for livestock and wildlife grazing, not necessarily for grazing good and excellent condition ranges.

Of the 50 studies reviewed by Driscoll in 1967, 5 did not show differential response to grazing schedule, 3 showed improved vegetation and 31 deteriorating vegetation under continuous grazing (CG), the equivalent of 31 favoring rotational grazing. Papers since 1967, have favored rotational grazing in approximately the same proportion. Vegetational responses have been expressed in different ways including maintained vigor and growth of shrubs and perennial grasses, vegetational changes toward higher condition ranges, and increased production of biomass.

The studies that do not show vegetational improvement or increased production from rotational grazing in comparison with continuous grazing are from certain vegetational types, including the Mediterranean annual grassland in California and Israel, mountain grasslands, shortgrass areas, and arid shrublands. Whether lack of vegetational response was due to design of the experiments and management, was not always clear. Proper before and after measurements may not have been taken, the trial may have been too short in time, or the study had a different objective. Another reason for few published vegetation descriptions in grazing trials is that investigators hesitate to predict longterm changes from shortterm studies.

Here are some results from longterm studies. From an experimental test of grazing plans in Texas, Merrill and Young reported apparent range improvement in 1952. After two more years, Merrill (1954) found an increase in desirable vegetation but no apparent benefit to livestock production. By 1960, Keng and Merrill were able to say that range condition had improved 25 percent more on the deferred-rotation units than on units grazed continuously. After 11 years of the trial, stocking was increased from 32 to 43 animal units per 260 hectares, where it remained for 6 years, until prolonged drought necessitated reduction to the original number (Merrill et al 1967). Changes in vegetation and production resulting from seasonal rotation of grazing are cumulative and tend to follow climatic cycles.

When results from 18 studies were combined, they showed that herbage production increased between 13 plus or minus 8 percent of continuous grazing. These studies implemented the grazing plans at moderate utilization levels (Van Poollen and Lacey 1979).

In their study of grazing systems on the Vale Oregon District, Bureau of Land Management, Bartolome and Heady (1988) based analysis on 95 individual pastures where they had records for 1966, 1976, and 1986. The pastures were sagebrush/grass, many of which had brush control, and others of crested wheatgrass with little sagebrush. The grazing periods on these pastures were called pasture treatments. Many of the pastures were grazed on a schedule using repeated seasonal periods of early turnout. Other treatments were a later turnout, spring grazing, summer grazing, and fall grazing or deferment. Some pastures were ungrazed for a year and others had seasonlong grazing. About half of the rotation plans changed yearly. The pastures where season of use was rotated between years were of many different schedules and were 78 percent of the 95 in 1966, 68 percent in 1976, and 58 percent in 1986. This was a gradual decrease of rotational grazing and an increase in pastures used seasonlong.

Among the results of the Vale District study were three that apply to seasonal grazing. (1) All started with moderate grazing and improved in forage production during the 20 years. Season of use made little difference. (2) The rotations became less complicated as the vegetational improvement resulted. (3) Flexibility in management is highly desirable, and it requires frequent consideration of individual pastures as treatments. As range condition improves, it improves on individual pastures more strikingly than simultaneously on several pastures in a grazing plan. When the forage resource changes in botanical composition, seasonality, feed quality, or forage quantity, the schedules of grazing plans should change accordingly.

The many successful applications of repeated seasonal and rotated seasonal grazing indicate that periods without grazing and rotation of grazing are effective range improvement practices. Failures suggest that rotational grazing has not been applied properly or should not be used at all in certain situations. Rotational grazing alone rarely suffices. Sharrow (1983) wrote that Mediterranean annuals probably were more productive with rotation in the green-feed season and maintenance higher with repeated seasonal grazing in the dry season. **Safe intensity of use and proper distribution of animals may be more important than season of grazing**, and an attainment, although unrealized, when a seasonal plan is followed.

Seasonal grazing plans appear to be of little use in the Mojave Desert because one year of overuse takes many years to improve range conditions (Hughes 1982). Sixty days is often mentioned as standard period of absence, but considering high and low precipitation regions and annual climatic variations any limit to length of ungrazed period is inappropriate. The best length of ungrazed period for recovery of any pasture is a matter of judgment.

LIVESTOCK RESPONSES

In the summary of 50 experimental studies reported by Driscoll (1967), 29 included livestock weight changes in their evaluation of grazing plans. Twelve favored continuous grazing, nine showed no difference among the plans tested, and eight favored some kind of rotational plan. Comparisons among these studies must be subjective, since none were sufficiently alike in vegetational type, design, season of use, degree of use, animals, and management to allow quantitative evaluations. Experiment station results summarized by Driscoll may not accurately measure practical results from ranching.

Papers since 1974 that include measurement of animal responses divide about evenly for those favoring continuous grazing, rotational grazing, or showed no difference. That is essentially the same as was found in earlier summaries and hardly justifies the use of any seasonal grazing plan based on livestock responses alone. The number of studies since 1974 using a measure of weight gains is small and does not indicate significant differences of grazing among vegetational types.

A number of studies comparing the effects of continuous and rotational systems on nutritive values of forages and diets have given various results. For example, no changes were found in content of crude protein and fiber of *Agropyron intermedium* in progression toward plant maturity (Nelson et al 1989) and SDG did not extend the green-feed season of seeded *Agropyron* (Olson and Malechek 1988). Of particular note is that quality of diets decreased during the 2d and 3d days of grazing *Agropyron desertorum/Agropyron cristatum* pastures (Olson et al 1989). This was especially pronounced with 3-day grazing periods and the decline was greater with higher stocking rates (Ralphs et al 1986). Different results are that SDG yielded higher quality forage and less quantity of forage than continuous grazing (Heitschmidt et al 1982).

Highly significant experimental tests with grazing plans were those on the Sonora Experiment Station and the surrounding region of west and central Texas. The commonly used 3-herd and 4-pasture plan (Fig. 17-4) or a variation of it gave increases in livestock production after several years of tests (Keng and Merrill 1960). Later work reported that average annual beef production per cow for seven years was 200, 211, and 223 kilograms for continuous, 2-pasture, and 4-pasture plans respectively (Stewart and Leinweber 1968). Calving percentages were higher and weaning weights averaged 9 to 14 kilograms in favor of the 4-pasture plan (Waldrip and Marion 1963, Waldrip and Parker 1967, Mathis and Kothmann 1968). Apparent superiority of livestock production for continuous grazing may be only shortterm, perhaps reflecting that many experiments have been shortterm.

Animal responses to seasonal rotation plans and to continuous grazing have varied from highly significant results in favor of one plan to little difference in another. On balance, the bulk of data and practical experience indicates a livestock advantage in many vegetational types of grazing them in a rotational plan. Annual grasslands and shortgrass regions appear to be exceptions (Shiflet and Heady 1971).

The Importance of Stocking Rate

Stocking rate and degree of forage utilization or intensity of grazing have more influence on vegetation than the season of grazing and rotation schedules. Results that confirm this point include studies on *Bouteloua curtipendula* in Texas (Mathis and Kothmann 1968), the Texas Rolling Plains (Wood and Blackburn 1984), Edwards Plateau in Texas (Thurow et al 1988), sagebrush type in northern Nevada (Eckert and Spencer 1987), and in South Africa (Fourie et al 1985). Short-duration grazing was one of the treatments in which stocking rates were of the most importance (Taylor et al 1980, Olson and Stuth 1984, Heitschmidt et al 1987b, Hart et al 1988, and Ralphs et al 1990). High stocking rates usually lowers livestock production.

Patch Grazing

The plants of low palatability, whether in a pasture of *Eragrostis lehmanniana* (Cumming 1989) or a mixture of plants in a native vegetation, are likely to show patchiness when grazed. High livestock density for repeated short times during the early growth of these species can give uniform utilization, if the grazing is severe. However, the highly palatable species in the pasture are likely to be damaged from overuse, because livestock continue to graze selectively (Danckwerts et al 1983). It is questionable if short-period rotations reduce that damage.

Another situation that leads to patchiness is low utilization that occurs early in the grazing of a pasture. Continuous grazing may promote frequent grazing of patches and their slow deterioration. However with adjustment of stocking rates, the patches tend to disappear as utilization becomes more complete. **Properly used pastures will nearly always show some degree of patchiness.** Continuously grazed, and rotation pastures should have little difference in appearance at the end of the grazing season, if properly grazed (Gammon 1978b, 1991). Cattle graze selectively regardless of the grazing method or stocking density (Kreuter and Tainton 1988). **Uniformly used rangeland is overused.** Patches of overused range within a mosaic of little used herbage almost always has a cause other than low grazing pressure.

Cattle showed no difference in preference for plant communities between SDG and CG in Texas (Walker et al 1989), in northern Mexico (Soltero et al 1989), in North Dakota (Kirby et al 1986), and in Zimbabwe (Gammon and Roberts 1978). These trials indicate that SDG did not improve distribution of forage utilization more than continuous grazing. Small pasture size probably eliminated problems of grazing distribution.

Patch grazing is a result of light and moderate grazing giving the landscape and vegetation a rough appearance. Although the studies have not been made, patchiness suggests an overall increase in biodiversity at the landscape level. The claims of reduced biodiversity by livestock grazing apply to overgrazed situations, not properly managed rangeland. Distinctions among the effects of light, moderate, and overgrazing should be made. **Not all grazing is overgrazing and certainly all grazing should not be so labeled.**

Effects of Livestock Density

Effects of high **livestock density (number of animals per unit area at any one time) and excited animal behavior are referred to as "herd effects."** These are soil chipping by the hooves of animals, planting of seed, laying of litter, and providing for even distribution of dung, all by the actions of the animals (Savory 1988).

Increased stocking density is said to increase hoof action (Savory 1988), or the number of hoofprints during 5 days in one pasture has an improved effect over the same number during 20 days at a lower stocking density (Tainton 1985). This is subject to question. Hoof action on a pasture is closely related to increased walking when the animal enters a pasture. Rates of animal impact much above moderate grazing are likely to destroy rather than promote range condition. After any disturbance, the soil begins to right itself through actions of small organisms and climate. Any damage or benefit is tempory. The concept of "beneficial herd effects" on the soil by livestock density should be discarded.

There is no argument that as the stocking density increases, the rate of forage use in a pasture increases. But not everyone agrees that the herd effects are important to increased animal production and better condition ranges. Low stocking density gave higher animal production than high stocking density at the same stocking rate on 6-hectare pastures in South Africa (Joubert and van der Westhuizen 1980). Increased stocking density did not improve distribution of forage utilization in a comparison of SDG with repeated seasonlong grazing on *Agropyron smithii* and *Bouteloua gracilis* (Kirby et al 1986). Neither forage production, plant species composition, nor live/dead ratios were significantly altered when animal density was increased, as from a system of 14 to 42 pastures (Heitschmidt et al 1987a). After 8 years of increased stock density, daily gains of cattle were depressed (Dahl et al 1987). High stocking density in the upper Karroo of South Africa did not attain uniform utilization among the forage species (Joubert 1986).

Many pastures in SDG plans are small and that in itself would be expected to reduce problems of animal distribution. But that might not be the result with long and narrowly triangular pastures in a wheel design around water. For example, half of the distance from water to the back fence includes about one quarter of the pasture area.The smaller portion near water would receive more trampling per unit area than that farther away. Shape, as well as size of pasture, needs consideration in developing rotation system arrangements.

Hoof action to trample seed of perennial species into bare ground was used on National Forests in the early 1900s and many times since. If a cover is present, the necessity of planting seeds is questionable. The annuals do well without help and few seedlings are necessary to maintain perennial stands with utilization that maintains good or better range. Excessive hoof action may destroy as many seedlings as it promotes. For example, Weigel at al (1990) found that SDG had no beneficial effect on emergence of *Panicum coloratum* or on reducing soil strength. Most attempts to duplicate natural vegetation by broadcasting seed have failed, with and without trampling (Hyder et al 1975).

In 1987 Skovlin reviewed the history and success or lack of it in southern Africa finding that SDG resulted in degradation of pastures and the claimed beneficial herd effects were a myth. He also cited a World Bank study in Zimbabwe that was against the number of paddocks exceeding 8 to 10.

SOIL RESPONSES TO GRAZING PLANS

Impacts of grazing animals on soil characteristics, with emphasis on comparisons among grazing plans, have received considerable research since 1970. Perhaps the principal question is: **Which grazing plan, if any, protects or does least harm to the soil?** This question has been approached from the standpoints of changes in soil bulk-density, soil organic matter, soil cover such as herbage and cryptogamic crusts, and infiltration of water into the soil. Infiltration appears to integrate the factors listed above and has received the most study. Time needed for soil to recover from damage has received little attention.

Water Infiltration into Soil

In southern Alberta, Canada, a 17-pasture SGM plan for 5 years in *Festuca scabrella* grassland at 2 to 3 times the recommended stocking rate reduced range condition, increased soil bulk-density, and did not incorporate litter into the soil with hoof action. Heavy animal impact did not improve range soil condition (Dormaar et al 1989).

The most important factor influencing infiltration appears to be total ground cover followed by soil texture, soil organic matter, soil bulk density, plant cover, biomass production, time of runoff, and time of ponding (Wood, et al 1987). As total ground cover decreases the impact of raindrops, abrasion by runoff, soil crusts, and sediment are expected to increase. Less cover would normally result in less soil organic matter, fewer soil aggregates, less infiltration, and reduced soil water. Plant cover improves soil tilth and the receptiveness of the soil to water, as do the cycles of wetting/drying, freezing/thawing, growth/death of roots, and the succession of micro/macroorganisms.

Sixteen studies in late issues of the Journal of Range Management reported measurements of water infiltration into soil and the influencing factors, all in relation to grazing schedules. Twelve found grazing in any pasture that reduced plant cover also reduced infiltration and increased sediment production. Short-duration grazing was one of the systems tested in most of the studies. Further it was shown that increased stocking density, as with increased speed of rotation, resulted in more trails and more walking for at least the first three days livestock were in a pasture; hence more trampling, less cover, and decreased infiltration. A claim that increased density of livestock and short grazing periods improves water infiltration into soil is a myth. The principal relationship is between ground cover, which depends upon degree of forage utilization, and infiltration.

DETERMINATION OF RESPONSES

Few grazing plans in practical use have been subjected to published economic analysis. If specialized grazing schedules are to be adopted by ranch operators, they must produce additional products or services that yield a profit greater than before the grazing plan was initiated. Current grazing capacity and its expected increase limit the intensity of development. Fence, for example as a per hectare cost, is less likely to justify small pastures than large ones. In areas where labor costs and capital investments in fence and water development are high, seasonal grazing plans must yield high returns. Costs and returns in the following examples are as given by the authors with no attempt to convert to dollar values of a certain date.

Perhaps more ranches could institute grazing plans with little added cost. Better distribution of grazing and efficient handling of animals are other values that may be important enough to justify improvement expenses. An analysis of 100 randomly selected ranches on the Edwards

Plateau of Texas showed that 52 could install a 3-herd and 4-pasture plan without additional fencing and that 22 more could adopt a seasonal plan by building less than 2.2 kilometers of fence (Keng and Merrill 1960).

Although seasonal grazing plans require control of livestock with fences and water, these improvements do not require rotational grazing to be of value. Leithead (1960) reports a range improvement program (deferred grazing included) that increased net returns per hectare from ten cents to $2.05 in 11 years. **Costs of additional fencing and water developments should not be incurred until inventory and analysis demonstrate the need in an overall management program.**

Costs and returns may be slow to change so patience is needed in determining the values of grazing plans. At Throckmorton in north central Texas, a 3-herd and 4-pasture plan yielded $1.60 greater annual return per hectare than did continuous grazing for a period of seven years (Stewart and Leinweber 1968). In a later report, the added return increased to $1.93 per hectare. Various seasonal grazing plans had little effect on total operational costs at the same stocking rate (Kothmann et al 1971). On shortgrass range at Barnhart, Texas, a 3-herd and 4-pasture plan averaged 83 cents more per hectare per year and a 2-pasture switchback plan $1.09 more per hectare per year than did continuous grazing over a 6-year period (Huss and Allen 1969). Increased stability of ranch income with rotational grazing over continuous grazing was further substantiated in the region by Whitson et al (1982).

The rest-rotation grazing trial at Harvey Valley in northeastern California between 1954 and 1966 cost the Forest Service 28 percent and the permittee nine percent more than did season-long grazing on nearby allotments. Added costs amounted to 34 cents per AUM for a 30-year payoff period. The payoff period will be shorter as range condition improves. In contrast, season-long grazing on ponderosa pine/bunchgrass range produced a higher net return than deferred-rotation grazing (Quigley et al 1984). Costs and returns in dollars may or may not be the principal indicators of value of grazing plans on public land.

Financial returns from experiments and experiences in the comparison of continuous grazing with rotational plans have been varied. If a winning factor emerges, it is an increase in stocking rates. However, the immediate objective may be range improvement, investment of capital, or quick profit. Increased stocking rates from SDG or any system or set of improvements do not insure increased profits above those without improvements. The stocking rates that yield maximum profit are always lower than those of maximum livestock production per hectare. Increased stocking rates must be accompanied by other forage and business practices (Tainton 1985). Therefore, rotations will be of most use on ranges in poor condition that can be improved (Martin and Severson 1988).

Costs and returns from grazing plans include a large measure of financial uncertainty because of variable weather, livestock prices and interest rates, pest problems, and longterm effects on the resources. Several analyses indicate that profits are maximized at the higher stocking rates (Hart et al 1988). A computer program entitled STEERISK has been suggested to estimate the risks from over- or underestimating optimum stocking rates on a shortterm basis (Hart 1991). Other models have been suggested, such as SPUR for simulation of production and utilization (Wight and Skiles 1987) and SMART to assess rangeland technology (Hart 1989).

In South Africa, the financial implications of number of pastures were modeled by a discounted cash flow analysis and few rather than numerous pastures appeared to give higher values (Mentis 1991). As yet a full analysis technique for predicting the value of rotational grazing plans as a producing part of a ranch rangeland system has not been attained.

OTHER BENEFITS FROM GRAZING PLANS

Invariably, a benefit derived from instituting a seasonal grazing plan is better husbandry of the animals. A person with enough interest and concern about the range to initiate scheduled grazing also takes added interest in animal health, adequate feed quality, breeding, and daily care of animals. With smaller pastures, livestock are not so scattered and therefore are easier to see, gradually become tame, and are easier to catch than animals in large pastures. Pride in the whole operation increases. A well-managed grazing plan usually means a well-managed ranch.

Grazing plans serve as aids in the education of better managers. Planning a grazing schedule must, of necessity, consider the management of the whole ranch. Alternative range improvements must be studied and selected. Usually a whole range improvement program results. The popularity of grazing plans has aroused interest and activity in other range practices. Benefits from whole programs are sometimes inaccurately attributed to the rotation schedule.

Seasonal grazing schedules, which bunch animals into a few pastures and leave other pastures ungrazed for a time, aid establishment of rangeland improvements that require no interference from livestock. An ungrazed pasture for a year presents an ideal situation for brush control and seeding since the rest provides protection to new seedlings. Through much of the tropical and subtropical savanna areas, periodic burning reduces brush. A long rest and deferred treatment promotes accumulation of sufficient fuel for that burning to be effective. In fact, any range improvement program that stipulates periodic burning for plant control also requires controlled grazing before and after the fire. Not all accumulations of herbage are desirable because they can increase hazards from wildfire. Sprouting of brush species after control may be discouraged with a rotation of goats.

Fire is used in coarse grasslands to remove the rough, standing dead material, and to improve feed quality, as in Zimbabwe (West 1958), in Australia (Ealey and Suijdendorp 1959), and in the marshes of the southeastern United States (Shiflet 1966). In these situations, standing dead material accumulates with any type of grazing program. Rotational grazing prevents overuse of newly burned grasslands where animals congregate on the young, palatable plants.

WILDLIFE RESPONSES

More and more rangeland will be used to produce game animals for profit or strictly for their values to a sightseeing public, as on the National Bison Range in western Montana (Fig. 18-1). Seasonal plans that concentrate wild or semiwild animals in certain pastures make them easier to view, hunt, and harvest. Wild animal species in game farming can be kept separate and moved from one pasture to another in rotation. Separation facilitates harvesting, handling, and controlled use by several species.

Bryant (1982) reviewed 214 studies on the responses of wildlife to grazing systems. Although overgrazing was seldom defined more than half indicated benefits to wildlife from grazing. Duck nesting habitats and riparian zones sustained most damage by livestock.

Needs and good health of a wildlife population are usually stated in terms of requirements for food and cover for resting, protection of young, and escape. For example, the highest population of whitetailed deer occurred on units in the Merrill 3-herd and 4-pasture plan which were periodically ungrazed and moderately grazed by cattle, sheep, and angora goats (Merrill et al 1957, Reardon et al 1978).

A study in north central Montana found that ducks nested in pastures that had residual cover because of no grazing or only very early grazing the previous year (Gjersing 1975). Lack of cover surrounding ponds in the "pot-hole-country" of the northern Great Plains is often given as a major reason for decreasing waterfowl populations. Herein lies a reason for rotation systems of grazing that protect nesting cover until after the young have left the nest.

Fourteen years after excluding livestock from a range in southeastern Arizona, comparisons with adjacent continuously grazed areas indicated that grazing appeared to favor birds as a class over rodents (Bock et al 1984). Destruction of ground nests by cattle trampling was no different in continuous and SDG (Koerth et al 1983, Bareiss et al 1986). Degree of utilization is more important. Bobwhite quail responded to changes in vegetative cover within systems of grazing. Close cropping and bare ground give too little cover and complete grass has too much, so **grazing is desirable but not in the nesting season** (Hammerquist-Wilson and Crawford 1981, Campbell-Kissock et al 1984).

Accusations that cattle grazing continues to damage rangeland and that all should be removed from the public land has been countered with the proposition that properly managed cattle grazing is one of the tools for wildlife habitat improvement. This proposition has been examined in Chapter 10 where the emphasis is on improving rangeland condition for wildlife.

POSITIVE RESPONSES TO ROTATION SCHEDULES

Properly managed grazing plans reclaim deteriorated ranges, increase yield of livestock products, facilitate animal husbandry, improve profits from the business enterprise, and permit flexibility in multiple-use management. No matter how stated and practiced, a period of time without grazing during the growing season allows the palatable species to gain in vigor and produce seed and lets seedlings become established, if climate permits.

Successful rotational plans, for the most part, have been those situated where every pasture had about the same set of conditions. In addition, having relatively level land facilitates an operation. Every pasture in a plan should be capable of being grazed during any part of the grazing season and as efficiently as any other pasture. This ideal situation requires similarity in topography, seasonal or altitudinal development of vegetation, slope aspect, approximate size and shape, water availability, accessibility, safety of animals from poisonous plants and predators, and forage production.

Rangeland in good or higher ecological condition can be grazed with any seasonal plan if the intensity of management, stocking rate, and utilization are adequate. It appears that in many vegetational types a well managed rotation system of any design will give 10 to 15 percent greater livestock production than continuous grazing.

Research and experience over wet and dry years refute the claim that SDG, or more specifically the SGM, can with increasing the stocking rate double animal production. This is a myth based on two or three years of "mining" the vegetation. Drought quickly brings forth the danger of increased stocking rate. Evidence does exist in areas with long growing seasons that rotating a short grazing with a long ungrazed period increases forage production by many species. Claims of improved diet through greater selectivity and achieving less patch grazing with more even distribution of animals are counter to each other. Greater selectivity leads to greater patchiness. Hoof action appears to decrease infiltration and seedling establishment much more frequently than it increases them. Research and experience conflict with many claimed attributes of SDG as stipulated for SGM as follows:

- There is an infinite number of climates and soils; therefore, a universal grazing plan is impractical.
- With livestock at high densities in rangeland pastures for a few days, diet quality decreases rapidly on the second and later days.
- Length of the green-feed period is not increased with SDG, especially in range vegetation with short growing seasons.
- Stocking rate and percentage of forage utilization are more important to vegetational health than season of grazing. In other words, SDG will not counter-balance overstocking and overutilization.
- Patchiness in utilization indicates moderate and light degrees of utilization, but it is confounded with the mixture of palatable and unpalatable species in the rangeland vegetation.
- Uniform utilization usually means less patchiness and overutilization. When the plants of low palatability are used the highly palatable species will be greatly overutilized.
- Chipping of the soil by hooves decreases infiltration of water into the soil, increases runoff, and causes erosion. High density of livestock compacts the soil and may churn the soil in wet weather or a heavy storm.
- Any decrease in soil cover through trampling and over- utilization decreases infiltration.
- High density of livestock often causes damage and the value of the "herd effect" is a myth. Desirable diet selectivity, patch grazing, and distribution are matters of degree of utilization rather than high density of animals.
- Grazing systems with annual rather than daily or weekly rotations are required to accommodate prescribed burning, protection of new seedings, brush control and other range management practices.

- During reproductive periods, accommodate wildlife and bird requirements for cover, food, and escape with longer ungrazed periods and less livestock density.
- As shown in Table 17-1, little is gained in percentage of the grazing season without grazing, where the number of pastures increase beyond eight. Three to nine pastures are enough.

PRECAUTIONS IN USING ROTATION SCHEDULES

The literature on practical and research examples of seasonal grazing plans is replete with examples of failures, alterations, and abandonment of rotations schedules. No one rotation plan has consistently produced more animal products or improved the range more than any other plan, including continuous grazing. With the intention of improving the success ratio of schedules of all kinds, the following are given as precautionary items for consideration (Gammon 1978a):

- Experimental results have limited application because of rigid designs and procedures. Practical application of rotations requires flexibility and simplicity.
- A safe intensity of utilization and proper distribution of animals are more important than a seasonal grazing plan. Stocking rate should not be increased before the feed is there.
- A certain stocking rate does not give the same pattern of defoliation on different range sites and different vegetational compositions within one range site.
- High stocking rate and stocking density that achieve even utilization of both patatable and unpalatable plants result in overutilization of preferred species.
- There is a loss of quality in forages on ungrazed areas.
- The rotation must provide enough time without grazing for vegetational improvement.
- Livestock gain less when subjected to short grazing periods and excessive moving to new pastures.
- Rotations must be altered in relation to seasonal change in the physiology of the forage plants and changes in botanical composition.
- Provision must be made for supplemental forage supplies when needed in droughts and unusual seasonal climatic variations.
- Different grazing capacities among pastures cause problems in grazing intensity.
- Pastures respond differently because they are in different ecological condition.

- Close relationships among selectivity, quality of forage, and intake must be recognized. Diet quality decreases rapidly after a day or two in pastures with high livestock density.
- The rates of change are slow in both forage and animal production, resulting in a new system not meeting expectations immediately.
- Shortterm indicators may be at variance with longterm results.
- Perhaps as important as any of the above is the lack of holistically combining rotation plans and the ranch operation. In other words, do not build water and fence before planning indicates that they will be profitable.

There is little doubt that increasing number of pastures and shortening grazing times in each requires keen judgment, often on a daily basis. The above listed points might be looked at as hazards along the way in the initiation and operation of grazing systems. An excellent manager successfully operates any system and the poor manager does not do well with any.

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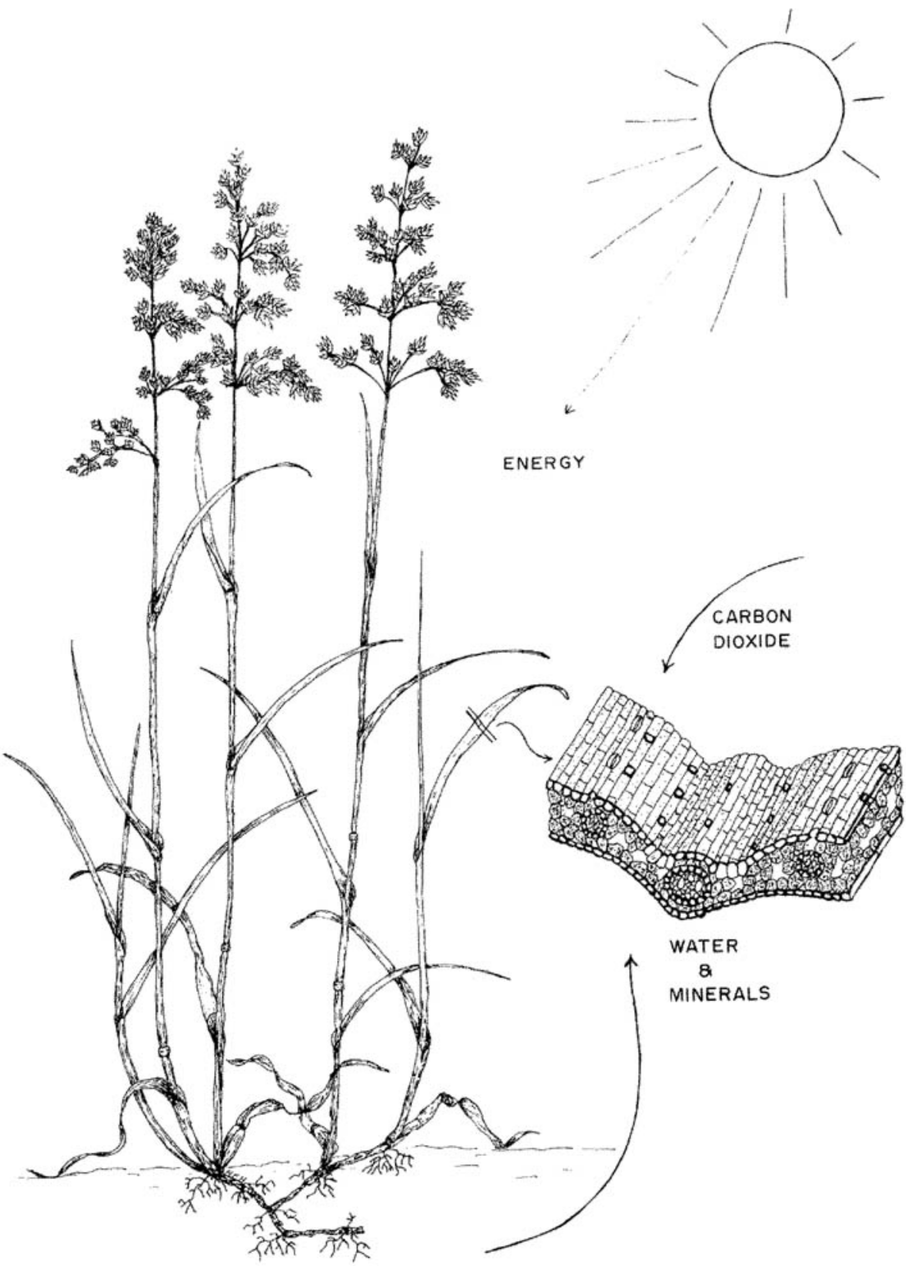
ENERGY
CARBON DIOXIDE
WATER & MINERALS

PART THREE

Vegetation Management


HFH

19

Modification of Vegetation

Rangeland Management includes techniques that are used to directly modify the species composition and/or structure of the vegetation. Manipulation of grazing effects have been examined in Parts One and Two of this book. Part Three includes discussion of using such tools as machines, chemicals, fire, and organisms to reduce undesirable species and thereby encourage desirable vegetation. New species may be seeded, and the site improved by fertilization and water management.

The undesirables are often called "weeds" or "noxious weeds." **"Weed"** and **"noxious weed"** refer to a plant that detracts from the use objective. **"Noxious"** also designates those **so declared and restricted in some way by law**. Dewey and Torell (1991) defined a noxious weed as: A plant that is extermely prolific, invasive, competitive, harmful, destructive, or difficult to control.

The word "undesirable" is difficult to eliminate from a discussion of vegetational modification because a plant may be both desirable and undesirable depending upon the use to be made of it. One example, *Artemisia spp.* in thick stands are generally undesirable for livestock but furnish food and cover for wildlife species. Another is that many of the thistles are not especially harmful on rangeland, but are problems on recreational sites. A plant may also differ in usefulness depending upon abundance and distribution.

THE PROBLEM OF UNDESIRABLE PLANTS

Undesirable woody shrubs, herbaceous weed species, and poisonous plants for livestock grazing cover much of the earth's land surface. In the United States, the estimated area of brush is 130 million hectares. *Artemisia* spp. occupy nearly 40 million hectares, and *Prosopis* in Texas alone inhabits 22 million hectares (Sampson and Schultz 1957). Over 80 percent of Texas rangeland is brush-infested. Half of it has brush cover greater than 20 percent (Smith and Rechenthin 1964). Large areas of brush occur in Mediterranean climates, Africa, Australia, and other continents, with little change since 1950.

Most undesirable weeds on United States rangelands are aliens. Including *Bromus tectorum,* they probably occur on more than 50 million hectares. Welsh et al (1991) listed 310 species (not all weeds) in 47 plant families that have been introduced into Utah and new ones continue to arrive. For the intermountain states Callihan and Evans (1991) estimated new arrivals at the rate of 6 or more per year over the last 100 years.

Many woody plants are undesirable because they are strong competitors that reduce the growth and production of understory vegetation (Dahl and Sosebee 1991). However, the understory vegetation appears to be tolerant to low density shrubs and herbage growth may be enhanced below certain woody-plant densities. Thick growth of annual weeds, especially winter annuals, adversely impact perennial grass yields.

Annual loss of forage production and direct losses from poisonous plants severely impact the range livestock industry. For example, leafy spurge (*Euphorbia esula*) is increasing rapidly. It is especially harmful to forage yield in the Northern Great Plains where a relatively small proportion of the cover by the poisonous and unpalatable spurge causes greatly reduced cattle grazing. Losses caused by this one plant were estimated in excess of $14 million annually (Lym 1991). The weed is difficult to control but it is palatable and nontoxic to sheep and goats and may be reduced by them.

Occupation of the land by weeds and brush in the 1960s resulted in plant poisoning, physical injury, and increased costs of management, estimated at $250 million annually on western United States rangelands (United States Department Agriculture 1965). Frandsen and Boe (1991) estimated the 1989 loss in the 17 western states at $340 million because of noxious weeds and poisonous plants.

KINDS OF UNDESIRABLE RANGELAND PLANTS

The kinds of undesirable plants and the problems they cause are as diverse as the soils and climates they inhabit. Platt (1959a, 1959b) developed a list of the important herbaceous range weeds and undesirable shrubs in the United States. The ten most important species and the millions of hectares occupied by each were as follows:

Important Range Weeds and Undesirable Shrubs in the United States			
Herbaceous Species	Area, million ha	Woody Species	Area, million ha
Salsola spp.	41	*Gutierrezia* spp.	58
Astragalus spp.	18	*Prosopis* spp.	38
Lupinus spp.	13	*Artemisia* spp.	35
Bromus tectorum	10	*Opuntia* spp.	32
Hymenoxys odorata	6	*Juniperus* spp.	26
Halogeton glomeratus	4	*Larrea* sp.	19
Zygadenus spp.	3	*Quercus* spp.	16
Xanthium spp.	2	*Flourensia cernua*	5
Delphinium spp.	2	*Adenostoma fasciculatum*	3
Oxytropis spp.	1	*Chrysothamnus* spp.	2
Total of 33 species	100	Total of 31 species	234

The shrub species given prominence in the 1991 book on noxious range weeds (James et al 1991) is nearly the same. These are the genera that have received research attention into their control since World War II. Joyce (1989) does not include *Artemisia, Juniperus, Quercus, Adenostoma,* and *Chrysothamnus* on her list, reflecting public concern and growing opinion that they are valuable for wildlife and other purposes than livestock grazing. Species in these five genera can dominate the vegetation to the extent that livestock and others do not use the land. Platt's list of major shrubs that are undesirable for livestock grazing remains valid.

The list of prominent herbaceous species in James et al (1991) is completely different from Platt (1959a, 1959b). Probably none of these ten species occur on more than 5 million hectares of rangeland, but some appear to be increasing in area. The especially noxious weeds are:

Centaurea maculosa	Spotted knapweed
Centaurea diffusa	Diffuse knapweed
Centaurea repens	Russian knapweed
Centaurea solstitialis	Yellow starthistle
Euphorbia esula	Leafy spurge
Isatis tinctoria	Dyer's woad
Chondrilla juncea	Rush skeletonweed
Cirsium arvense	Canada thistle
Carduus nutans	Musk thistle
Onopordum acanthium	Scotch thistle

Joyce (1989) mentioned 32 species "of special concern on pastures and rangeland" of which 8 are woody and 27 are exotics. The 1989 and 1991 lists of herbaceous species do not include most of Platt's 1959 listing. However, most of the plants on the three lists are undesirable for livestock grazing.

Change in the listing is the result of two factors. For a few species, management problems have diminished because of different land-use objectives. For most, the problem is the danger of spread to cultivated land, damage to wildlife habitat, and competition with native plants, some threatened and endangered. Now, those considered undesirable represent pressure from special interests, at least for management of public land.

DEMANDS FOR A CLEAN ENVIRONMENT

An explosion of frustration over damage to habitats, organisms, and human health by the chemicals being added to the environment began in the 1950s. The public is still led to distrust agriculturalists, foresters, rangeland users, chemical companies, and natural resource professionals for endorsing management that some consider malpractice. Court and legislative actions dictate many changes in the way rangeland is managed. Current topics of emphasis are biodiversity and threatened-and-endangered species. Demands for clean water, air, and space will continue.

ECOLOGICAL INTEGRITY OF RANGELAND MANAGEMENT

Some of the questions being asked are: Is brush really a problem? Why not alter objectives and production procedures to take advantage of natural systems rather than alter the systems to meet objectives? For example, woody plants on rangeland may be used for browse, fruits, charcoal, fuel wood, posts, shade for animals, gum arabic, oils, and wood for numerous purposes. The deep rooted shrubs hold the soil, useful herbage grows in their shade, and many are ornamental because of their flowers, shape, and color.

The impacts of the plant-control procedures on all values, processes, and profitability in the rangeland system must be considered. For example, *Cirsium* spp. and the poisonous *Rhus* spp. need to be controlled for visitor comfort. While controls of thistles and flowers have little direct monetary return on rangeland, they have value for people. Grass dominance and ungrazed grass herbage reduce display of wild flowers. Grazing can reduce the grass and increase the visibility of flowers. Care for the wishes of the public changes the land-use objective and promotes popular support.

Desirable forage species for livestock and game, and other desirable species for human recreation, have been encouraged on many thousands of hectares of formerly unproductive rangelands. Modification of vegetational structure and composition has been successful, but not necessarily better for different uses. Whatever the type of vegetational manipulation, increasing care for the needs of all objectives must be taken in its application.

THE VEGETATION

A major problem of manipulating vegetation is in the biology of all the species. Some quickly regenerate after removal of old plants. Some species are climax, others are successional, and still others may be either in different areas. Some live only a few years and vary in density as climatic cycles and environmental upsets occur. Others live for many years and may dominate their ecological systems for decades.

The effects of factors such as fire and grazing have changed with the advent of domestic animals, but only in degree or intensity. Mechanical, chemical, biological, and burning procedures for controlling plants are used as replacements for impacts that originally maintained ecological balances. It is well to keep in mind that desirable changes cannot always be attained, and if they are, sustaining them may not be possible.

One of the range manager's goals, as a practicing ecologist, is to combine the ecology of nature and the economy of humans. This goal requires that risks be predicted and evaluated and that damage as well as benefits to the environment be determined for every action. Understanding of basic ecological and economic processes is crucial. A second goal is to help society gain high production within an environment unimpaired for humanity. Choices among the tradeoffs to reach that goal must anticipate the future because present knowledge is imperfect and perfect ecological solutions are not in sight.

Let us apply these ideas to the pollution of rangeland with an oversupply of brush, which reduces the herbaceous component. Either complete or partial conversion may be the goal. A single use may require pure grassland, but the unreality of complete conversion, the advantage of diversity with mixed vegetational types and numerous animal species, and economic pressure for many rangeland products suggest that brush management, rather than brush control is the practical goal. Many rangeland practices may be criticized because they have a single goal. Ecological responsibility within an ever-changing complex of processes and demands for products requires flexibility in application of techniques. The public's recently expressed distrust for rangeland management by traditional users and for tinkering with rangeland ecosystems by scientists will lead to a greater wisdom in application of techniques (Day 1972). The balance sought is a better life and a better environment for all who use rangelands directly or even indirectly. Controversies are beneficial because they promote caution and consideration of all sides. The wisdom with which a technique is used, as much as or more than the technique itself, determines its harmful or beneficial ecological effects. They are a part of the fabric of humankind, but the technique of application often receives more attention and criticism than does its appropriateness.

ECOLOGICAL TACTICS FOR VEGETATION MANAGEMENT

Modification of range vegetation is a subtle art based on the manipulation of physical, biological, and chemical factors. Usually treatments aim at one or a few target species while most of the flora is ignored. Pesticides and plant controls of all types are sometimes used indiscriminately, and they do have secondary effects. Mechanical brush control often destroys valuable grasses and shrubs. Machines, herbicides, fire, animals, and water conservation practices are widely used in attempts to obtain a yield revolution on rangeland comparable to that achieved with food crops on cultivated land. These tactics aim to replace the natural assemblages of organisms with a few high-yield species of forage for domestic livestock.

This approach to rangeland management is no longer appropriate. Conflicts of interest--arguments over the type of products rangelands should produce--suggest that rangelands should be managed on an ecological basis, that the aim should be to help or to guide ecological processes, that the consequences of seeding or fertilization should be considered as part of the total system, not just as a means of obtaining forage for livestock. Balanced use of resources means diversified plant and animal communities managed on an ecological basis rather than on the basis of obtaining pure stands, mono-cultures, and replacement of native communities.

Every addition or subtraction to an ecological system may be looked upon as a catastrophe that stimulates new actions. Weeding a garden brings a new crop of weeds, by succession chaparral soon replaces itself after a burn, and reproductive rates increase following catastrophe to many animal populations. An ecological error seldom is absolutely wrong, but rather favors some species and hinders others. In fact, ecological systems may not change much until a disaster occurs.

To convert a forest to a meadow requires continuous application of saw or herbicides to keep the trees from invading and the forest from replacing itself. Superficially, it may seem that removal of part of the vegetation simplifies the system. In fact, removal is never complete and the attempts at removal stimulate the ecological processes and the return of stable systems. If the objective is a stable system, or a highly unstable one, for that matter, the intensity with which a practice is applied may be as important as the technique itself.

All range improvements involve decisions as to the intensity of application. Should an area be chained once or twice to kill adequate brush? What is the best recipe for application of herbicides? Improvements involve benefits and risks that vary biologically according to dosage levels. The questions to be answered are the following: How much benefit? For whose benefit? Who should decide? It is beneficial to nation and industry to be careful (Dominick 1973).

Chemicals, prescribed burns, weed control, and other practices are applied to defined sites. Careless application to unintended sites causes problems; for example, escaped fire can seriously jeopardize other prescribed burning programs. Air currents can result in herbicides drifting beyond the site of application.

Mistakes or blind spots in ecological management of rangeland were listed by Costello (1957): (1) The complexity of all environments tends to be oversimplified; poor interpretation and treatment of symptoms result. (2) Producers and technicians alike look for quick results and become impatient with gradual improvement from management. (3) Many failures have been glossed over by stressing the successes and figuring averages. (4) Range improvements should be based upon biological units rather than physical and political land units. Unfortunately, these four ecological mistakes have tended to be repeatable. For example, the parallels between grazing and recreational problems suggest that land policy mistakes made in grazing management are being repeated in recreational and other uses of the land (Heady and Vaux 1969).

TOWARD FLEXIBILITY FOR THE FUTURE

Increasing human population reduces available acreage for grazing, recreational services, clean air, and production of clean water. Because land becomes scarce when demands increase, range-vegetation management must be practiced with increasing intensity. Every tool must come into use. The era of extravagant use of natural resources is over. At no time do we know how much of each product society will require in the future. Wise use and conservation today must provide natural resources that can be manipulated or managed as needed tomorrow.

Vegetational management in this book follows the concept that any treatment is only one of a number of options available to the manager. However, due to limitations of linearity caused by one page following another, the techniques are described one at a time in the following chapters. Whatever the technique, it is understood that application follows inventory, problem assessment, and consideration of all techniques. After application, management and monitoring occur.

Vegetation management has two major aspects. One is using land in a way that will maintain vegetation according to prescribed specifications, and the other is altering the vegetation to the type to be maintained, such as the species composition, its height, its succulence, and density. Sampson and Schultz (1957) put these decisions in the questions: "Is control biologically and economically justified? What should be the choice of method and the intensity of its application?"

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20

Mechanical Control of Rangeland Plants

Modification of range vegetation by removal of certain plant species or individuals has been practiced since the beginning of land cultivation and the domestication of animals. Centuries ago it was learned that certain chemicals, such as salt and arsenic, killed plants and that fire was a powerful tool in altering vegetation. Hand pulling, followed by hand tools, animal power, and then machines were used for plant removal. All these remain in use but to a limited extent. Volumes 33 through 44 (1980 through 1991) of the Journal of Range Management did not publish a paper on the use and specifications of mechanical plant control, although a few made reference to results of mechanical treatments. Scifres (1987) hardly mentioned the use of machines in his excellent paper on brushland management. Manual control is used in third world countries where labor is relatively inexpensive.

High cost of machinery, its operation, and usually a short time until the control needs repeating, have almost eliminated brush removal by physical means from extensive rangelands. The peak in brush manipulation and use of herbicides to control noxious weeds and poisonous plants occurred before 1980.

OBJECTIVES

Mechanically altering the plant cover on a range area has many purposes. After World War II these techniques were largely limited to removal of woody plants. The most common objectives were to increase herbaceous cover and forage, browse, fruits for livestock and wild animals, flow of water from springs, accessible areas for hunting and for viewing, opportunities for seeding and planting, erosion control, and decrease in the wildfire hazard. After 1980, reducing the cover of shrubs to increase herbaceous forage gave way to environmental concerns for protection of the natural resources.

SPECIFIC SITES AND PROBLEMS

Since 1980, emphasis has been placed on selected sites with specific problems and the control by carefully prescribed mechanical means, burning, chemicals, and biological techniques. Such sites usually are on relatively level land where soils are fertile and deep, as indicated by plant growth of exceptional density and height. The vegetation on these "best" sites have potential to be changed and to be properly used afterward. They present little risk of increased erosion. Medium-textured soils greater than 50 centimeters in depth, with a pH range between 6 and 8, often characterize the land. Treating steep slopes, rock outcrops, and irregular drainage patterns increase costs, have limited response, and increase erosion hazard.

Physical plant control on steeper lands often aims for easier wildfire control and fuel modification. Rehabilitation after wildfire may require physical treatment of the soil. Damaged land, such as mine spoil and rights-of-way, use mechanical treatments during rehabilitation. Riparian zones are excellent sites for vegetational modification by some means.

THE METHOD, TIME, AND INTENSITY OF APPLICATION

In choosing a technique for mechanical brush control, one must consider effectiveness on the target species; reduction of regeneration by seed and sprouting; potential damage to nontarget and desirable plants; suitability of the land for seeding and other follow-up treatments; matching equipment to the size of the problem; erosion hazards; and cost.

Undesirable vegetation in almost every region in the world has been treated with various techniques, so many of the brush-control-equipment problems have been answered locally through practical experience. The popular methods of a region have survived practical tests and specialized equipment or specifications for its construction are available.

Common practice points the way to the best timing and intensity of control. A few examples illustrate this concept. Undesirable plants should be mechanically removed before the seed crop is mature, so that the control operation does not scatter and plant the seed. Breaking and crushing of woody plants operates most effectively when materials are dry and brittle. Machines that remove woody roots and crowns operate with least energy and damage to equipment when the soil is moist, neither too dry nor too wet. In all situations, mechanical controls should be timed to be most effective in removing undesirable plants and least damaging to desirable rangeland values. For example, Longhurst (1956) reports 100 percent sprouting of four *Quercus* spp. when trees were cut during the wet season but as low as 25 percent sprouting for one species when cut in the dry season. Cutting at the termination of leaf growth was most detrimental to *Prosopis* near Lubbock, Texas (Wright and Stinson 1970).

Machines used to control brush operate differently on various kinds of terrain and in different types and age classes of vegetation. Nonsprouting species do not require removal below ground level, light brush is easier to remove than heavy brush, flexible woody stems bend before the blade, slopes facing away from the sun may be difficult to prepare for burning, rocky soil resists machines that remove roots, rock outcrops and steep slopes reduce maneuverability of equipment, and soil moisture alters drawbar energy requirements.

METHODS OF MECHANICAL PLANT CONTROL

Each of the following commonly used techniques has its own operational characteristics and effectiveness on different brush species (Scifres 1980). Joyce (1989) listed a number of perennial herbs that are at least partially susceptible to mechanical control among which were *Centaurea diffusa* and *Euphorbia esula*, but other methods are more effective. *Larrea*, *Opuntia* and *Prosopis* were also listed.

Tractor with Dozer Blade

Straight or regular bulldozer blades effectively crush brush, and are used in clearing and piling woody materials in preparation for burning and other treatments. Effective bulldozing requires kinds of plants that pull or break easily, soil with few rocks larger than 3 to 4 decimeters in diameter, and smooth topography. Intense soil disturbance, piling of soil with the brush, and subsequent erosion signify that poor attention was paid to site conservation.

Tractor with Modified Blade

Front-end tractor blades for brush and tree removal vary greatly (Fig. 20-1). Two general types in common use are the brush rake and the short, often pointed blade for pushing individual trees. The rake, one type of bulldozer blade, may be short teeth attached to the lower edge of the bulldozer blade or a complete unit that replaces the blade. The space between the teeth leaves the soil in place while taking the roots of the shrubs. The operator can be selective as to which trees to leave, miss rock outcrops, and avoid slopes with an erosion hazard.

Another major type of bulldozer blade is the tree-dozer, which is made to remove individual trees. The blade may be V-shaped or straight and is approximately 1.5 meters wide. It operates with a push bar that puts stress on the root system before the blade goes under the tree. With one pass this machine effectively removes single small trees such as *Juniperus* spp. in the United States and *Acacia* spp. in Australia. The regular dozer blade usually takes two passes.

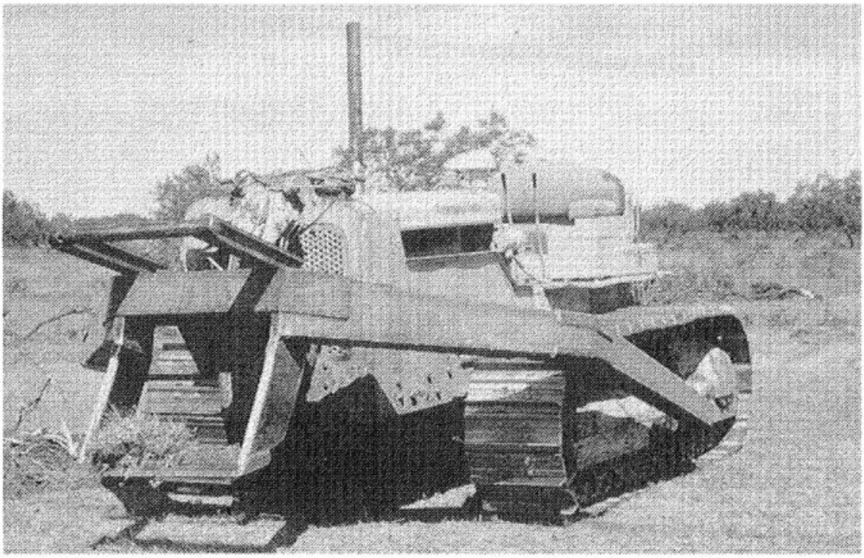
A pulled root-plow-blade may be attached to the tractor drawbar or built as a self-propelled brush eradicator. Some tractors are huge, pulling a 6-meter-long blade horizontally 15 to 25 centimenters below the soil surface. Abernathy and Herbel (1973) described a machine that root plows, picks up the brush, forms large soil pits, firms the soil, plants seed, and replaces the brush via an overhead conveyer as a mulch on the planted area. Herbel et al (1973) claimed successful control of *Larrea tridentata* and *Flourensia cernua* and good to excellent stands of seeded grasses on 50 percent of the sites treated with this equipment. Because of cost and environmental concerns this machine and other similar machines developed in south Texas and Canada have not been widely used.

Disk

The brushland disk consists of heavy models of the disk-harrow and wheatland-plow, which have been used for many decades to prepare land for agricultural crops. Effective disking requires individual blades over a meter in diameter and gangs of disks at least 3 meters wide. Two gangs in tandem positioned at an angle to each other with the disk blades set to plow in opposite directions give a double disking with one pass of the equipment. A "stump-jump" disk mounts pairs of disks separately so they can ride over obstacles without lifting the whole gang of disks. The disk-chain combines disks with a heavy chain in a V-shape behind the tractor.

Disking turns many roots, crowns, and root burls out of the soil, but some species are more difficult to remove than others. The soil remains in place but is loosened. Remnant perennial bunch grasses usually are damaged. However, the debris acts as a mulch, and rainfall infiltration may be increased.

20-1a



20-1b

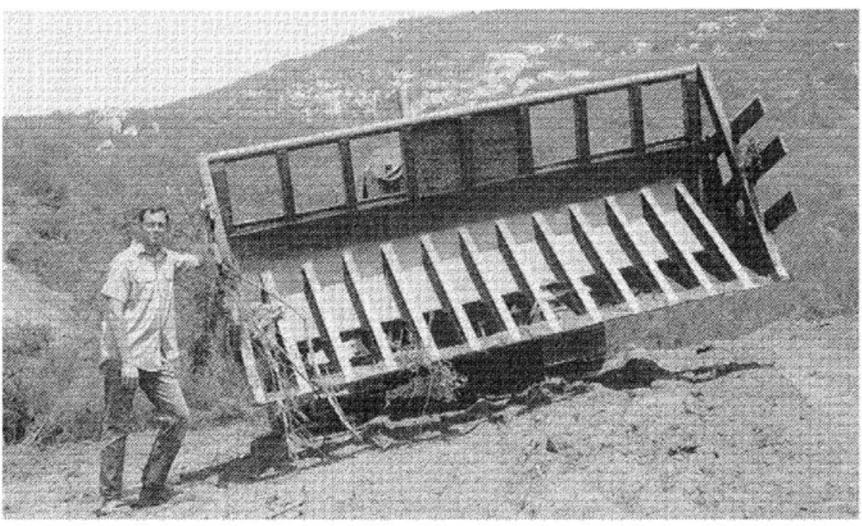


Figure 20-1 Photo 20-1a shows a short blade used to uproot individual trees. Photo 20-1b shows dozer attachments operating as a root plow and brush rake. (Photo by San Diego County Department of Agriculture)

Chaining and Cabling

Two tractors dragging an anchor chain have been used as a brush-control method. Anchor chains range in weight from 60 to 135 kilograms per meter and come in 27-meter lengths. Two or three lengths commonly are used. The heaviest chains are the most effective, but they need to be cut into shorter lengths for ease in transporting. A tractor on each end of the chain maintains an average swath width about half the length of the chain. Pulling the chain in a J shape gives more drag on the bushes and less sliding over them. On slopes where rolling materials might be dangerous to the tractor operator, the lead tractor should be the lower one.

Unmodified chains tend to be ineffective because they pass over fine and flexible woody stems without great damage to them and leave too many root crowns in the soil. An effective modification is the Ely chain (Aro 1971). Crossbars of hard steel 2.5 by 10 by 45 centimeters are welded to every link or every third link so that adjacent bars are perpendicular to the chain and to each other. The bars cause the chain to roll and to do an improved job of crushing and pulling brush plants. The modified portion of the chain needs a swivel on each end and the unmodified sections a swivel 6 to 8 meters behind the tractors.

Two passes, in opposite directions, with the Ely chain prepare California chaparral for prescribed burning. One pass may be enough for certain burning conditions, but doing two provides additional flexibility in time of burning. The second pass tends to windrow and pile the brush more than the first. Chaining can be done on slopes as steep as 45 percent and in rocky terrain. This equipment was widely used because of low costs per hectare, effectiveness on some species, and adaptability to relatively difficult terrain.

Rolling Cutter

The rolling cutter developed as an enlarged version of the cotton-stalk cutter. It is a drum about 3 meters in length and 1 meter in diameter with the steel blades fastened on the outside and parallel to the axle through the drum. As the cutter rolls, the heavy weight (2,500 to 4,000 kilograms per linear meter of the cutter) gives the blades chopping action on the brush. Two cutters hooked in tandem but not aligned parallel with each other add a shearing action to the chop as each blade falls forward. The tandem cutter can be turned with ease only toward the side with the shortest hitch between the rollers. Slopes greater than 20 percent cause considerable sideslip. The cutting action crushes and compacts the woody material for improved prescribed burning, removes a few plants from the soil, and incorporates parts of the organic residue into the soil. Depressions in the soil made by the cutter blades should be on the contour to reduce runoff; therefore, the equipment should work up and down the slopes.

Other Types of Brush-Control Equipment

Brush shredders or beaters are made with hammers or flails that operate from the power takeoff. Brittle woody material such as sagebrush may be mulched with shredders more readily than the brush species of Texas and much of the chaparral in California. Little distribution of soil and herbaceous perenials occurs.

Railing is the crushing of brush with a railroad rail or other large beam that is dragged behind a tractor. It removes brittle shrubs, burned stems, and covers broadcast seed.

Hand or manual clearing was the first means of brush control and is the only means in situations where machinery becomes inefficient or damaging to other values. The common hand-clearing tools are chain saw, brush hook, axe, backpack-type power saw, and grubbing hoe. Hand clearing is the most selective of all brush control methods and can be used to create the desired vegetational architecture. However, it is the most expensive method in the United States. Herbel et al (1958) found grubbing effective on young, light stands of *Prosopis*. Arnold and Schroeder (1955) suggested hand grubbing of *Juniperus* spp. on the Fort Apache Indian Reservation as off-season work. Even if a small percentage of an area is cleared per year, clearance of extensive areas can be accomplished in time. Hand pulling may be the best control of small and thin stands of *Senecio jacobaea* in western Oregon (Coombs et al 1991). Early control of *Delphinium* on mountain rangeland was mainly by grubbing. Now herbicides are used.

DEBRIS ARRANGEMENTS

Mechanical treatments of brushfields leave the debris in different arrangements. Crushing produces coarse materials essentially in place but compacted close to the ground surface. The rolling cutter makes small pieces still more compacted. Shredders, clippers, and rotary mowers make fine materials that closely compact on the soil surface. Mulching, as a general rule, increases infiltration and decreases erosion; therefore, these treatments would be expected to improve soil conditions. Chaining of pinyon/juniper with the debris left in place increased soil moisture storage (Gifford and Shaw 1973) and did not increase either runoff or sediment (Gifford et al 1970, Gifford 1973). The second pass in chaining tends to arrange the debris in interrupted windrows. Scalping with a bulldozer blade and root raking usually result in piles or windrows, depending on job specifications and tend to leave soil in the windrows.

Too frequently, an excellent job of brush control is equated with a complete cleanup in which the debris is neatly piled and burned. The needs for animal cover, protection for seedling grasses, and erosion control suggest that a variable degree of cleanup is a better overall management policy than is complete removal of debris.

SOIL DISTURBANCES

Resident grasses are healthiest and densest when soil disturbance is minimal. Shredding, mowing, crushing, and hand cutting of brush have little direct effect on the soil beyond the impact of tractor wheels and tracks. Bulldozing of brush into piles and windrows tends to scalp the topsoil and to mix it with the woody debris. Scalping sometimes exposes subsoil and increases erosion hazard. Root raking takes the tops, crowns, and large roots and leaves the soil in a loosened condition. The soil may be compacted in the equipment tracks, and a bit of the residue may become mixed with the soil. Friable soil and debris on the soil promote infiltration.

Equipment that is extremely heavy and difficult to handle has potential for local damage. Chaining will destroy the berm on roads, remove cover from road fills, and damage drainage structures. A chain pulled in a line behind one tractor will cut a soil trench that is a potential gully. When pits are dug, the soil is loosened and fine organic residues become buried; tracks of equipment and tractors should be on the contour as much as possible.

When proper care is taken in using the techniques, mechanical brush-control procedures increase erosion hazard only temporarily, if at all. Runoff usually is more highly correlated with soil cover than with mechanical treatment (Kincaid and Williams 1966). If the soil does not become saturated during the rainy season, cover treatments may have little effect (Hill and Rice 1963).

PLANT KILL

For sprouting species to be killed, root crowns and other organs with stem buds must be removed from the soil. *Opuntia* spp. must be removed from contact with the soils because the joints take root. Many species that do not sprout are killed by top removal below the lowest green limb. Methods (chaining, crushing, shredding, etc.) that remove only the tops of plants have little long-term effect on the sprouters. Root plows, root rakes, tree-dozers, etc., remove sprouters most effectively. However, wet soils may permit many sprouters to take root although they are disturbed. Chaining and using the rolling cutter with two or more passes remove many of the plants. Both sprouters and nonsprouters reproduce by seed, and brush seedlings often appear in abundance after the control operation.

Except for land clearing for cultivated crops, very few examples exist of complete brush kills by mechanical means. Cropland originally taken from brushland and abandoned soon returns to woody plants. Thick stands should be opened for specific purposes with the knowledge that kill will not be complete and that woody plants will return. If the original stand was a mixture of shrub species, the returning stand is likely to be dominated by the ones most difficult to kill.

HERBAGE INCREASE AFTER BRUSH REMOVAL

Herbage for livestock greatly increases after removal of various subspecies of *Artemisia tridentata* and woody associates in the intermountain region. Hyder and Sneva (1956) found that grubbing the brush doubled the quantity of grass in central Oregon. It is well known that seedlings of *Artemisia tridentata* gradually invade seeded and natural grasslands where the shrubs were part of the original vegetation.

Removal of *Juniperus osteosperma* by chaining increased forage production from 250 to 1,100 kilograms per hectare in northern Arizona (Clary 1971). Grass and forb standing crop biomass was 55 percent higher two years after chaining of *Quercus/Juniperus* in Texas (Rollins and Bryant 1986). Bulldozing of pinyon/juniper on the Kaibab did not increase production of browse which was principally *Cowania* (McCulloch 1966, 1971). Sparse stands of pinyon/juniper should not be removed from winter deer range. Woody plant reestablishment was documented after mechanical treatment of pinyon/juniper woodlands in New Mexico (Severson 1986a). Rodents increased in numbers but not to the same degree for all species after reduction of pinyon/juniper and whether or not slash was burned (Severson 1986b).

Clearing of *Prosopis* and *Opuntia* spp. resulted in a threefold increase in native grass production and an eightfold increase in production from seeded grasses (Everson 1951). In contrast, Pieper (1971) reported inconsistent grass increases after removal of *Opuntia imbricata*. He speculated that the cholla cactus may improve the environment for grasses and furnish no competition for water and nutrients.

Increases in tree canopy density reduce yields of understory vegetation (Fig. 20-2) and vice versa. These results were shown for *Pinus ponderosa* in eastern Washington (McConnell and Smith 1965, 1970) and in western South Dakota (Thompson and Gartner 1971). Mechanical, or any type of weed removal, will give varied responses of herbaceous plants and in time the weed will return.

Reduction of *Serenoa repens* appeared to be about 40 percent by rolling cutter in one year and perhaps another 40 percent by repeating the treatment the second year. However, *Serenoa* quickly returns to full density when the treatment stops (Tanner et al 1988).

COSTS OF MECHANICAL BRUSH CONTROL

Common opinion is that the cost of applying mechanical plant controls to large rangeland areas is beyond any hope for a profitable return. Current data on cost effectiveness are not available, perhaps because large scale operations are no longer attempted. Applications to special situations like fuelbreaks and winter game habitate often have nonmarket values that do not apply to grazing values.

APPEARANCE OF THE ALTERED LANDSCAPE

Success in brush control more often than not is evaluated by the appearance of the job rather than by measured results. The appearance that pleases one person does not necessarily satisfy another. The manager with domestic livestock looks for an increase in forage, water, and accessibility. The game manager wants cover, water, and food for the particular combination of shootable birds and big game in the area. The recreationist usually likes a variation in scene, few straight lines, water, accessibility, abundant life, etc. Attaining species and habitat diversity is currently appealing. The ideal number of woody plants per hectare depends upon who is evaluating.

Brush control can be done in a way that preserves or creates a landscape pleasing in appearance. Great variation in physical conditions and environmental concerns increasingly require more than one piece of equipment and more than one technique in a brush-control project. For example, a fuelbreak can be effective and can be made pleasing to the eye if the edges are irregular rather than straight, if islands of brush are left in the break, and if different brush densities are maintained along the edges. Cleared and uncleared land adjacent to each other and contrasting

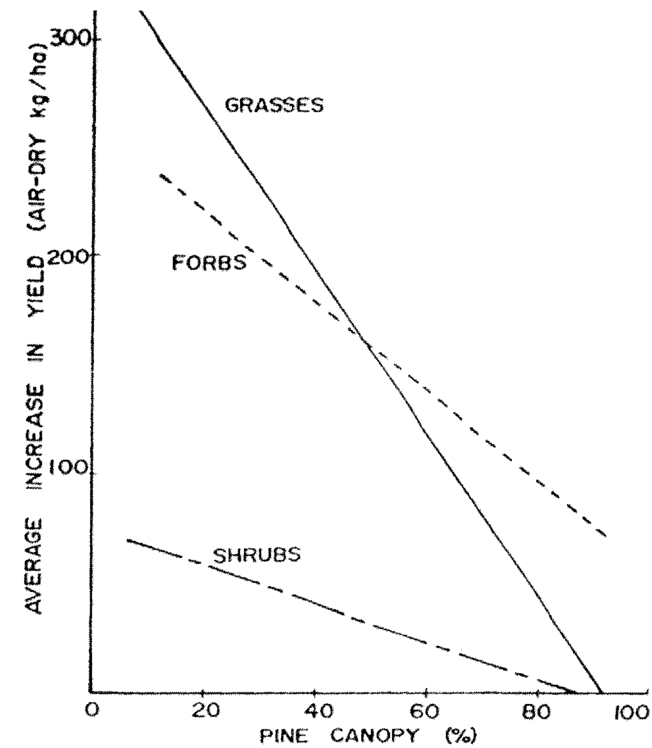


Figure 20-2 The relationship between *Pinus ponderosa* percent canopy cover and yield of understory plants (McConnell and Smith 1970).

boundaries are to be maximized. Irregular applications require maneuverability in equipment and flexibility in operation. Although brush clearing equipment is massive, it can be operated with care to preserve the appearance of an area.

A landscape mosaic with pleasing appearance has numerous values for domestic and wild animals. For sage grouse habitat, control of *Artemisia tridentata* should be done in strips and limited to areas under

100 hectares in size. Small brush areas and areas adjacent to booming grounds, streams, and *Populus* thickets should be left untreated. Sage grouse need mature stands of *Artemisia* for brooding and winter feeding, but during spring and summer the chicks must have a variety of young forbs and grasses that most commonly occur in disturbed areas and meadows. Complete conversion to grass for livestock should probably be restricted to the meadow sites (Schneegas 1967). *Artemisia* provides food and cover for sage grouse during some periods of the year, but they also need open areas (Martin 1970).

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21

Chemical Control of Rangeland Plants

Since the release of 2,4-D for general use in 1945, herbicides have become an indispensable tool in vegetational management on rangeland. Chemicals are widely used to reduce woody species, poisonous plants, weeds of cropland growing on rangeland, and competing herbaceous species during land rehabilitation.

An extensive literature describes chemical control of undesirable plants in all phases of agriculture. Numerous papers review various aspects of noxious range plant control; several hundred report research results, and an even larger number relate knowledge acquired through range management practice. This chapter selects from that body of knowledge and makes no pretext of being complete in its coverage of herbicides. Recipes for specific chemical controls should be used as stipulated on the herbicide container and locally determined by test and experience. No complete prescription for chemical control of rangeland plants is given.

APPROVAL OF HERBICIDES

On February 28, 1979, the Environmental Protection Agency suspended uses of 2,4,5-T and silvex on forests, rights-of-way, and pastures. Silvex was further suspended from areas around homes, aquatic sites and recreation areas. These regulations signaled the large scale reduction in the use of herbicides on rangeland. However, a number of herbicides have approval by state and federal agencies for use on public and private lands. The regulations are enforced through registration requirements prior to release for public use, instructions on the label, and requirements for periodic reevaluation.

Emphasis for herbicide use on rangeland was directed toward fewer shrubs and more forage until about 1980. Since that time attention has shifted toward agricultural weeds on rangeland, rehabilitation, preparation of forest land for tree regeneration, enjoyable uses of public lands by people, and specialty uses such as maintenance of parks and golf courses.

Although wildland managers have compiled an impressive safety record, accidents have occurred. Herbicides have been accused of simplifying plant and animal communities, causing nutrient loss and erosion, accumulating in and damaging food chains, causing human health problems, endangering existence of species, reducing ecosystem productivity, and other adverse effects.

Traditional evaluation of toxicological impacts has been done at the single-organism level in laboratory tests. Few have been done at the level of rangeland watershed or ecosystem, because of difficulty in attaining experimental controls over the ecological interactions of climate, soil, topography, and the communities of plants and animals. Direct effects measured in the laboratory are replaced by far-reaching indirect effects in the field (Norris 1981). Unknowns about herbicides still abound.

Many pesticides have left the market and few new ones are being developed. It takes about 7 years and $40 million to create a pesticide. In that time genetic engineering may produce plants with their own resistance. At the present time, registration is required for about 600 ingredients in the 20,000 pesticides sold in the United States and standards for the testing are increasingly difficult. Adverse effects may appear after many years. Lawsuits try to attach liability to product makers long after the products are no longer made. The risks of not securing registration, and consequently markets are too risky for herbicide development.

MAJOR CHEMICALS USED AS RANGELAND HERBICIDES

Only a few of a large number of available herbicides have been applied extensively on rangelands. For control of both herbaceous and woody plants, the following herbicides are selected for special emphasis. They best meet requirements of an ideal herbicide: (1) selective action, (2) economical application, (3) ease in handling, (4) efficacy on the target species, (5) nontoxicity to animals, (6) noncumulative and nondamaging consequences in food chains and the environment. None of these chemicals is ideal in all respects:

2,4-D ([2,4-dichlorophenoxy]acetic acid)

2,4-D was the first selective herbicide to become widely used. It was released after World War II, and it continues as a popular chemical for weed and brush control. It is not toxic to livestock and humans at concentrations used. It is translocated, selective, and does not accumulate in the environment.

Acid forms of the phenoxy chemicals are essentially insoluble in water; hence these herbicides are sold as esters or as water soluble salts. They are usually in liquid form for dilution in water, light oils, or emulsions. Volatility is low for the salts and some of the esters, but all may drift when applied in fine spray droplets and when conditions are windy during application. Sensitive crops, plantings, desirable organisms, and habitats nearby can be damaged.

2,4-D is used on rangelands, forests, rights-of-way, home lawns and on cropland. It is effective as an aerial spray on *Artemisia tridentata* subsp. *wyomingensis* in the Great Basin and Colombia Plateau but the same plant seems to be more resistant on the Colorado Plateau (McDaniel et al 1991). The difference may be related to soil moisture. *Chrysothamnus nauseosus* was susceptible in Utah (Whisenant 1988), but effects have been variable in other places, probably because of differences in growing conditions at the time of treatment. Fire and mechanical treatments of *Artemisia* have also given variable results in removing *Chrysothamnus.* 2,4-D had little effect on *Geranium viscosissimum* in a montane meadow (Murray et al 1991). Most attempts to control *Isatis tinctoria* have been ineffective but 2,4-D is the favorite herbicide for application during the rosette stage of growth (Evans 1991). This weed sprouts from the root crown so deep hand removal is effective.

Picloram (4-amino-3,5,6-trichloropicolinic acid)

Picloram (tordon) is an organic compound readily absorbed by foliage and roots. It is selective on broad-leaved and woody species and does little harm to well-established grasses. Picloram shows great promise for control of noxious woody plants on rangelands throughout the world. It is widely used in Australia, Africa, and South America.

Picloram can be applied in liquid or pellet form in spring and fall. The compound persists in soil, but is water soluble. Treatments where it can be leached by water and moved to crops should be avoided. About 6 percent left the treated area in Texas during one month of especially conducive conditions for transport in surface water (Mayeux et al 1984). Toxicity to mammals is low.

Picloram, or picloram plus 2,4-D, is moderately effective on *Euphorbia esula* when applied at flowering time but results vary (Lym and Messersmith 1991, Lym and Whitson 1991). It is economical for control of moderate and heavy stands of *Xanthocephalum sarothrae* but not thin stands. Success depends on active growth and rate of chemical applied. **Metsulfuron** is also effective (Carpenter et al 1991). Biennial thistles are susceptible to picloram (Beck 1991). This herbicide is the best available for control of *Centaurea maculosa* (Fay et al 1991).

Clopyralid (3,6-dichloro-2-pyridinecarboxylic acid)

Clopyralid is related to picloram and is highly toxic to *Polygonaceae, Compositae,* and *Leguminosae.* This herbicide is readily translocated and is currently considered the most effective one available on *Prosopis* spp. (Meyer and Bovey 1986, Jacoby and Ansley 1991). The response was correlated with fast growth and fast uptake. Whisenant (1988) reported effective control of *Chrysothamnus nauseosus.*

Tebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-triadiazol-2-yl]-N,N'-dimethylurea)

Tebuthiuron excels in control of many undesirable woody species on rangeland and weeds in noncrop locations. Application is by pellets formulated as 20 or 40 percent active ingredients. The herbicide acts primarily through absorption by roots and the pellets are usually spread around individual plants. It is applied anytime when the plants are growing. This compound can be selective at low rates of application or nonselective at high rates. It has low toxicity to warmblooded animals. In Arizona tebuthiuron moved to a depth of 15 cm in 8 months with 326 mm of precipitation and remained there with more rainfall. Less than half of one percent was retrieved in runoff after 21 months, where it was effective on *Flourensia cernua, Larrea tridentata, Acacia constricta, Condalia spathulata, Atriplex canescens,* and *Rhus microphylla* (Emmerich et al 1984).

Tebuthiuron applied at low rates to stands of *Artemisia tridentata* subsp. *vaseyana* and other subspecies thinned the stands and promoted an increase in grass but that was not the result in stands of *Tetradymia canescens* (Murray 1988). Control has been variable with hand application of pellets on *Juniperus* spp. and *Chrysothamnus* spp.

This is the principal chemical used to control *Tamarix* spp. However, the question is whether or not to control? The points in favor include promotion of more diverse riparian habitats, increased channel flow, reduced flooding hazard, and reduced salt accumulation in the soil. The opposing views include the use of thickets by birds and other wildlife, production of pollen and nectar by bees, increased erosion, and potential damage to ornamental *Tamarix* (Frasier and Johnsen 1991).

Round-up or Glyphosate (N-phosphonomethylglycine)

Glyphosate is nonselective and easily translocated, therefore, a very effective control of both annual and perennial herbs and grasses. It is registered for pre-till weed control in orchards, forest plantations and on cropland where it is effective on *Cynodon* and *Convolvulus*. Toxicity to animals is low and it is short-lived. **Atrazine**, a premergent herbicide in the group of chemicals known as triazines, is also effective on annuals.

Dicamba (3,6-dichloro-0-anisic acid)

This herbicide is selective and translocated. Its use is mainly on broadleaved weeds of pastures and cropland. Application is by spray or granules, and it is often mixed with 2,4-D. Toxicity is low to fish, wildlife, livestock, humans, and it does not accumulate in the environment. In some trials on *Chrysothamnus nauseosus* in Utah it has given excellent results (Whisenant 1988).

Triclopyr ([{3,5,6-trichloro-2-pyridinyl}oxy]acetic acid)

This is a new, selective herbicide for rights-of-way, industrial, and forest sites. *Prosopis* is moderately susceptible when given as a basal treatment of individual plants. Triclopyr shows moderate toxicity to warmblooded animals, but degrades rapidly in soil.

APPLICATION

Different herbicides are placed on foliage, stems, and soil by equipment varying from a hand-held bag to aircraft. All applications must deliver the right amount of herbicide at the proper time in the plant's growth cycle to be effective. Proper use of herbicides is less expensive than mechanical controls, usually more effective, and less damaging to the environment (Bovey 1991).

Liquid herbicides are sold in high concentrations. The user diluts them with water or diesel oil or sometimes both water and oil with an emulsifier. The volume per acre may be less than 5 gallons when oil is used. A surfactant to increase wetting action by reducing surface tension is required when leaves of target plants have a thick cuticle or a waxy coating. Commonly the surfactant amounts to about half a percent of the liquid volume.

Guidelines to minimize both losses and damage caused by drift of herbicides to nontarget species include: Use materials of low volatility in air temperatures less than 24 degrees Centigrade, relative humidity above 50 percent, and wind speeds below 10 kilometers per hour. Low flying speeds, heights less than 10 meters above the vegetation, and nozzles that produce large droplets are recommended for aerial applications. Spray thickeners, invert emulsions, foaming agents, and granular polymers that imbibe the sprays and swell to limited size are drift-reduction aids.

Time of application in relation to plant growing conditions have shown consistent positive correlation. Some examples are: The time to treat *Prosopis glandulosa* is often stated as soil temperature above 24 degrees Centigrade to half a meter deep and 7 to 11 weeks after first leaves or when pods have elongated. The best results have been application immediately post-flowering for *Gutierrezia sarothrae* and *Opuntia*. The rosette stage is the time to control *Artemisia caudata*. These are times of low and replenishing total nonstructural carbohydrates. The best time for application varies among species, but most woody plants are susceptible after leaves and shoots have developed and before leaf cuticle has thickened. Ralphs et al (1991) listed the effective herbicides with rates and time of application for the control of rangeland plants poisonous to livestock. The chemicals were described above.

The equipment for spraying foliage may be hand-operated sprayers, booms with several nozzles, or aerial sprayers. Mist blowers provide excellent coverage, but spray drifting may be a problem. Basal treatments, such as treating stumps, painting or wetting the lower trunks of woody stems, and pouring chemicals into frills and girdles are done with hand sprayers or squirt cans with long spouts. Tree injection is accomplished with tools that make a cut into the bark and inject a measured portion of chemical with each stroke. Treating soil around bushes and trees is usually done by sprinkling pellets or powder forms of the herbicides.

HAZARDS

Hazards of herbicides to livestock, wildlife, humans, and the environment are slight under directed and recommended use as given on the container. Available herbicides have gone through intensive evaluation that would require books to give more than cursory examination. However, brief remarks on the subject are worthwhile. One yardstick is LD50, the dosage that is 50 percent lethal. For the phenoxy compounds such as 2,4-D, it appears to be no less than 375-500 ppm in the diet of rats, and for picloram it is 8,200 ppm. No effect was found from feeding 1,000 ppm picloram to rats for 90 days (McCollister and Leng 1969). Picloram is low in toxicity to fish, birds, aquatic chain organisms, and soil microorganisms (Goring and Hamaker 1971). Spraying of 2,4-D with or without picloram at ten times the normal rate of field application had no effect on chickens and pheasants before and after hatching (Somers et al 1973). A mature cow showed no permanent effect after 112 days on a diet containing 500 ppm of 2,4-D (Palmer and Radeleff 1964). On a field with complete foliage cover, the total amount of 2,4-D eaten in this study would be the daily equivalent of the amount that would be taken in by a cow eating all the forage from 100 square meters of land that is freshly sprayed each day at the rate of 2.24 kilograms per hectare. Consumption rates might approach that amount, but spraying of herbicides more than once per year seldom occurs.

Phenoxy herbicides are classified as moderately to mildly toxic. Common table salt is rated mildly toxic to humans, with LD50 at 3,300 ppm (United States Department Agriculture 1967).

The question still arises, "How safe is safe?" This question cannot be answered because standards change. For example, in 1950, safety evaluation required feeding to rats for 30 to 90 days. By 1971, safety tests required 90 days of feeding to rats and dogs; three generations of effects in rats; teratogenesis in rodents; effects on fish, shellfish, primates, humans, and birds; two-year carcinogenesis evaluation in hamsters; and evaluation of mutagenesis. Permitted analytical contents were lowered during 1950 to 1971 from 1 ppm in food crops to 0.01 to 0.05 ppm and as low as 0.005 ppm in milk (Johnson 1971, Mullison 1973).

Safety involves stability, movement, and accumulation in the environment, hazards of handling and residues, effects on nontarget organisms, and other environmental impacts (Johnson, 1971). Condemnation of herbicides and other chemical additives to the environment characterizes a fashionable position whether or not they are harmful. To be hazardous, a chemical must have high toxicity and a high potential for exposure to nontarget organisms. To determine toxicity one must stipulate how much chemical is present under what conditions. Even the most toxic chemicals are not hazardous if there is no exposure. The likelihood of exposure to herbicides depends upon their chemical behavior, distribution, persistence, and movement in the environment and in food chains. The large doses of the major herbicides necessary to make them acutely toxic are not likely because the herbicides do not persist in the environment, lack biomagnification in food chains, and are excreted rapidly by animals. Sheep and cattle void 89 to 98 percent of 2,4-D and picloram within four days after consumption of single doses (Norris 1971). Residues on grass forage immediately after spraying at the rate of 1.12 kilograms per hectare were about 100 ppm, which rapidly decreased to 30 to 50 ppm within two to four days (Morton et al 1967, Getzendaner et al 1969).

The decomposition and environmental dilution of herbicides include many processes. Biologically, herbicides are metabolized by *Aspergillus* (Altman and Dittmer 1968). Chemically, they are reduced by oxidation and hydrolysis. Light destroys 2,4-D and picloram (Weber et al 1973). Transfer through the air, through soil, and by runoff dilutes these chemicals to extremely low concentrations. Norris (1971) never found herbicide concentrations greater than 1 ppm and seldom found concentrations over 0.1 ppm in running water during seven years of monitoring spray application in the western United States. Picloram or mixtures of picloram with the phenoxy herbicides at 1,000 ppm had no detectable effects on four soil processes: ammonification, nitrification, sulfur oxidation, and organic matter decomposition (Tu and Bollen 1969).

Herbicides may enter water in lakes and streams via drift of materials and via direct application where water sources are within the boundaries of treated areas. Herbicides may enter groundwater from surface flow and by leaching. Direct application can be avoided, but the flow over and through the soil cannot be eliminated. However, the short persistence of most herbicides and the resistance of them to leaching reduce the potential for stream pollution. Hazards to fish are reduced if spraying over and near streams is avoided (Juntunen and Norris 1972). Where proper precautions are taken, the hazard to fish is nil from the use of the herbicides emphasized in this chapter.

When 2,4-D and picloram are applied according to recommended procedures, there is little hazard to humans, animals, and food chains. These chemicals are selective, potent, easy to handle, nonpoisonous, nonaccumulative, and noncorrosive (Klingman and Shaw 1971). Their regulated use on rangelands needs to be continued.

RESPONSES OF RANGELAND PLANT COMMUNITIES TO HERBICIDES

Reduction of top growth and elimination of some brush by chemical and mechanical means brings no more than temporary change in the vegetation. Soil sterility caused by phenoxy herbicides is short-lived. The selectivity of phenoxy herbicides leaves sufficient cover for erosion control (Barrons 1969, Hunter and Stoble 1972, Isensee et al 1973, Mullison 1972). These chemicals may cause longterm changes in the habitat (Klebenow 1970), but the danger that cow's milk will be tainted lasts no more than a couple of weeks for 2,4-D and its commonly used relatives (Leng 1972).

Herbicides are applied to areas of land and vegetation, but more often than not the results are reported for individual species. Conversions of stands from mostly sagebrush to grass showed success at rates of 100 to 400 percent increased forage on 70 percent of the treated areas in Wyoming (Kearl 1965). Clearly, spraying of sagebrush, mainly *Artemisia tridentata,* in other states as well, has increased forage for livestock. Also as clearly, sagebrush has returned and the stands thickened when spraying, fire or other forms of control are stopped.

The effects of herbicides on other species associated with *Artemisia tridentata* have been erratic. Hyder (1972) reported 90 percent kill of *Delphinium geyeri*; Laycock (1967) found a two-thirds reduction of *Petradoria pumila. Chrysothamnus viscidiflorus* and *C. nauseosus* being less susceptible than *Artemisia tridentata* hardly changed. *Purshia tridentata,* a highly palatable browse, was relatively undamaged if the dose of 2,4-D was less than 2.25 kilograms per hectare, favorable growing conditions occurred after the spraying, and the *Purshia* plants soon became more than 30 centimeters tall (Hyder and Sneva 1962). Undesirable annual forbs and grasses return quickly unless perennials are established. The life expectancy of sprayed, mechanical treatments, and seeding of *Artemisia* stands has been estimated between 15 and 20 years (Sneva 1972). Good management can extend that period.

Reduction of *Artemisia* monocultures to mixed sagebrush, grass, forbs, and other shrubs does more than provide forage for livestock. Moisture loss from deep soils is reduced (Sturges 1973), and wild animals may be favored with more grass and forbs, as are elk (Wilbert 1963, Ward 1973), pronghorn, and sage grouse if patches of *Artemisia* are left. The presence of more grass and less brush and forbs may favor mice and reduce the number of pocket gophers (Turner 1969). Tops of shrubs such as *Salix scouleriana* and *Amelanchier alnifolia* may be reduced and sprouts increased; thus game habitat improved (Mueggler 1966). The appearance of larger forage supplies on the sprayed areas permits improvement of untreated areas by reducing the grazing pressure on them. ***Artemisia* control on 5 to 15 percent of the best land promotes management and increasing forage supplies on all the land.**

Reduction of *Prosopis* has been tried on a practical scale with machines, herbicides, and periodic fire. None have had more than temporary results and the mesquite brush always returns. Many reasons have been given for the increased *Prosopis* including overgrazing and bare soil. Brown and Archer (1989) showed that the seedlings rapidly developed deep root systems, escaping competition for moisture from shallow rooted grass and forbs. Perhaps a better objective than removal of *Prosopis* brush and its woody associates would be raising of exotic and/or native animals that prefer the brushy habitats. That objective could support brush management rather than brush control.

The genus *Quercus* contains many species that occupy sizable rangeland areas. Most species sprout from the base when the tops are removed or killed with herbicides. *Quercus* furnishes browse for game, and the acorns are valuable food for many animals. If *Quercus* control is desirable, each species must be approached as a separate problem. No treatment fully prevents regrowth or reestablishment of oak. Each stand needs to be managed for stated objectives and the oak controlled or encouraged to increase accordingly. Herbicides are tools to be used in that kind of management.

Undesirable annual plants occupy many millions of hectares of western rangeland. Chemical and mechanical control of them, such as *Salsola* spp., *Halogeton glomeratus, Madia glomerata,* and *Bromus* spp. have not been successful, except on a small scale and in conjunction with other practices. Most annuals abound in pioneer successional stages, and problems with them disappear when range condition improves in response to managerial and cultural practices. Spraying to reduce annuals may be justified to promote establishment of seeded perennial grasses and shrubs. However, without competition from the perennials, the annuals will rapidly dominate.

Shrubs in Arkansas hardwoods and mixed brush in southern Texas regrows in a few years thereby reducing livestock forage production. **Short of clearing for cultivation, brush control by any means has a finite life expectancy until the original stands return.**

Herbicides are highly valuable tools in rangeland management, but always the objectives for using them must be clearly stated. **Herbicidal treatments, like other tools, must be parts of overall rangeland management programs.**

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22

Prescribed Fire in Rangeland Management

Prescribed fire tends to replace other techniques for rangeland vegetation management and research into its benefits and use have increased for several reasons. Perhaps the most important is its replacement of herbicides to control undesirable plants. Cost of mechanical treatments has increased beyond practical usefulness. Fire is a natural environmental factor, now looked upon with little disfavor.

To use fire as a tool, one must employ it skillfully, confine it to predetermined areas, and control intensity of heat and rate of spread. This is **prescribed burning** or, as it is sometimes called, **controlled burning** (Biswell 1989). In contrast with activities aimed at prompt discovery and suppression of wildfire, **prescribed burning concentrates on the setting of fire in a manner that will accomplish desired purposes.** Accumulated understanding of fire behavior, precaution, good judgment in its use, and tested firing procedures have made prescribed fire a safe tool for use on rangeland.

FIRE CHARACTERISTICS

Burning or combustion is an oxidation reaction that requires the proper combination of heat, oxygen, and fuel. Ignition will not occur until all three factors permit combustion. Variation in the rate of burning is controlled by the balance among them. Smoldering indicates a combination of heat, oxygen, and fuel that permits slow oxidation. As combustion conditions increase, flaming occurs; and under extremely favorable conditions, flaming may involve leaping flames, loud noises, and rapid air movements. **In fire-management operations, control of heat, oxygen, and fuel regulate combustion.**

Heat intensity and heat duration probably are the principal ecological influences of fire on plants and animals. For a fire moving through vegetation on a single front, **fireline intensity has been expressed as Btu released per second per meter of fire front** (one Btu equals 252 calories). This index varies directly with the energy per kilogram of fuel, the weight of fuel in kilograms per square meter, and the rate of forward spread in meters per second (Byram 1959). Intensity expressed this way was shown to vary from 1.5 to 9000 Btu/second/meter in forest and 1.5 to 2000 Btu/second/meter in grassland in Australia (McArthur and Cheney 1966). Calculation of the fireline intensity index is relatively easy because fuel quantity and rate of fire spread can be measured. The number of Btu per kilogram of fuel is relatively constant (approximately 187,000). In the Australian study, fire did little damage to trees when intensity ratings were low. If the rating was high, boles and crowns of *Eucalyptus* were damaged, and trees 5 meters in height were killed.

Fire reaction intensity is the rate of heat release per unit area and it varies with both quantity of fuel consumed and rate of spread. McArthur and Cheney (1966) found that as the quantity of fuel doubled, the rate also doubled, and as a result, reaction intensity increased fourfold. For example, fuel consumed increased four times between 6.4 and 23.2 tons per hectare and intensity increased by a factor of almost 8. Fast-moving fires usually consumed more fuel than did slow fires.

The available quantity of fuel that will burn is a function of the moisture profile in the vegetation as indicated for four time periods after rain (Table 22-1). If another line were added to Table 22-1 in which intensity was 6560 Btu/second/meter, a crown fire would be indicated, adding about 7.4 more tons of fuel per hectare, and resulting in a wall of flames 20 to 25 meters in height. If such a fire traveled at 0.6 meters per second, the intensity would be 100,000 Btu/second/meter of fire front. Fireline and reaction intensities are closely related but measure separate ecological effects.

Fire duration--burnout or residence time--also influences fire effects. It is directly related to heat yield and fuel quantity, and indirectly related to rate of combustion. In the Australian study, the rate of combustion was faster when moisture content, particle size, and compactness of fuels were low, Under similar burning conditions, twenty-five tons of *Eucalyptus* material per hectare burned at the rate of 353 seconds per square meter, while 5 tons of grass per hectare burned in 10.3 seconds. Heat penetration into soil, through bark, and into living tissue increases as fire duration increases.

Table 22-1 Fireline intensity in a *Pinus radiata* stand in Australia as influenced by fuel moisture (McArthur and Cheney 1966).

Treatment, Days after rain	Total fuel tons/ha	Fuel consumed tons/ha	Rate of spread m/min	Flame height m	Intensity Btu/sec/m
1	42.2	6.9	1.5	0.3	220
2	42.2	6.4	1.5	0.6	275
14	42.2	23.2	2.9	1.2	1770
30	42.2	34.1	4.0	2.7	3675

Damaging effects of fire on living organisms are related to fire intensity and burnout time, which have been characterized by studies of stationary fire under controlled conditions. Fires in ecological settings are moving fires that seldom have the characteristics of laboratory fires. Continuously accurate prediction of effects from prescribed burning requires knowledge of the correlation between fire characteristics and biological consequences. An adequate system for analyzing these relationships is not available for rangeland burning. One needs to be developed.

FIRE BEHAVIOR

Knowledge of fire behavior is essential to successful use of fire in rangeland management. As a fire proceeds across a landscape, it responds to characteristics of weather, topography, and fuel. Fire control requires that unplanned increases in fire intensity and rate of spread be held to a minimum. Fire storms or blowups should be avoided.

Fire continues across a landscape only with heat transfer sufficient to ignite new fuels, which is accomplished by heat conduction, convection, radiation, or some combination of the three methods. Conduction is of little consequence in managed burning because wildland fuels are poor conductors of heat. Convection, or direct movement of hot air masses, is associated with weather phenomena and with the fact that warm air rises. Radiation, the rays of energy sent out from the fire, plays a major role in fire behavior. Burning piles of debris radiate heat toward each other. Radiant heat received by an object decreases as the square of the distance from the fire. An object 10 meters away from a fire receives 0.01 as much heat as one a meter away. Thus fire behavior, including ignition, combustion, and spread, is closely dependent upon convection and radiation. These elements are supplied in amounts that vary because of differences in weather, topography, and fuel characteristics.

Weather

Precipitation, air temperature, relative humidity, and wind velocity are the major weather variables that relate to prescribed burning. The seasonal precipitation pattern determines the length and severity of the dry season. Mediterranean climates often have a dry period lasting six months or longer. During this period, wildfires are frequent and prescribed burning possible. Areas with monthly rain or a short growing season due to cool temperatures are not so susceptible to wildfires. However, burning a few days after a rain can be of value in reducing unwanted standing debris without damaging the base of living plants or exposing mineral soil.

Water, as moisture in fuel, acts in three ways. First, it has a cooling effect, because heat is used to convert water to steam, thus reducing intensity of burning. For this reason, **water used to stop a fire should be directed at the fuel in front of the flame rather than on the flame itself.** Partial combustion and increased smoke indicate that less heat is being liberated than was being liberated before water was applied. Second, moisture present in the air as steam or humidity reduces radiation, which retards drying of fuels near the flames. Third, cooling reduces release of volatile and flammable oils.

Rainfall influences the amount of herbaceous material produced, the time of its curing, and its moisture content. Dampening of light fuels quickly reduces combustion, but they dry rapidly. A grass cover may be unburnable immediately after a light shower or after dew in early morning but may become an extremely combustible fuel a few hours later. Conversely, heavy fuels, such as logs, stumps, and limbs, wet slowly and dry slowly.

Air temperature has a direct effect on fire behavior. When temperatures are high, less heat is required to raise fuel temperature to the ignition point, and for continued combustion as a fire spreads. High air temperature has an indirect effect because it decreases moisture in air and fuel, thereby favoring fuel burning conditions.

Relative humidity is the measure of air dryness. Other conditions being equal, humidity decreases with increase in temperature. The drier the air, the drier the fuels and the more likely prescribed fires will burn out of control. While no exact guidelines can be given, probably prescribed fires in light fuels (grasslands) should not be attempted when the relative humidity is below 25 percent and the temperature is above 24 to 27 degrees Centigrade. If fuels are dry and heavy with loose mixtures of twigs and combustible leaves, relative humidity should be above 35 percent and temperature below 24 degrees Centigrade during prescribed burning. In most regions, these conditions fluctuate more or less predictably according to time of day and season of year. These three weather conditions, along with wind conditions, determine whether prescribed burning should be done in morning, afternoon, night, or not at all.

Wind causes a flame front to move ahead, crown, and jump to new locations. Moving air brings oxygen to the flames and removes carbon dioxide, increasing combustion rate. It also moves hot air masses ahead of the flame and close to the ground, where radiant heat dries and preheats new fuels; thus, ignition is made easier or even spontaneous ahead of the advancing flame front. Combustion runs with high winds; long fingers of burned areas result. As the fire point is pushed forward, the sides tend to be drawn inward.

Control of oxygen often is accomplished by the smothering of the flames with soil, water spray, and chemical fogs. These substances reduce the oxygen content of the air reaching the flames. Combustion ceases when the oxygen content of the air becomes lower than 15 percent. Beating a light grass fire with wet sacks or special swatters removes oxygen from the fire for an instant. Reignition depends on the amount of heat retained in the fuel.

Awareness of wind conditions at the time of ignition and prediction of winds until a prescribed burn is completed are necessary for success with fire as a tool. Seldom should a fire be set if the wind velocity will be greater than 10 to 12 kilometers per hour. At those speeds, trees of pole size in open stands sway gently, wind is distinctly felt on the face, loose paper moves, small flags flutter but are not continuously extended, and grasslands show continuous wave motion.

Topography

Roughness of the land surface influences weather generally and causes day-to-day variation in weather, and hence in fire behavior. Fuels on the upslope side of the flames are closer to the heat source and receive more radiant heat than do fuels on the downslope side. As steepness of slope increases, rate of fire-spread increases. Narrow, steep-sided canyons tend to act as chimneys that enclose heat, so fires burn rapidly with the upward air movements.

Elevation influences the growing season and fire season. Grasslands and shrublands at low elevations may be subject to burning for six months or longer, while alpine grasslands a few kilometers away may not be dry enough to burn. Mountain tops tend to be cooler and more moist than the lowlands by day but warmer and drier by night.

Fuel

The third major element that controls fire behavior is fuel. **Fuel moisture, more than any other single factor, reflects precipitation, air temperature, relative humidity, and wind velocity.** It has been used extensively in fire-danger rating systems. Precautions to prevent wildfires and even admission to forests and brush fields are determined by fire danger ratings. In fine fuels, dryness and fire danger change rapidly. When fire danger ratings begin to indicate that care is needed to prevent wildfires, prescribed burning should not be attempted.

Fuels themselves have several characteristics, such as volume or size, continuity, and compactness. Small materials with a high ratio of surface area to volume dry quickly and burn readily. For example, a sheet of paper burns easily, but a book may be difficult to ignite. Twigs, needles, and grass leaves ignite quickly and completely oxidize in a short time, while logs and large limbs may only char on the outside. A mixture of large and small materials is the most flammable fuel in terms of size. The small materials ignite easily and promote rapid fire advance, while the larger pieces increase heat release and burnout time.

The horizontal and vertical continuity of fuel influences fire behavior. Patchy fuels will burn irregularly, leaving unburned islands. A young coniferous forest that has abundant herbaceous fuel, dead overtopped shrubs, and lower limbs draped with pine needles is subject to rapid and severe burning. Chaparral and sagebrush/grass provide combinations of material size and continuity of fuel which burn rapidly. Species in both types and others have volatile oils that promote rapid burning.

Compact material does not burn as readily as fuels that are loosely structured. Mulch on the soil surface has little influence on rate of fire spread, but it may contain a smoldering fire for long periods. It may flame if drafts bring oxygen, or go out with lack of oxygen. Other conditions being equal, fire spreads most rapidly in grasslands and second most rapidly in logging slash with fine woody materials and a mixture of dry herbaceous plants. Brush fields and forests with abundant dead materials are intermediate. Timber stands with little or no ground fuels burn least rapidly, if at all.

Few precise descriptions exist of extremely complex weather-topography-fuel interactions that occurred in a particular fire behavior and that caused certain ecological effects. Without combined work on all these aspects of fire, burning will remain a tool in the hands of experienced persons, but a danger for the novice.

RESPONSES TO BURNING DURING CERTAIN SEASONS

Individual plants, species, and vegetation respond to burning during different parts of the growing season. A long series of studies in the Kansas Flint Hills has resulted in specific recommendations when to burn the prairies. Late spring burning maximizes the tallgrasses when it is near the initiation of spring growth, but is damaging after growth begins. Earlier burning reduces yield of cool-season species (especially *Poa pratensis*), promotes more perennial forbs, and increases diversity (Towne and Owensby 1984). Late spring burning reduced cool-season and shortgrass species in the loess hills (mixed prairie) of southern Nebraska (Schacht and Stubbendieck 1985). Burning after cool-season growth begins favors warm-season species but should not be done in drought years (Engle and Bultsma 1984).

In Montana, burning before late June stimulated production of *Agropyron smithii* and *Bouteloua gracilis* but did not affect *Carex filifolia* (White and Currie 1983a). Spring burning of *Artemisia cana* with moist soil resulted in sprouting, but fall burning killed more plants (White and Currie 1983b). Burning in March reduced *Juniperus pinchotii*, *Aristida*, and *Gutierrezia sarothrae* (Steuter and Wright 1983), but burning of *Juniperus virginiana* should be in late spring because of low leaf-water content (Engle et al 1987). In Texas, changes in *Stipa leucotricha* biomass and density were due to season of burning, effects on competition, and post-burn weather (Whisenant et al 1984). When *Sporobolus wrightii* is burned at any season quality of green forage is temporarily increased but quantity is reduced for at least 2 years (Cox 1988). Plants and vegetation respond to season of burning, as well as other environmental conditions.

TEMPORARY OR PERMANENT EFFECTS?

Burning can cause longterm changes in woody vegetation. For example, burned *Coleogyne ramosissima* in southwestern Utah showed no signs of recovery after 37 years (Callison et al 1985). On a shortterm basis most brushlands return to shrub dominance a few years after burning. In south Texas fire temporarily reduced *Ericameria austrotexana* about half as well as other species (Mayeux and Hamilton 1988). Shrubs that tolerate fire return quickly to previous stand dominance, including *Serenoa repens, Prosopis* spp., many *Acacia* spp. and the sprouters in the California chaparral. South of Tucson, Arizona, regrowth of semidesert shrubs in 5 years was equal to the stand before the fire (Martin 1983).

Burning is the most effective control of *Artemisia tridentata* subsp. *wyomingensis* in southwestern Montana. It also showed a reduction over an 18-year period without grazing (Wambolt and Payne 1986). This species, which reproduces only by seed, gradually invaded seeded *Agropyron* stands after all types of brush control in southeastern Oregon (Heady 1988).

OBJECTIVES IN THE USE OF FIRE

Primitive man used fire as a tool with which to manipulate vegetation and animal populations for his benefit. Modern man has developed public attitudes and has built a firefighting organization aimed at eliminating and controlling fire on wildlands. This organization is highly effective, but it has not achieved full control of wildfire.

Increasingly, rangeland managers are making use of prescribed fire as a tool. As might be expected, the objectives of these persons vary widely as to kinds of conditions they hope to develop, to maintain, or to prevent with fire. Effects of burning are many and most have been stated as objectives of prescribed fires, although they may have no more than a minor impact.

To Alter Vegetational Composition

This objective comes in numerous forms, such as removal of undesirable shrubs and herbaceous species, less competition for desirable species, to favor certain plant species, and as stated by Biswell (1989), "to restore the ecology." Perhaps it is the most common purpose of prescribed fire in natural vegetation.

Dominants in the tallgrass prairie in Oklahoma increased by burning and annual weedy forbs were reduced (Gillen et al 1987, Svejcar 1989). Plants that are not climax dominants and those which require bare soil for seedling establishment often are encouraged by burning. In addition to trees, the seral species include many that produce abundant forage, browse, nuts, berries, seeds, and tubers that favor various animal species. Fire every 3 to 5 years decreases *Aristida* and *Sporobolus* and increases

Andropogon dominance in south Florida (White and Terry 1979). Fire can benefit old stands of *Cercocarpus ledifolius* but not vigorous young stands or those in heavy fuel such as *Artemisia* (Gruell et al 1985). Both *Hilaria mutica* and *Eragrostis curvula* withstand high burning temperatures, which allows effective burning of shrubs in the stand (Roberts et al 1988).

To Increase Livestock Forage and Facilitate Management

Domestic and game animals prefer to graze on recently burned areas. Animals are attracted to more palatable feed, to more easily available feed, or to both. Often they overgraze burned areas, especially when these areas are small in relation to the number of animals attracted. However, this behavioral characteristic of large herbivores may be used to advantage in certain situations. Duvall and Whitaker (1963, 1964) found that burning every three years increased forage production on cutover pine rangelands in Louisiana that were dominated by *Andropogon tener*. Forage utilization was heavy on the new burn, moderate on the two-year-old burn, and light on the three-year-old burn. Animals followed the burn, so rotation of burning resulted in rotation of grazing without the cost of extra fencing. Patch grazing tends to disappear in the ungrazed parts (Andrew 1986).

Fire on the Texas coastal prairie removes shrubs, the rough grass debris, improves livestock distribution, reduces external parasites, and removes excessive mulch. Winter burning of *Spartina spartinae* encourages grazing on new growth during the winter. Burning of marshes along the southeastern United States Gulf Coast reduces *Spartina* and encourages legumes and annuals, thereby encouraging grazing and increasing waterfowl food (Givens 1962). Wolters (1981) recommended thinning *Pinus palustris* to between 12 to 20 square meters of basal area per hectare and winter burned on a 3-year schedule for combined grazing and timber.

Reduced cover produced by burning facilitates movement and visibility for the traveler. Hunters prefer relatively open vegetation. Their uses of land and hunting success are directly related to accessibility. Few modern hunters camp, hunt, and hike in dense brush and forest when openings and edges are available.

Access is important to the modern land manager and administrator. Livestock control is difficult in dense vegetation. Openness in the forest understory facilitates timber inventories and sales. Viewing natural landscapes requires openings. Various reasons exist for maintaining open vegetation with prescribed fire.

The ability of prescribed rangeland fire to increase quantity of livestock feed depends almost entirely upon changes in botanical composition of the vegetation, such as development of grasslands in place of woody vegetation. Shrubs that furnish browse for domestic animals and game often grow beyond their reach. Burning can be used to maintain shrubs in a usable size by killing the taller growth, stimulating sprouts, and fostering seedling establishment that renews browse production without greatly altering botanical composition.

Burning appears to reduce the quantity of forage produced in the grasslands of central North America (Aldous 1934) and on annual grassland in California (Hervey 1949). Conversely, Wahlenberg et al (1939) reported increased forage for ten years after burning stands of pine and bluestem in Mississippi. In Idaho, increase of grass in *Pinus ponderosa* after prescribed fire was related more to duff consummed than to fire line intensity (Armour et al 1984).

To Increase Quality of Forage for Livestock and Game

The increase in animal production following burning of coarse grasses probably is due to the improved quality of the feed rather than to an increase in quantity of feed. Smith (1960) in Australia found that the crude protein percentage in the herbage was increased after burning although the total herbage per hectare decreased. Similar results were obtained in Louisiana by Grelen and Epps (1967) who found that spring burns gave better-quality feed than did winter burns. Several studies in longleaf pine/bluestem and pine/wiregrass ranges in the southeastern United States showed that burning improves quality, palatability, and availability of forage, all three improvements resulting in increased livestock production (Duvall 1962, Southwell and Hughes 1965).

Where grasses are tall and the mature herbage unpalatable, it may be necessary to burn accumulations of undecomposed old growth. Burning of *Distichlis spicata* improves the quality of forage. Most studies in the coarse-grass areas of tropical grasslands have shown increased quality of forage with burning. In the central United States prairies, this benefit appears in a few studies when timing of the fire is carefully controlled. Farther west in the mixed prairie, burning is not a common practice and has received little study, nor has burning been found advantageous in the bunchgrass and annual-grass types of the western United States.

A system of burning 10 to 15 percent of a management unit each year in the chaparral of California has been suggested for deer-management objectives. Unburned areas provide cover, and burning results in nutritious sprouts for two to three years. The proportion of the area burned each year is determined as a fraction of 1 over the years it takes the chaparral to reach burnable conditions and to become too dense for efficient deer use (Biswell et al 1952).

To Prepare Land for Seeding

Prescribed fire is used to prepare sites for and to encourage regeneration of many desirable plant species. Ruyle et al (1988) reported that areas where burning reduced cover also had 40 percent more seedlings of *Eragrostis lehmanniana* than unburned areas. Competition, climate, and other factors influenced seedling establishment.

After a wildfire in chaparral and forests in the western United States, favorable sites usually are seeded to grasses and legumes for soil protection and forage. Where the ash is white and thick, both plant establishment and growth show a response to reduced competition and the residual minerals for a year or two. Black ash indicates incomplete combustion and contains few available minerals. It results in new stands lower in vigor than those growing in white ash. Any increase in available minerals due to burning is temporary because fire cannot add minerals to the system. It releases those minerals already present but unavailable in organic compounds. Advantage is taken of the minerals released by a rangeland fire, but this release seldom is a major objective in prescribed burning.

For greenstripping to reduce wildfire in monocultures of *Bromus tectorum*, seeding strips to *Agropyron cristatum*, *Kochia prostrata* or some other plant with low flammability help in fire control.

Burning to Manage Wild Animals

Burning encourages many species of animals by changing the vegetation. Numerous animal species are best adapted to seral vegetational stages and to mosaics of dense and open vegetation which provide shelter and food. As the following examples show, favorable conditions for certain species may be developed with judicious use of fire, but other species may be adversely affected. In Michigan and Wisconsin, grassland with less than 25 percent woody cover is needed for the prairie chicken (Amman 1957). Sharptail grouse require less than 40 percent woody cover in scattered clumps (Miller 1963). Ruffed grouse are best adapted to woody cover with a scattering of openings about 0.1 hectare in size where grass, herbs, and brush are dominant. The habitats for these three grouse species may be maintained by general burning, selective burning, and spot burning. Blacktailed deer along the Pacific

Coast increased several fold when forest was converted to brush (Dasmann and Dasmann 1963). Prescribed burns in aspen promote sprouts that favor elk and deer. Prescribed fire is a useful tool in the development and maintenance of optimum wildlife habitat, including food, cover, and ideal conditions for animal harvesting.

Control of tsetse flies, other insects, ticks, and reptiles has been attempted with burning. In tsetse fly reduction schemes in Africa, the real purpose is to change the fly's habitat from brush/grass or woodland to grassland. The fire itself kills few flies and is only one of many methods used to combat them. Success depends upon the completeness of vegetational conversion to grassland and its maintenance.

Burning destroys ticks that are on the herbage at the time of the fire, but those on hosts and in sheltered positions escape the heat. A high reproductive potential makes effects of fire on tick populations temporary. So many individual ticks, and other animals too, escape the heat of fire that direct control with fire has doubtful value. The use of prescribed fire to control animal populations through change of habitat is more promising.

To Reduce Hazards from Wildfires

As undecomposed organic materials accumulate, the danger of damaging wildfire increases. Potential fuels may be in the form of large debris deposits left after logging; thick litter, dead shrubs, and young trees making a continuous fuel supply from soil to tree crowns; large areas of mature chaparral; or grasslands with abundant litter. Wildfires have a greater chance of burning unchecked and doing considerable damage to life, property, and natural resources when fuels are abundant. Land managers have used prescribed burning to reduce the fuel supply and thereby to reduce the chance of large catastrophic wildfires, especially in forests and woodlands.

PRESCRIBED BURNING

Planning for a prescribed fire begins with accumulating knowledge about the ecological conditions to be changed or perpetuated, processes involved with the fire itself, and the possible objectives in using fire. To determine the appropriate application of fire to the landscape a plan of preparation is absolutely essential because many neighbors and interested agencies must be involved before the fire is set.

Planning for a Prescribed Fire

Planning for a prescribed fire begins when the manager realizes that a certain area of land might be improved for certain purposes if it were burned. Evaluation of alternative methods such as bulldozing and use of chemicals should have indicated that fire would do a better job at less cost than other methods.

The prescription or plan for burning a particular land area includes four main types of activities. The first is a planning phase, the second concentrates on preparation for the fire, the third concerns the fire itself, and the fourth is postburn management. In practice the second, third, and fourth steps require continual updating.

The exact area to be burned requires careful consideration in two respects. First, soil and vegetation must be such that they will produce a favorable return on objectives; the area, in other words, must be both worthy and capable of being improved. Second, the area must be of a size and shape that will permit burning in a day with reasonable expectations of successful burning and complete fire control.

Costs of burning need to include many items and analyzed so that the landowner is not over-extended financially. Costs include labor, rental of equipment, supplies, food purchase and preparation, liability insurance for men and property, any loss of forage that must be left as fuel, and depreciation on equipment. These costs may total five or six times more per hectare on a 20-hectare burn than one 200 to 250 hectares in size. Conversely, costs per hectare tend to increase with fires larger than about 500 hectares because the danger of escape increases, and thus more, insurance, workers, and machines are required. However, the helitorch is less expensive on larger areas with rough topography than ground ignition (Rasmussen et al 1988).

Prescribed burning requires cooperation among many organizations. The necessary skills and experience to be a good "fire boss" reside in only a few people. The tools for fuel preparation and fire control may belong to different organizations. For example, a private landowner may have adequate machinery to build fire lines but is not likely to have adequate fire-suppression equipment. Rangeland ownerships are usually mixed, so neighbors, those responsible for public lands, police forces, air pollution organizations, and firefighting organizations will need to be kept informed from the beginning day of planning until the fire is out. The labor and equipment in service on the actual fire often include volunteers and persons working on an exchange basis. Where prescribed burning has succeeded, there has been continuous cooperation among all concerned. Service to the people must be provided, including water, food, first aid, and toilets.

An effective group pools available talents in many aspects of the program. They schedule the burns so that equipment and men are available; they appoint the fire boss for each burn; and after onsite inspection, they give the landowner instructions to make sure the burn is successful. Included in the instructions are items such as fireline location, distance to clear debris from firelines, preburns or night burns to widen firelines where danger of escape is great, winter cleanup of brush piles and logs, and date in the spring to discontinue grazing so that grass will carry the fire. A common adage about prescribed burning is that preparation gives a successful burn, planning promotes adequate preparation, and cooperation permits adequate planning.

Preparation of the Site

Construction of a fireline that completely encloses the proposed burn is of major importance. **Firelines, sometimes called firebreaks, firelanes, or control lines, are strips of land devoid of burnable materials**. Roads are utilized for this purpose, and other firelines are constructed by scraping of land with a bulldozer blade, road grader, disk or other power equipment, and by hand. The width of bare soil depends on the width of the required machinery and the conditions of fuel and topography. One pass with a bulldozer blade is about the maximum width. Other strips, hand prepared in light fuels, may be as narrow as 0.3 meter. A width greater than 3 meters is of little value because conditions that cause fire to spot will cause it to jump much farther than 3 meters. **If a fireline 3 meters in width will not permit fire control, prescribed burning should not be attempted.**

A fireline may be a part of a **fuelbreak system, which is a strip perhaps as much as 400 meters in width, in which fuel has been modified to facilitate fire suppression**. Examples of fuelbreaks include reduced tree cover and snags in woodlands and strips of chaparral on ridges converted to grassland. The reduced fuel provides soil cover against erosion and still permits firefighting in dangerous chaparral fuel situations. Removal of snags within 60 meters of a fireline, burning-out of danger spots, and winter cleanup of debris add effectiveness to a fuelbreak system.

Placement of the fireline in an advantageous relationship to topography, access, fuels, and predictable wind changes reduces danger of fire escape. The fireline is placed so that the fire crew can reduce spotting, have control if the direction of fire spread changes, and be prepared if the speed of fire travel increases. The most common location for a fireline is a ridgetop. Irregular and gusty air currents, including whirlwinds, may carry embers across a ridgetop fireline, but the fire must spread downhill after crossing the ridge. A rule of thumb for reducing fire spread is that most trees, snags, and brush cover that extend above the ridgetop level on either side of the fireline should be removed. Resulting brush piles near the fireline should be removed ahead of the prescribed fire. Obviously, sharp angles in the fireline and narrow fingers to be either burned or unburned should be avoided. Firelines should not be placed at the bottom of a narrow valley, and attempts to burn part of a narrow, steep-sided valley should be avoided. Saddles are danger points where air currents converge and move to cross slopes.

Firelines may be needed within the prescribed burn for control of rate of burning in projected hot spots, exclusion of areas from the overall fire, and facilitation of a firing plan. For these lines to be properly located, the sequence of firing must be selected early in the planning process.

Closely associated with preparation of internal fire lines is manipulation of fuel. Undesirable trees, such as *Pinus sabiniana* in the California chaparral, should be felled several months ahead of the fire, allowing time to dry so that they will be consumed and will not contribute to dangerous fire spread during burning or hinder land use after the fire. Alternate strips of crushed and uncrushed brush (strips the width of one or two bulldozer blades) will provide sufficient dry fuel to burn the adjacent live brush. The advantages of fuel preparation are more complete consumption of large woody materials, reduced fuel moisture content so that burning may occur when danger of escape is minimal, and rearrangement of fuels to facilitate ignition.

One-Day Preignition to Fireout

The day ahead of the prescribed burn is one for final check on permits and preparations. These include notification to police, fire-fighting organizations, and neighbors for three purposes. The first is to warn them of impending fire, the second is to invite observers, and the third is to confirm who will be helping with particular equipment at appointed places and times. Invitations to press, radio, and television personnel for them to report the objectives and progress of the fire will help gain public acceptance of prescribed fire. Other preignition activities include taking due regard of air-pollution regulations and obtaining the necessary permits concerning smoke.

Most prescribed burns are set mid-morning or later. The time before setting gives the fire-boss an opportunity to review the fire plan. Also a review of the communication system, safety precautions, exit routes, the duties of team captains, and answers to questions provide confidence that all will go well.

Slope may be used to advantage in prescribed burning. Fires set at the bottom may burn to the ridgetop and go out under fuel conditions that would prevent burning on level ground. Fires set on ridges burn slowly downslope. However, burning material may roll and cause spotting ahead of the flame front. In forest areas, a ground fire moving downslope against a wind can develop into a racing upslope crown fire with slight increase in wind. At night, downslope winds can fan a ground fire out of control.

The time of day that the fire is set may result from local experience which has shown the time when sufficient heat will be generated to obtain the desired objectives. The cooler, more humid parts of the day can be the times for best containing a fire. A plan of ignition during late morning after dew has dried and burning of the whole area by midafternoon often meets these specifications. Logs, stumps, limbs, and other large fuels will continue to burn, but fire escape from them is unlikely because lighter ground fuels are gone. Late afternoon, when air turbulence tends to increase, should be a time of patrol and containment rather than one of fighting escaped flames.

Prescribed burning at night usually takes advantage of the highest humidity and least wind for extremely hazardous fuels, but night burning may reduce communications and visual appraisal of burning progress. This is especially true in mountainous areas. Night burning is most successful on flat lands. The actual day and hour of ignition, then, is determined largely by tactics for managing the fire and the generation of smoke.

Smoke management requires attention in planning prescribed fires. There is less smoke with dry fuels, backfires than in headfires, and high energy fire that produces a tall convection column (Green 1981). Many locations have burn days for agricultural and rangeland burning when the smoke travels away from people. Night burning may be prohibited because smoke settles or is not blown away. Fuels with high moisture content produces more smoke than when they are dry; therefore, pile heavy fuels before the fire and burn when they are dry to obtain faster and more complete combustion.

Although the day of the burn may have been selected a year or more before ignition in order for personnel and equipment to be properly scheduled, the final decision by the fire boss to set the fire is left to the last minute. Excellent weather forecasts are prerequisite to successful prescribed burning. Predictions of wind direction and velocity, air stability, temperatures, and relative humidity are essential. These need to be available to the fire boss on the day before the fire, on the day of the fire before it is set, and afterward if changes are likely to occur.

Published information and experience with rangeland burning are accumulating, some of which is given here as additional hints for rangeland fire.To burn mature *Juniperus ashei* provide a few windrowed trees that have been cut less than 100 days so that the leaves are dry and still attached (Bryant et al 1983). Prescribed burning of *Artemisia tridentata* is feasible with ice and snow on the ground, if the canopy is over 50 percent, the distance between plants is not more than half their height, and the wind about 8 kilometers per hour (Neuenschwander 1980). Monospecies stands of desert shrubs such as *Coleogyne ramosissima* and *Larrea tridentata* will not burn with less than 500 kilograms of fine fuels per hectare to carry the fire. Two hand prepared firelines about 0.6 meter wide, 15 to 25 meters apart, with the area between them burned when danger of fire escape is extremely low make a highly effective firebreak in grassland. This system has been used in preventing wildfire burning of isolated tree thickets in wide expanses of grassland that were burned later.

Weather and Fuel Prescriptions

Safe weather and fuel moisture conditions for prescribed burning have been published for a number of vegetational types. A few examples are as follows: *Juniperus ashei* stands should have at least 500 kilograms per hectare of herbaceous fuel, wind less than 10 kilometer per hour, humidity greater than 45 percent, and air temperature less than 30 degrees Centigrade (Bryant et al 1983). Recommendations for windspeed and temperature should be less and humidity more for burning in some forest stands (Zimmerman and Neuenschwander 1983).

Semidesert grass/shrub in the Southwest needs about 700 kilograms per hectare of fine fuels to burn effectively, less if temperature is above 24 degrees centigrade. The humidity should be below 18 percent and wind 5 to 10 kilometers per hour. Heavier fuels require higher air temperature, less humidity, and less wind. A fireline 3 to 4 meters wide and strip headfire of 30 meters in the spring provides a very wide fireline (Wright 1980).

Burning of *Prosopis glandulosa* is effective at wood moisture less than 9 percent with more than 1,000 kilograms per hectare of fine fuels, temperature above 20 Centigrade, humidity about 40 percent, and wind less than 13 kilometers per hour. At 6 percent wood fuel moisture all the debris will be consumed (McPherson and Wright 1986, Wright 1986).

Designs for Igniting Prescribed Burns

Many designs for igniting wildland burns have been used. **The simplest is a single line of fire that is set to burn as a headfire (either with the wind or upslope) or as a backfire (against the wind or downslope). A flanking fire travels at right angles to slope or wind.** It may be set to burn slowly downhill or rapidly uphill. If a backfire increases dead material by killing woody vegetation, dangerous conditions can increase for headfires.

Another design, used extensively in the California chaparral, is ignition of the entire perimeter of the prescribed area. Normally, fire is first set on the lee or uphill side and is allowed to widen the firebreak before the windward or downhill side is set. As the perimeter flames burn toward the center, heat builds up and a very hot fire develops. In such a fire, the time of spread is less than that of the single-line type of burn, but heat intensity varies over the area from a relatively cool fire that consumes little woody material, near the edge, to one that burns all organic material, near the center.

Whatever ignition design is used, the original fire sets should be 15 to 30 meters inside the outside fireline, where they will burn in two directions. Sparks, burning embers, and heat are drawn into the prescribed area since that is the center of heat intensity; therefore, the chances of fire jumping the line at ignition time are reduced. The principle that one fire tends to draw another toward it, in this case across an already burned strip, is used in developing a slow-burning fire that widens the firebreak.

The same principle is used in developing intense heat and rapid burning where fuel exists between the fires. Many designs take advantage of this principle. In one design, a new line of fire is set repeatedly a few yards ahead of an advancing wall of flame by helitorch. As the center of one strip burns out, another strip is set (Fig. 22-1). Still another design calls for ignition in the center of a prescribed area at the same time as or just before the perimeter is set. If danger of escape is high, most of the perimeter is set first and the center lighted only when a safe firebreak has been burned (Fig. 22-2). A more intense type of set is one in which the perimeter is set at about the same time as ignition occurs at more or less regularly spaced locations over the entire area to be burned (Fig. 22-3).

The latter designs are known as types of area ignition. An extensive example of area ignition is used in the Karri and Jarrah (*Eucalyptus* spp.) forests in western Australia. Spot fires are set by incendiaries that are dropped from an airplane. The grid pattern spaces the spot fires so that each burns about 2 hectares. Ideally, each fire spreads slowly during the day, joins other fires toward evening, and goes out at night. Prescribed fires as large as 12,000 hectares have been burned in a day with this procedure. Incendiaries should be dropped first on the ridges and later on lower slopes so that the fire cannot spread rapidly (CSIRO 1970).

Postburn Management

A single prescribed fire, although it may result in desired effects, seldom attains a land management objective. Burning is only a part of a management program. Other aspects of management need to be included. Treatments before a fire contribute to the intensity of the fire. Grazing before the fire reduces fuel supply and fire effectiveness. Herbicidal treatment and bulldozing increase fire intensity by killing plants that then dry and become more combustible.

Treatments after a burn contribute to the results, as was practiced in control of *Adenostema fasciculatum* (Fig. 22-4). A land manager may use burning to obtain sprouts and seedlings that are more susceptible to herbicides than is old growth. Heavy grazing reduces establishment of native and introduced plant species and soil deterioration may occur immediately following a burn when cover is thin or absent and precipitation extremely heavy. Seeding must follow prescribed burning of woody vegetation if productive grasses and legumes are to be obtained quickly. Prescribed burning, then, is one land-management tool to be used on a continuing basis, when necessary, along with other practices, to promote desired vegetational composition and production.

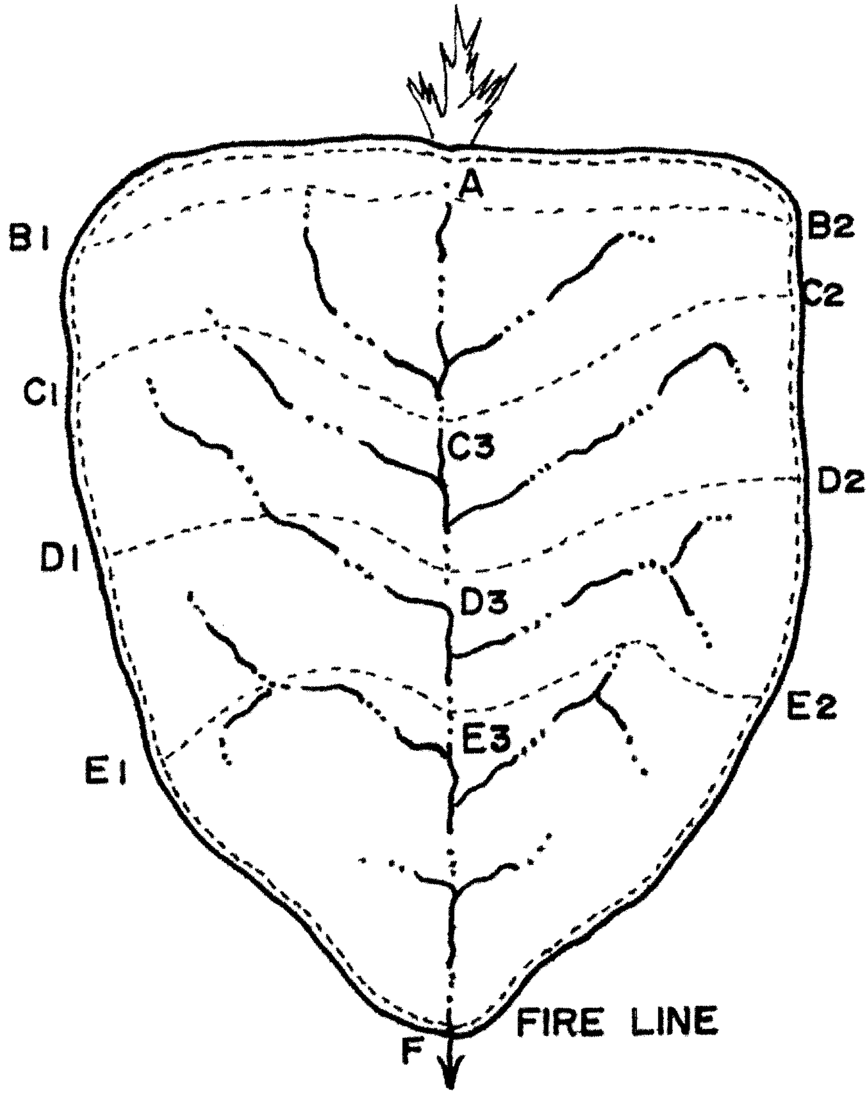


Figure 22-1 Firing in successive strips permits greater control with somewhat less intensive burning than the types shown in Figures 22-2 and 22-3. The first fire set is at A, and crews move toward B1 and B2, setting fires as they go. After a sufficient firebreak has developed, the crews set fire to C1 and C2, and at the same time, two other crews begin setting fires from C3 toward C1 and C2. When that block is burned out, the crews move to the next area and repeat the process. This design is well suited for relatively flat lands where internal fire lanes permit fire control, access, and safety of personnel.

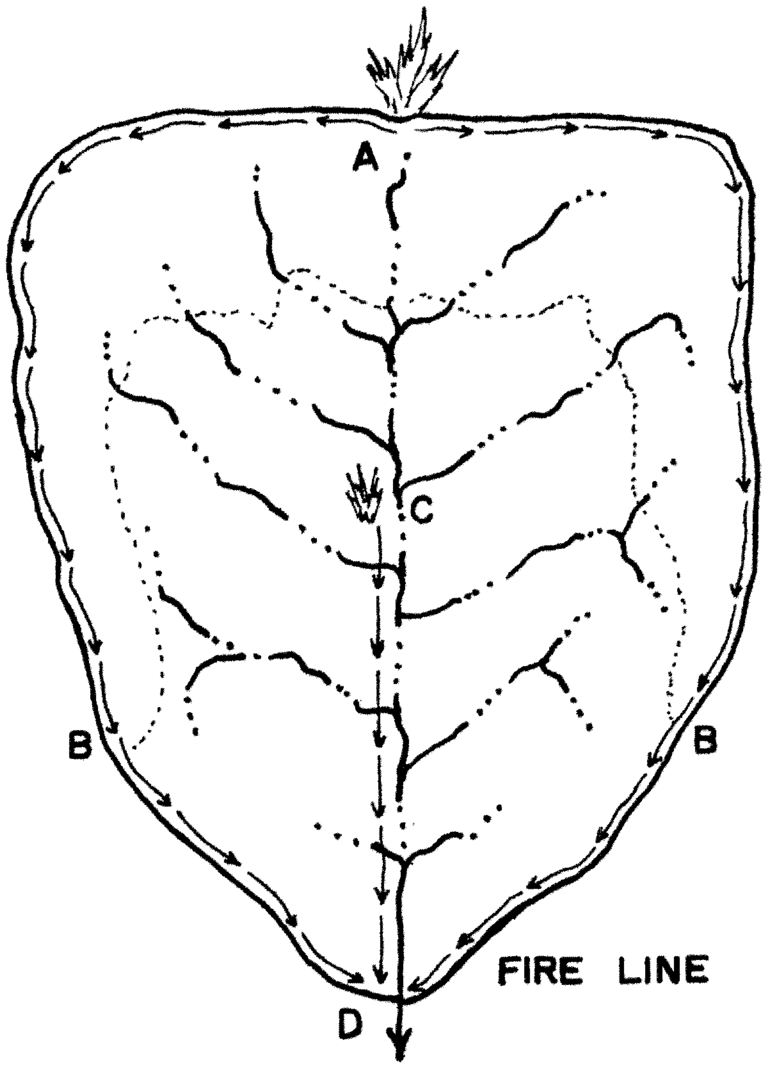


Figure 22-2 This is an example of center firing after the perimeter is set in order to promote intense heat from rapid burning. The first fire is set at A, and the flame front is gradually extended, as safety allows, to points B on either side of the watershed. When the flame front is at points B, it approximates the dotted line. Crews are held at points B while another crew begins setting fire at C and along the drainage toward point D. When the crew reaches point D, but not until then, crews at B proceed to point D. Shortly, the whole watershed will seem to be aflame as the fires burn together.

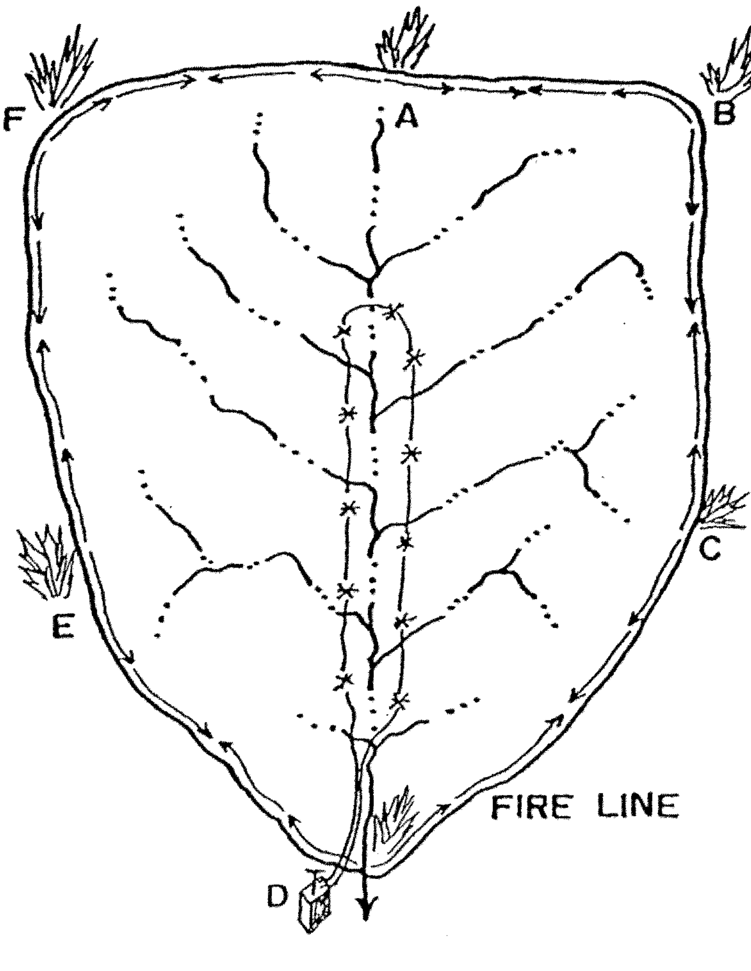
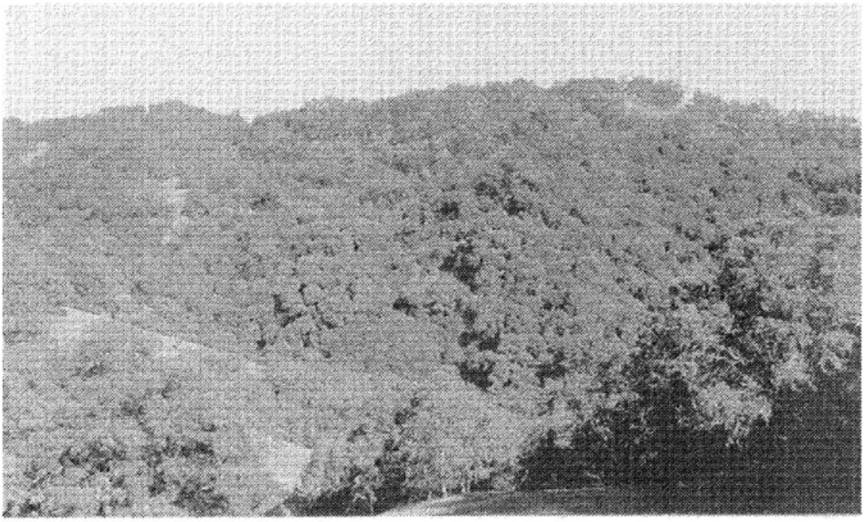


Figure 22-3 This illustrates area ignition in which all fires are set as rapidly as possible. A circuit of preset incendiaries near the bottom of the watershed ignites fire by electric shock at points marked*. When smoke appears from these points, personnel stationed along the perimeter fire line begin setting fires in each direction from lettered locations. Flames envelop the whole watershed and burn the fuel rapidly. After the fire is set, personnel patrol the fire line.

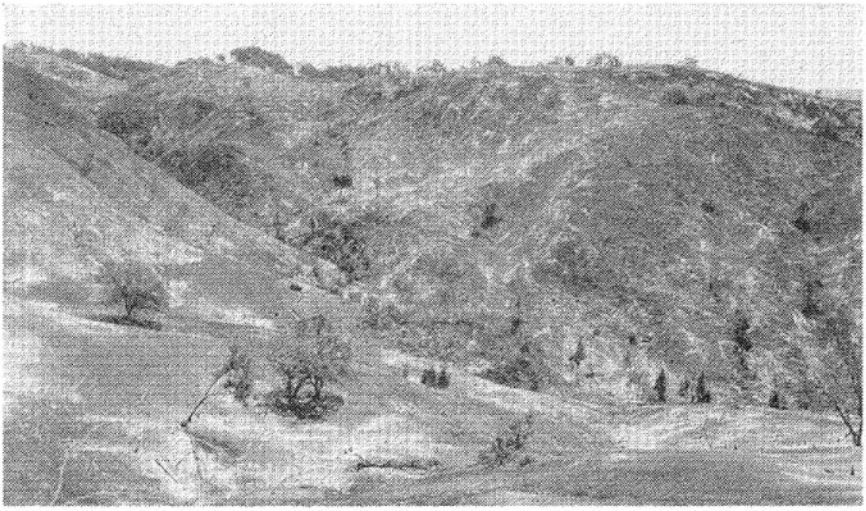
22-4a



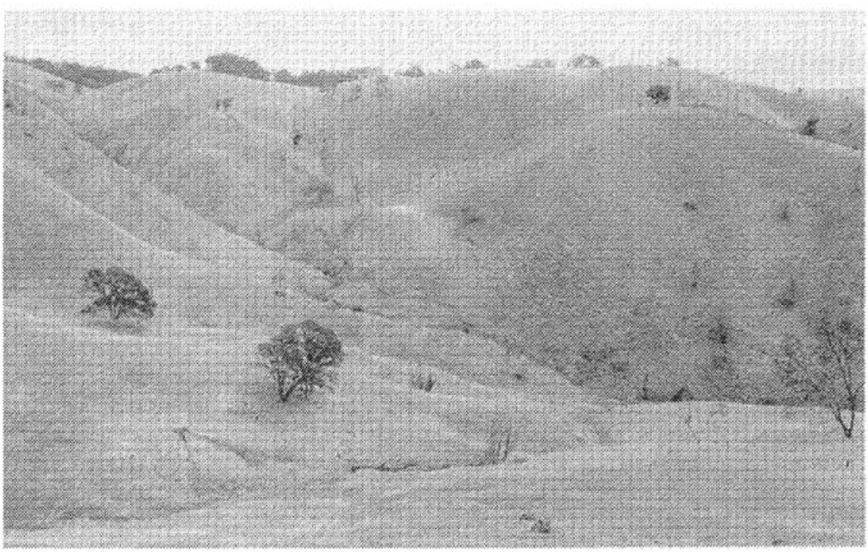
22-4b

Figure 22-4 Photo 22-4a is an untreated oak woodland in California. Photo 22-4b is the same location five years after the trees were killed by girdling and 2,4-D. Photo 22-4c was taken after burning. Photo 22-4d shows an excellent cover of grasses one year later.

22-4c



22-4d



RELUCTANCE TO USE PRESCRIBED FIRE

Justification exists for a cautious attitude toward using prescribed burning as a management tool. Catastrophic wildland fire destroys homes, resources, and lives every year, although large fire-control organizations exist. Years of educational efforts regarding destruction by fire and ways to prevent fire have resulted in a general view that all fire is bad.

Laws to regulate or to prevent fire on western United States lands started with forest fire statutes in California and Oregon in 1850. Early problems caused by fires included loss of forage for livestock accompanying wagon trains crossing the plains, reduced forage for bison, destruction of roads by erosion in blackened areas, the disaster of the Peshtigo forest fire in 1871, and many Northwest forest fires in 1910. Each major catastrophe resulted in new laws and appropriations aimed at fire prevention and control. The principal thrust of these laws and appropriations was building larger and larger firefighting organizations.

Most people fear fire to a certain degree. A fear of prescribed fire escaping stems from inability to predict fire behavior. Occasional floods and severe erosion after a fire develop a fear of land destruction. A view that prescribed burning is good raises fears that support for wildfire control might be weakened. Other arguments against prescribed burning center on lack of knowledge of its effects, dangers of air pollution, unfavorable cost-benefit relationships, and unknown tradeoffs with alternative practices. During the 1980s arguments against prescribed fire have decreased and its use has increased. Individual situations vary from a need to burn annually, or more often, to infrequent use of prescribed fire. Different areas have their individual problems, but in most, the ecology is sufficiently known to prevent ecosystem damage.

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23

Biological Control

The processes of natural biological control maintain the so-called balance of nature. Left unchecked, any species has the reproductive capacity to cover much of the earth, but all species are subject to checks on population numbers. The manipulation of grazing animals for the purpose of attaining certain types of vegetation or densities of interacting species is a form of biological control. However, the professional field of biological control concentrates on the use of parasites, predators, and pathogens to reduce population densities of unwanted organisms to levels below economic significance. **Biological control is defined as the planned use of living organisms to reduce the vigor, reproductive capacity, density, or effects of undesirable plants** (Quimby et al 1991). Activities within this definition are foreign exploration, introduction, and testing of possible control organisms; augmentation of native controls; and developing resistant cultivars. When integrated with other techniques, it is commonly called **"Integrated Pest Management (IPM)."** Conditioning of livestock to avoid or select certain plants suggests possibilities for training animals to exert specific influence on vegetation. The future of rangeland grazing management includes IPM, better plants, trained animals, and biological control organisms.

Biological control presently concentrates on the use of insects to control pests, which may be noxious plants or noxious insects on desirable plants. The word "predator" is used here to include insects that prey on both kinds of pests. Suppression of pests may stem from direct kill, weakening and replacement by competitors, reduced reproductive capacity, and infection by pathogens. Reduction of European rabbits in Australia by the Myxomatosis virus is a type of biological control.

PRACTICES

Biological control has had its greatest success when both the species to be controlled and the predator have been introduced. Weeds usually arrive without their natural population controls, hence they thrive and often become more aggressive pests than in their original habitats. An objective in biological control is to introduce a natural predator that becomes aggressive because its enemies have been left behind. In the new situations, the total environment may be more favorable to an insect predator than the original environment or it may favor a combination of control organisms. For example, secondary invasion of parasitized *Opuntia* by fungi and bacteria speeds the destruction of the weed. Abundant weed populations appear more susceptible to predator destruction than scattered stands.

No sound basis exists for selection of insects to introduce for biological control. The predator and host can be matched closely in terms of climate, competitors, etc., but success or failure must be determined by actual testing and introduction. There is no shortcut in finding the ideal enemy for a rangeland pest, one that keeps a weed at low densities and is relatively free of resident predators and diseases. Some of the characteristics of an effective natural enemy are (1) high searching ability, (2) high degree of host specificity, (3) as great reproductive capacity as the host, (4) adaptability to the host environment, (5) application on land where other controls are excluded because of cost or terrain, (6) permanency where the host appears annually, (7) environmentally safe, and (8) potential for integration into a pest management program (Joyce 1989). The rangeland manager must foster increases in desirable plants to replace those eliminated. Otherwise, biological control has little lasting value.

Of practical necessity, biological control should aim for low host population numbers rather than eradication. The usual sequence of events after release of a successful predator is alternating cycles of weed and insect. As the weed population declines, so does the predator, but small amounts of the host support a permanent population of the predator. A successful example is the biological control of *Opuntia* in Australia, where the abundance of plant and insect reached an equilibrium at low population densities of both.

Almost all successful examples of biological control center around one most effective enemy, but combinations of several agents may improve control. Because of adaptation to different environments, effective combinations of predators may differ over the range of the pest.

RISK

Biological control with introduced species of insects and other control agents carries considerable potential that the predator may increase in numbers, change host plants, and attack species of economic importance. Developing a biological control is a slow process because of the lengthy testing required and the large number of possible control agents. A worldwide system of research laboratories helps in the screening to prevent undesirable escapes. Extensive testing under quarantine remains the most effective assurance against excessive risk of an introduced insect becoming a pest.

Host specificity relates to the amount and kind of essential oils and alkaloids that serve in different plants as either attractors or detractors. However, an insect's dietary preferences may change, but these changes are difficult to determine because the full food spectrum of an insect is seldom known.

The risk of an insect attacking economically valuable plants appears to be reduced when weed and crop are greatly different in morphology and taxonomic relationship. Highly specialized insect feeders present less risk than general leaf and flower feeders. Excellent control of *Hypericum perforatum* by *Chrysolina quadrigemina* is an exception to that rule. *Chrysolina* does not attack ornamental *Hypericum* spp. (Wilson 1943).

SUCCESSES AND PROBLEMS

Several highly successful examples of biological control have occurred on rangeland. Biological control is more extensive and has been highly successful with agricultural pests because of great economic need to produce food and fiber crops.

Opuntia *Spp. (Cactus)*

Several species of *Opuntia* that are native to North and South America were transported to other continents for livestock feed, hedge fences, erosion control, and fruit for human consumption. *Opuntia* escaped cultivation and covered many millions of hectares in Hawaii, Australia, India, Ceylon, Celebes, Mauritius, and South Africa. Australia alone reported 25 million hectares in 1925, of which half were so dense that people and animals could not penetrate the stands (Dodd 1940).

Australia pioneered in the highly successful biological control of seven *Opuntia* spp. *Opuntia stricta* and *O. inermis* were the worst invaders and the former did not succumb until the moth, *Cactoblastis cactorum*, was introduced in 1925. *Cactoblastis* did so well that breeding programs of all insect predators on *Opuntia* were omitted in the third year, and the problem was one of distribution of field colonies of *C. cactorum*. The plant species and the moth proceeded through diminishing cycles of regrowth and have remained at low population levels for many years. This is the finest example of plant control by introduced insects on rangeland.

Hawaii had a problem with the large Mexican cactus, *Opuntia megacantha*, which was used as an emergency livestock feed. A number of slowly spreading insects failed to control it. Not until 1951 were objections to *Cactoblastis cactorum* and the cochineal insect, *Dactylopius tomentosus*, overruled and successful control obtained. The moth became dominant at upper elevations and the cochineal in the lower elevations of the cactus stands. However, a few *Opuntia* plants survive at elevations above and below major insect attack zones. These two insects, singly or together, have been successful on other *Opuntia* species in Asia.

Opuntia control illustrates ideal use of biological procedures. This highly specialized plant type had no close relatives of economic value in the invaded countries. Feeders on *Opuntia* in their native home could be imported without their enemies with little fear that they, in turn, would become pests. A favorable climate, unlimited food, and a lack of enemies permit rapid population explosions and effective biological control.

The need for testing possible biological control agents in the full spectrum of ecological relationships is illustrated by two examples. In Mauritius, control of the pineapple mealybug with an introduced parasite resulted in loss of the cactus cochineal. The second is that drought, fire, soil type, and native insect predation regulate the abundance of plains pricklypear (*Opuntia polyacantha*) (Laycock and Mihlbachler 1987), not overgrazing that reduced the competition by grasses as sometimes claimed. Native biological control is most effective.

Hypericum Perforatum *(St. Johnswort)*

This species, called St. Johnswort, Klamath weed, or goatweed, is known throughout the temperate world. White-skinned animals are photosensitized by it, and the plant crowds out valuable forage species. Before control, *Hypericum* occurred in extensive patches on rangeland, in abandoned fields, and along roads throughout the northwestern United States from western Montana to central California. It first appeared in California about 1900 and covered a million hectares in the state by 1952 (Huffaker and Kennett 1959). In Australia, it spread from a single introduction in 1880 to 200,000 or more hectares by 1930 (Crafts and Robbins 1962).

Between 1927 and the early 1940s, a large number of insect feeders on *Hypericum* were tested on economically valuable plants in different European districts. Several species passed the tests and were released in Australia, where local control of *Hypericum* was attained. The first beetles introduced into the United States arrived in 1944, and they soon passed starvation tests by not feeding on sugar beets, flax, cotton, and several other crop plants (Holloway 1948). Four colonies of *Chrysolina hyperici* were released in late 1945. *Chrysolina quadrigemina* took longer to test, and release of it began in 1946. Distribution of colonies to the northwestern states and spread of the insects through the stands of *Hypericum* proceeded rapidly.

The adult beetles aestivate in the soil during the summer dry period beginning in late June. Both *Hypericum* and *Chrysolina* become active after the fall rains, and the insect eggs are laid in October. Hatching and feeding by young larvae follow quickly. In the spring, third- and fourth-stage larvae feed near the ground and pupate in the soil (Holloway and Huffaker 1951). Destruction of procumbent growth by the beetles during fall and spring prevents flowering and seed production and reduces the ability of *Hypericum* to compete with other herbaceous plants. *Chrysolina quadrigemina* became the dominant species among the introductions because its life history and the phenology of the plant were well synchronized.

The beetle reduced *Hypericum* to less than 1 percent of its former abundance in California within a decade (Huffaker and Kennett 1959). These authors measured the percentage species composition on several sites and found that forage grasses increased in response to decrease in *Hypericum* (Table 23-1). Plant succession proceeded toward perennial grasses with only a nucleus of *Hypericum* persistent; but in pastures where heavy grazing occurred, undesirable annual species remained. Suppression of *Hypericum* by insects has been less successful in Canada and Australia than in California (Clark 1953, Holloway 1964).

Senecio Jacobaea *(Tansy Ragwort)*

This plant, toxic to cattle, horses, and sheep, has been controlled successfully in western Oregon with an integrated pest management program that includes chemical, physical, fertilizers, irrigation, and biological techniques. The latter is based on a flea beetle and two other introduced insects that feed upon the plant. The biological agents do not persist in the drier parts of eastern Oregon where tansy ragwort continues to be a problem (Coombs et al 1991).

Table 23-1 Change in percentage composition of vegetation at one site in nortwestern California after release of *Chrysolina quadrigemina* in 1947 (selected from Huffaker and Kennett 1959).

Species	Percentage composition					
	1947	1949	1951	1953	1955	1957
Hypericum perforatum	57.6	0.0	0.0	0.0	0.0	0.0
Other forbs, mostly annual	17.8	22.3	49.2	30.1	15.1	27.6
Danthonia californica	9.2	22.7	28.9	30.3	52.6	45.0
Annual grasses	10.8	42.8	19.7	37.9	30.1	25.0
Miscellaneous species	4.6	12.2	2.2	1.7	2.1	2.4

Centaurea ***spp. (knapweeds, starthistles)***

Several species in this genus are of major rangeland interest. *Centaurea solstitialis* (yellow starthistle) currently infests about 3 million hectares of rangeland and cropland in California, Oregon, Washington, and Idaho. It is toxic to horses and especially undesirable in parks and along roadsides where it inhibits people and reduces recreational values. The United States is researching biocontrol possibilities in California and Italy, but with little success on a practical scale. This plant appears to be susceptible to a rust disease (*Puccinia jaceae*) and to a fungus (*Sclerotinia sclerotiorum*) (Rosenthal et al 1991).

The knapweeds, *Centaurea*, including diffuse (*C. diffusa*), spotted (*C. maculosa*), and Russian (*C. repens*), have received many scientist-years of research, but they still resist biological control. Lowering of seed production is not enough to manage the knapweeds. An integrated pest control program including herbicides remains the best approach (Rosenthal et al 1991).

Euphorbia Esula *(Leafy Spurge)*

At least eight Eurasian insect species have been released in the United States and twelve approved in Canada for control of leafy spurge. Defoliators, including sheep and goats, have had little impact on this weed. A number of flea beetles of the genus *Aphthona* have shown promise. The adults feed on the leaves and the larvae on roots. One species, *A. nigriscutis,* is under intensive study. The aim is to reduce *Euphorbia esula* to an unimportant member of the vegetation, as it is in Eurasia (Rees and Spencer 1991).

Gutierrezia *Spp.* *(Snakeweeds)*

These native weeds are host to as many as 300 native insect species. One approach to control is importation of insects that attack other *Gutierrezia* species in South America (DeLoach 1991). *Gutierrezia sarothrae* often follows soil disturbance by mechanical brush control operations. Burning reduces the current stand but not the next crop of seedlings. Several herbicides will reduce the weed, but it is best to improve the grass stand that will reduce the snakeweeds through competition.

Carduus Nutans *and* Cirsium Arvense *(Thistles)*

The musk thistle group (*Carduus nutans*) is annual or biennial; therefore, reproducing only by seed. The growing points, stems, leaves, roots, and flowering heads are attacked by alien insects that reduce the vigor of the hosts. However, enough seed matures unharmed to perpetuate the stands. Canadian thistle (*Cirsium arvense*), conversely, reproduces mainly by rhizomes and is little reduced by seed-eating insects (Rees 1991). Herbicides are the most effective control measure for both.

Grasshoppers

In Wyoming, insecticidal control of economically damaging populations began in 1949 and has covered as much as one million hectares per year. In the shortgrass region, destruction is by 3 to 5 grasshopper species. The ideal longterm microbial control should be moderately pathogenic, survive in the environment, be capable of transmission in the host population, be able to reduce host fecundity, and should maintain the host population levels at a stable state. *Nosema locustae*, a grasshopper protozoan disease meets these criteria and is a registered microbial insecticide. Airplane application of it and chemical insecticides is a common control method throughout the western rangeland area, especially when grasshopper outbreaks threaten agricultural crops (CAST 1982).

GRAZING ANIMALS

Commonly goats, sheep, and cattle are used to control brush, as for example in douglasfir forests (Sharrow et al 1989). However, sheep were not effective in controlling the introduced mustard *Isatis tinctoria*, which is commonly known as dyers woad (West and Farah 1989). Heavy fall, winter and spring grazing by mule deer of *Artemisia tridentata* leads to its demise (McArthur et al 1988). Urness (1990) concluded from a number of papers that cattle, sheep, horses, and goats can benefit wildlife populations. However, planned grazing prescriptions must be followed so that favorable results are not left to chance.

Control of blacktailed prairie dogs may be justified on a basis of forage for livestock and because they are a reservoir of contagious disease. However the costs may include little increase in forage, undesirable secondary impacts of rodenticides on other wildlife, decreased hunting for a price, and less diversity (Uresk 1987).

Euphorbia esula is moderately palatable to sheep and goats but not cattle and is being reduced by grazing in the northern Great Plains (Fay 1991). Containment of animals on the spurge is needed and may be by electrical systems. The selection of *E. esula* and other plants, may be passsed from mother to offspring.

A fact known and recorded for decades is that large grazing animals, either domestic or wild, reduce many species of plants. In the last two decades research has shown that food imprinting with training near weaning time; social learning from mothers and other adults, and individual learning from post-ingestive consequences describe three ways by which young domestic animals learn and can be trained to select certain foods (Provenza and Balph 1988, Provenza et al 1992). Thus, the possibility exits that they can be trained to graze certain noxious plants as well as to avoid toxic species.

DEVELOPING PLANT RESISTANCE

Genetic research has resulted in many cultivars of field crops, fruits, vegetables, and flowers of commerce that are resistant to various diseases. Asay (1987) gave four objectives in breeding of range grasses: (1) resistance to specific pests, (2) additional resistance to several pests, (3) reduction in vigor of a plant pest to increase its vulnerability to natural predators, and (4) promotion of diversity by conserving natural predators. For example, cultivars of *Thinopyrum ponticum, Elymus trachycaulus,* and *Thinopyrum intermedium* appear to be at least partially resistant to black grassbug. Natural selection has not yet developed biological balance between these newcomer plants and resident pests (Hewitt 1980).

THE FUTURE OF BIOLOGICAL CONTROL

Every rangeland biome supports countless plant-eating macroinsects and herbivores as small as protozoa, nematodes, mites, and microarthropods that feed on the microflora. Occasionally a herbivore species explodes in population numbers. Defoliation of large areas may occur, and at times, patches of rangeland plants are killed. It seems reasonable to suggest that natural enemies of insect herbivores prevent many from attaining outbreak proportion. The more subtle effects on vegetation of less than outbreak numbers and the causes of outbreaks are frequently observed but poorly understood. Within this complex, opportunities surely exist to develop biological controls. The roles of the smaller grazers, especially the insects and diseases, will command increasing attention.

A seed feeder may destroy as much as 98 percent of the seed crop, but this is not sufficient for effective control of most established stands. The major advantage with seed and flower feeders may be reduction in the rate of spread of an invading weed. Biological control of annual species, such as *Halogeton glomeratus*, may be most effective with seed-destroying insects, but annual weeds in particular must also be attacked ecologically through competition from perennial grasses.

Conflicts of interest over rangeland weeds are likely to increase. *Centaurea solstitialis* is an important honey plant; *Opuntia* spp. furnish dairy feed in part of Mexico and emergency feed for range animals during droughts in many regions; *Cytisus* is an excellent plant for control of soil erosion; and all plants are in the habitat of animals. Reduction of one species may lead to the demise of another on the threatened and endangered list, or at least close relatives with economic value.

Arbitration of real or imagined conflicts should precede any method of plant control. The control of any given pest should be considered in an ecosystem context in which other potential pest populations exist, in which various control actions take place, and in which costs and benefits are generated. Every action needs to be preceded with positive answers to questions of ecological effectiveness, necessity, and economic justification. The time has past for successive pesticide syndromes and other single-practice crusades on rangeland.

The time is also past for single purpose management of every parcel of rangeland. The concept of integrated pest management embraces the ecosystem framework with consideration of plant pests, food chains, pathogens, insects, lower organisms, and the economics of alternative actions. Biological control has a bright future as a component of ecological rangeland management.

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24

Seeding of Rangelands

Rehabilitation of rangelands by seeding began in the western United States in the late 1800s. More literature exists on range seeding than any other practice in range management. Practical trials and experiments have failed and succeeded in numbers sufficient to serve as a foundation for seeding practices. Specific recommendations can be made with assurance of adequate stands in the seeding of many range sites, for example, on high elevation rangelands (Laycock 1982). However, the environmental movement during the two decades after 1970 demanded less seeding of rangeland, less monoculture of introduced species, and more seeding of native species. Rehabilitation and prevention of erosion after wildfire and other land disturbances have replaced forage production as the principal objective of seeding public land. Success with the native species has been difficult because of low seed availability, high seed shattering, high seed dormancy, low seed retention hence low harvesting amounts and lack of knowledge about seedbed requirements.

A measure of luck still exists in achieving a reasonable stand, as expressed by the adage: Reduce the competition. Prepare an adequate seedbed. Plant a mixture of species that fits the site and the need. Pray for rain.

DECIDING TO SEED

Before the actual seeding can begin, several questions concerning the need for seeding, changes in management, the seeding site, cost, and expected returns must be answered. The questions, slightly reworded, also apply to decisions about the use of other range management practices, such as grazing schedules, chemical brush control, and prescribed fire.

Is Seeding Necessary?

Seeding does not substitute for management. In southeastern Oregon, a few plants of *Agropyron spicatum* growing in the protection of *Artemisia tridentata* quickly expand to dominate the vegetation when the brush is killed, making seeding unnecessary. Short (1943) observed in eastern Montana that competition prevented establishment of sown grasses when bunchgrasses covered 15 percent or sodgrasses 7 percent of the land. As a general rule, if 5 to 10 percent of the present vegetation is desirable, stand improvement should come through management that fosters increases of the desirable species.

Often, where overgrazing has badly depleted the native vegetation, good management permits excellent range to develop on much of the land with little cost. The actual percent in the rule of thumb given above depends upon several factors, including the time for plant succession to occur and the income lost while it does so. On areas where heavy animal use, former cultivation, or fire have completely eliminated the important forage plants, seeding may be the only practical reclamation means. The areas where native species will not return and where seeding is necessary will become evident under proper management.

Competition from undesirable plants may prevent establishment of seeded species. Seeding has its greatest potential for profitable returns where desirable native vegetation does not exist. Rehabilitation of rangeland after wildfire often includes seeding.

Is the Climate Favorable?

Successful seedings are infrequent in areas receiving less than 250 millimeters of precipitation. In areas with more than 600 millimeters of rainfall, there are few seeding failures due to lack of moisture. Precipitation on many rangeland areas throughout the world averages between 250 and 600 millimeters, but is below average in many years, leading to irregular seeding results. In dry areas seeding may be successful in wet years. The western United States rangeland has erratic rainfall that results in the unpredictable success and failure of seedings. Fourteen species of 300 tested at 400 locations within the Chihuahuan and Sonoran Deserts since 1890 warrant general consideration where precipitation averages greater than 25 to 30 centimeters (Cox et al 1982). *Eragrostis curvula* and *E. lehmanniana* have been successfully seeded worldwide in the low rainfalls. *Cenchrus ciliaris* and *Panicum coloratum* var. *makarikariense* are planted worldwide in moister situations.

Is the Habitat Favorable?

Soil characteristics, slope, and exposure limit the production of forage, the use of seeding equipment, and the use of the planted species. Soils of heavy clay or pure sand are difficult range sites on which to obtain satisfactory seeded stands. Alkaline soils, intermittently flooded soils, sterile soils, thin soils, areas where industrial wastes have accumulated, road cuts and fills, mine spoils, and steep slopes are other difficult habitats. Seeding on these sites and on slopes where machinery tends to increase erosion requires special techniques and frequently is done for objectives other than forage production. Special methods such as terracing, contour furrowing, hand seeding, fertilization, and mulching may be needed to protect site and seedlings.

Habitats with medium-textured soils 30 centimeters deep and high organic matter content have adequate infiltration capacity and soil moisture for seeding. In mountainous or hill country, these areas are likely to be the lowlands where runoff is slight and run-in water supplements the rainfall. Vigorous growth of *Artemisia, Purshia, Quercus,* and other shrubs generally indicates favorable sites for seeding. Low herbage growth and undesirable species composition often indicate that seeding is not the proper solution.

A rule of thumb in selecting sites for seeding (or any range improvement method) is to start with the best habitats and proceed to the less productive ones. The better sites give greater chances for establishment of new stands, high yields of forage, and profits on the investment. Managers should apply intensive methods to small areas before using extensive techniques on large areas. Abandoned cropland is potentially good seeded rangeland.

What Species Should Be Seeded?

The need for erosion control, additional forage at certain times in the forage year, rehabilitation concerns, environmental protection, and the necessity to match species with habitat determine the species to be seeded. Yearlong ranch operations often have a period when forage is scarce that may limit the size of the operation. Times occur on many ranches when feeding of supplements and hays could be replaced with less costly grazed forages. In selecting species for seeding, the manager needs to provide forage to meet seasonal deficiencies. An early-growing species or a late-growing species will lengthen the grazing period on green feed and shorten the period of feeding supplements. More is likely to be gained by making the seasonal adjustments in feed than by simply adding more forage into the whole operation. Therefore, the selection of species for seeding rangeland requires analysis of the restraints on production and careful planning of inputs and outputs. Decisions of what to seed and where to seed it are determined, to a large degree, by the deficiencies in the sequential feeding requirements during the whole forage year.

Of almost equal importance with the climate, site, and need for special feeds is the ability of the species selected to continue producing under grazing pressure. Species and varieties of plants have a great deal of inherent variability in resistance to grazing. Sodgrasses withstand grazing, but most of them produce little seed and are difficult to include in a seeding operation. The manager can vegetatively establish some sodgrasses by planting live pieces of rhizomes, stolons, or plugs of sod.

Grasses that spread by rhizomes are illustrated by *Poa pratensis* and *Agropyron smithii*. *Buchloe dactyloides* of the western Great Plains and *Trifolium repens* are common forage plants with stolons. In the tropics and subtropics around the world, *Cynodon* spp. are widely known for having stolons, rhizomes, or both, depending upon cultivar or variety.

Those range grasses that depend upon seed for regeneration must be grown and grazed under conditions that will permit the production of seed. Many are less resistant to grazing than are sodgrasses, but *Agropyron cristatum* and *Bouteloua gracilis* can withstand heavy use. Species resistant to grazing should be favored in the selection of species to seed rangelands.

One should consider the relative palatability of the plants in a seeding mixture. The inclusion of one or two extremely palatable plants with others of lower palatability could result in overutilization and eventual elimination of the favorites. Results from cafeteria grazing studies show that some species and varieties become overused before others are grazed. A range that has been seeded to a mixture must be managed correctly so that the preferred species are perpetuated, just as any mixed forage type needs special management .

Thousands of grasses, legumes, and other forage plants have been introduced from foreign countries, collected from North American rangelands, and tested for seeding purposes. About 50 grass species have survived rigorous screening by climate, vegetational competition, livestock use, and other characteristics to become valued parts of the range seeding resources (United States Department of Agriculture 1948, Hanson 1965). Introductions from other countries, adaptation trials, selection, and breeding have continued to produce new cultivars. For example, cultivars of *Andropogon gerardi* var. *paucipilus* are successful on the Nebraska sandhills, prostrate growth forms of *Medicago sativa* subsp.

falcata do well in pinyon/juniper (Berdahl et al 1989), and steers have shown the most palatable clonal lines of the hybrids of *Elytrigia repens X Pseudoroegneria spicata* (Truscott and Currie 1987).

Fortunately, native forage plants are responding to the selection and breeding programs as well as the introduced species. Local strains and varieties often do better in their own habitats than plants from other regions. Within a species, genetic material from harsh environments frequently has a higher range of adaptation than that from move favorable environments.

Interspecific hybridization has combined the genetic resources of important grass species. The cultivar Hycrest came from *Agropyron cristatum* and *Agropyron desertorum* and is preferred over either of them. A hybrid from quackgrass, (*Elytrigia repens*) X bluebunch wheatgrass (*Pseudoroegneria spicata*), called "NewHy" has gained attention for saline sites. Other popular cultivars are Snake River wheatgrass (a subspecies of *Elymus lanceolatus*), Bozoisky-Select Russian wildrye (*Psathyrostachys juncea*), and many more. Excellent opportunities exist for continued contributions to rangeland improvement from plant breeding (Asay et al 1991).

Seeded mixtures of species appear to have several advantages over stands of a single species including:

1. A mixed diet is more desirable and often will produce greater livestock gains than a diet composed largely of one species. However, livestock have gained well even when grazing single species of relatively low palatability.
2. Periods of growth vary for different species, thus a mixture increases the length of the grazing season on green forage and the uniformity of forage production throughout the season.
3. Differences in depth of root systems may result in greater use of soil moisture and nutrients in some cases, but in others the increased competition may decrease the total forage produced.
4. All pastures have variable habitats. Seeding mixtures increase the chances of sowing plants that will dominate in each localized set of habitat factors.
5. Some plants benefit others, as for example, nitrogen fixed by legume *Rhizobia* has a fertilizing effect on grasses. Grasses in legume stands help to prevent bloat in animals.
6. Diseases and insect pests may not attack the grass species equally and are less likely to damage mixtures as much as they do pure stands of one species.

Difficulties with seed mixtures include the following points:

1. More time and labor are necessary to get the seed ready for planting, and the total seed cost may be higher than with a single species. Seeds of native species are hand collected for the most part and a small proportion of them in the seed mixture can be expensive.
2. Differences in seed characteristics make drilling at proper rates and depths difficult.
3. If seed production is an objective, pure stands give best results because harvesting can be uniform and properly timed. The product from a pure stand is easier to clean and to sell at a profitable price.
4. A single species may be the only one adapted to an extreme soil condition or a special seasonal forage need.

Thus, a species is selected to do well on the site where it will be planted and to fulfill a certain purpose. The plant should be easy to establish, high in production of palatable forage, resistant to grazing pressure, and able to withstand competition. The seed must be available at a reasonable price. Fortunately, most species that meet these specifications are also effective in holding the soil and aiding infiltration of water into the soil. Hull (1973a) reported that 4 of the original 37 species seeded on the Davis County, Utah, watersheds in 1936 to 1939 were still effective soil stabilizers. The 4 species were *Bromus inermis, Agropyron intermedium, Arrhenatherum elatius,* and *Festuca rubra.* Native species returned to all the seeded areas.

Is Proper Management Possible?

Too heavy utilization, poor distribution of animals, improper seasonal control of animals, and other poor managerial practices contribute to the need for most range seedings. Little is gained if the newly seeded stand succumbs to the same faulty grazing practices. Perennial grasses, for example, require certain management practices in order to become established.

During germination and establishment, seedlings in both humid and semiarid regions have open space in the plant cover. Low successional plants, mostly annuals, rapidly occupy the available space. They shade the perennial seedlings and use available moisture, perhaps to a degree that prevents seedling establishment of the planted species. The situation is posed as a problem in control of weed competition.

The manager has several techniques that can improve the chances of stand establishment. The most common management recommendation is not to graze the stand until near the end of the second growth period. Young plants may be fatally injured by trampling, by pulling or loosening when they are grazed during wet weather or in muddy soil conditions, and by defoliation, which reduces plant food reserves.

Animal Management Is Essential to the Success of Range Seeding

In contrast to no grazing for a year or two after grazing, instances have been observed in which grazing in the first year did not reduce the number of plants that became established. The beneficial aspects of early grazing should be recognized and used. Where the weeds are dense, a short period of grazing, even heavy grazing, will take the top off the weed crop, reduce shading, increase available space, and make more water available for the seeded plants. Care must be taken to remove the grazing animals before damage is done to the seeded plants. Not all weed growth needs to be removed because mulch or litter controls erosion and ameliorates the microclimate near the soil surface. If properly handled, most seedlings can withstand and may benefit from careful grazings during the establishment period. Unrestricted grazing and careless management during that period is to be avoided.

Range seedings on abandoned cropland where debris is minimal may be mowed during the first growing season to reduce competition from weeds. Mowing at a height no lower than 7 centimeters above the soil should be done before the weeds produce seed. The objective is to leave the desirable grass seedlings unclipped or to clip them as high as possible, and to cut the weeds as low as possible. That difficult compromise often leads to a decision to use herbicides or to graze the weed crop. On steep slopes, grazing and herbicides applied by air may be the only ways to reduce weed competition (Bovey et al 1986).

If a legume or other broadleaved plant is included in the seeded mixture, herbicides should be avoided and grazing encouraged. *Trifoliums* and other legumes belong to the early successional stages. Taller plants must be kept low and sufficient bare ground maintained for legume seedlings each year. Some of the twining subtropical legumes do well in thick grass stands, but these, too, need regulated grazing during the first year after seeding.

Pesticides may be needed to assure a seeded stand. Seed-eating birds, rodents, ants, and termites may gather and consume the seed, or an epidemic of grasshoppers may destroy the seedlings. **Elimination or reduction of most pest problems starts in the planning stage for seeding rather than after the planting is finished.**

In many instances, an apparently poor grass stand the first year after seeding has become an acceptable stand in the second and third years. Seedlings of most perennial grasses on rangelands in temperate regions are inconspicuous and the stands do not thicken sufficiently to reduce the annual weeds for two or three years. **A seeded area that has been considered a failure through cursory examination should not be plowed for reseeding until after the second growing season.** Seedlings in tropical and humid climates make rapid growth the first year.

Seedings often require shifts in seasonal grazing plans. Rotation schemes and deferred grazing treatments may be sufficient to give new seedlings all the relief from grazing they need. Fencing to protect a new seeding should be finished and grazing schedules fully planned into the ranch operations before the planting begins. Fenced pastures in existing seasonal grazing plans provide opportunities for seeding and other improvement practices.

Raising grasses for seed necessitates a different management program than that for forage production. The stand for seed production may be grazed only until tillers begin to elongate early in the year and not again until after the crop is harvested. The largest seed crops are produced by planting thin stands of one species in rows 0.5 to 1.0 meter apart, and clean tilled. Grazing only partly substitutes for the tillage. Forage producing stands generally are seeded in rows much closer together. Three grasses that give reasonably high yields of seed are *Agropyron cristatum*, *Bromus inermis*, and *Agropyron trachycaulum*.

Predicting Seeding Costs and Returns

Economic analysis of possible costs and returns helps in the decision of whether are not to seed deteriorated rangelands. Workman and Tanaka (1991) described three economic standards by which the projects must be judged. (1) **Will the project pay?** (2) **Will the project provide the most productive use of available capital and other inputs?** (3) **Will the project be cost effective?** The last standard includes projects of repairing critical sites no matter what the cost in order to satisfy public opinion, stipulations by law, nonmarket values, and relationships to other ranch values.

Economic feasibility is indicated by positive answers to the three questions. Optimization of the three standards may require unavaialable longterm data. If that is true, the second-best approach is to use simulated data to help in decision making (Workman and Tanaka 1991).

Analysis includes projection of interest rates, risk, project life, as well as the purchase of seed, labor, hiring of equipment, control of brush, and other range improvement operations that require immediate payment of money. Costs of seed vary widely from year to year. Seeding of burned watersheds and forests in bad wildfire years takes all available seed within a short time, often causing the market to go from an over-supply to an under-supply. Costs of labor, equipment, and application vary according to site and methods. These costs fluctuate widely with changes in economic climate. They also vary by objective, whether for erosion control or grazing.

A second set of guidelines have been used in determining whether the economic analysis indicates proceeding with the project. One guideline is that costs should not exceed those that can be covered by increased net income within a seven- to ten-year period. A second guideline stipulates that the costs should not exceed the sales value of the land with its new crop. Still a third guideline amortizes the change in rental value on a basis of values in the open market. These three approximations of seeding values give similar answers. In short, the total expense of the seeding operation should not exceed the costs of buying other land that would give equivalent production.

Both the allowable costs and the expected returns depend to a considerable extent upon biological success in the seeding project and upon the way it is managed afterward. Although grazing values may be increased several fold, the actual increases may be low or high per unit of land. Real values must be favorable in terms of alternate uses of the money; or nonmarket determined values such as conserved soil, game products, and esthetic opportunities must justify expenditures that cannot be expected to return a profit.

THE SEEDING OPERATION

No attempt will be made in this section to present prescriptions for individual seeding operations. Local variation in environment requires local prescriptions. This section assumes that the decision to seed has been made.

Assembly of Seed, Equipment, and Labor

The seed and necessary tools are assumed to be available in the community. Sources of information about them include local seed stores and offices of the County Agriculture Extension Service, Soil Conservation District, Soil Conservation Service, Bureau of Land Management, and Forest Service. People in these organizations have and will give the latest information on approved techniques. For example, the Soil Conservation District may have the only rangeland drill in the community, which is rented on a tight first-come-first-served schedule. Planning so that seed, the right equipment, and skilled operators are on hand at the right time and place usually requires information and scheduling.

The Seed

The seed source influences seeding success. Plants of the same species from seed grown at widely separated places develop their flowers and herbage at different rates. Seed produced locally gives more satisfactory stands, on the average, than does seed of the same species from other regions. Strains moved from colder climates generally have high variability in germination, filling of the seed, and viability (Chambers 1989); and produce plants with lower yields and earlier maturity than locally grown seeds.

Strains of southern origin, when moved too far north, may fail to mature seed before frost. In general, northern strains are lower in yield and earlier in maturity, while southern strains vary in yield and are later in maturity, than local plants. **The rule is not to move seed more than 500 kilometers north or south and certainly not out of the natural range of the species**. While these comments do not apply to the seed of introduced species, they too, have a range of habitats on which they do well, and moving them beyond these restrictions will lead to failures.

High-quality seed enhances the chances of obtaining a stand. Good seed is bright in color and large in comparison with others in the lot (Carren et al 1987). Moldy, dark, or discolored seed suggests poor quality. A few seeds should be sectioned with a knife or broken to determined whether or not the endosperm fills the seed coat and is of healthy appearance. Seed should never be purchased without a visual test of quality. Seed that goes through regular markets must be labeled according to percentages of purity, germination, and adulteration with seed of noxious species. The weeds of cultivation must not be planted on rangeland because of the danger that they will spread to cropland. The allowable quantity of noxious weed seed in commerce is controlled by law in most states.

Seed purity is the percentage by weight of apparently live seed within the lot. The impurities include foreign matter that the harvester takes along with the seed and which processing does not remove. Small pieces of straw, chaff, broken seed, small rocks, and parts of insects are common impurities. Most impurities differ in weight, size, and shape from the seed. A manager can estimate the amount of this material by ocular examination and by noting the amount that separates from the seed in a water float test. Accurate measurement of purity requires separation and weighing. Impurities cause drilling problems. They feed through the drill at different rates than the seed, separate from the seed due to the shaking of the drill, and clog the seed openings.

The germination percentage is another factor of seed quality. **The proportion of apparently live seed which germinates under standard laboratory test is the germination percentage**. Satisfactory germination tests can be accomplished easily. Two to four samples each of 100 apparently pure live seeds should be placed without crowding on several thicknesses of moist paper towels in a glass-covered dish. The glass cover reduces danger of the seed drying and permits light to enter the chamber. The dish should be placed in indirect light at ordinary room temperature, and the seeds kept moist but not allowed to stand in water. The final germination percentage is determined by an average of the number of seeds that germinate in the samples.

Pure live seed (PLS) content is the most important aspect of seed quality. One obtains this amount by multiplying germination and purity. Thus, a 50-kilogram bag labeled "germination 90 percent and purity 90 percent" contains 81 percent or 40.5 kilograms of pure live seed. A bag of seed with lower quality, say germination 50 percent and purity 75 percent, contains only 37.5 percent pure live seed. The second lot is worth less than half as much as the first. State laws require that notations of purity, germination, and PLS on the seed label. They are guides for comparing prices and for determining seeding rates.

The listing of pure live seed on the label stipulates that it was determined on a certain date because viability changes with time. Most grass seeds require an after-harvest ripening period during which germination percentages gradually increase (Table 24-1). Seed of *Stipa* spp. should not be planted until at least a year after harvest. *Poa arachnifera* is noted for its short-lived seed, lasting about six months. Seeds of *Andropogon scoparius* and *A. gerardi* seem to drop in viability suddenly at about the fifth or sixth year, and germination often is the highest the second year.

Seeds of many grasses retain viability for several years. Certain strains maintain life better than others. Seeds of six grasses remained viable for 20 years even though they were stored without humidity and temperature control (Tiedemann and Pond 1967). Seeds that remain alive for four or five years under storage give considerable flexibility in time of their use.In one study, stored grass seeds lost all their viability within 27 years, legumes lived somewhat longer, and 37-year-old seed of *Erodium cicutarium* was the oldest to germinate (Hull 1973b).

Table 24-1 Average percentage germination of different aged seed of three species (Wilson 1931).

Species	Germination percentage at end of		
	1st year	2nd year	3rd year
Bromus inermis	70	74	55
Bouteloua gracilis	23	18	4
Agropyron cristatum	47	65	85

Seeds of some plants on rangeland have a dormancy either because of a hard seed coat that prevents imbibing water and oxygen or a physiological immature condition of the embryo. Scarification is scratching the seed coats or making them pervious with acid. Breaking internal dormancy is commonly accomplished with cold/moist storage or with heat treatments.

Oryzopsis hymenoides may be scarified by acid or mechanical means so that germination can be increased. *Buchloe dactyloides* should be treated with 24 to 48 hours of soaking in a solution of 0.5 percent potassium nitrate, stored wet at 0 to 5 degrees Centigrade for six weeks, and dried immediately. This process increases germination from approximately 10 percent untreated to 75 percent.

Seed Growing, Harvesting, and Processing

Lack of seed availability prevents promising species from widespread use. Successful seeding on rangeland often begins with the harvesting of a handful of seed, the purchase of a small quantity of seed, or perhaps the receipt of a gift of a few seeds. These seeds are nurtured with care, grown alone in the home garden or nursery, and the quantity of seed gradually increased. A stand of a few square meters to a hectare can be the homegrown, economical source of seed for range improvement or for a venture into the seed production business. The care and handling learned in the small scale operation teaches the special techniques needed for success on a larger scale.

Grass seed has been harvested with many types of equipment, most of it homemade. Grain combines will collect small seed of little weight after proper adjustments to the fan, concave distances, and cylinder speed. The various kinds of hand harvesting equipment include a knife or sickle, a comb and scoop to catch the seed, a pair of paddles, and sweeping or vacuum mechanism that gathers seed loosened from the plants or sucks-up fallen seeds and burs from the ground. A revolving drum with protruding nails strips seed from the standing grass.

The seeds of many grasses need processing before they can be stored or successfully planted. First, drying prevents mold. Not all seed ripens at the same time so the harvester collects some green seed. For example, individual culms of *Panicum antidotale* can have seeds from the milk stage to the completely mature stage. Harvesting, when 50 percent or more of the seed is mature yields the greatest quantity but it contains moist seed.

Second, the bulk seed needs processing. Awns, hairs, empty florets, pieces of stems, and other debris hinder passage of seed through the drills. The *Andropogons* have paired florets, one fertile and one sterile, which constitute a fluffy unit. The sterile floret and long hairs need to be separated from the fertile floret and discarded before drilling. *Stipa* awns twist together, making the separation of seeds extremely difficult. Seeds of many species planted on rangelands are bulky, fluffy, and light in weight. A modified hammer mill, commonly used to grind grain for feeding, removes the debris if adjustments are made in screen size, clearance of the hammers, and speed. After processing, the impurities are removed with a fanning mill.

The Season to Plant

The season of the year in which best seeding results can be expected varies from place to place, from year to year, and among species. All plantings require ample soil moisture and favorable temperature from germination time until the plants have become well established. The seedlings of many species are tender for several weeks after germination and are easily destroyed by drought, soil blowing, flooding, soil crusting, competition from weeds, frost, hail, disease, and insects. Extreme weather conditions often cause failure regardless of the planting season, and favorable weather may allow an acceptable stand to become established although the rules are not followed completely. In a choice of the time of year in which to seed, the most important considerations are seasonal distribution of rainfall and amount of soil moisture.

Fall seedings are favored in the northern and parts of the western United States and Canada, where the majority of the precipitation occurs in winter and the major growth occurs in a short early-spring period. Spring seeding misses that part of the growth period which occurs before machinery can be put onto the land. Fall seeding places the seed into the soil, where they can take advantage of the first warm spring days.

In the Mediterranean-type climate in California, plantings are made in late fall before the first rains. The seeds germinate and the seedlings have a month or two to grow before low winter temperatures slow their progress.

Fall seedings in grain stubble take advantage of the firm seedbed, and the stubble prevents blowing of soil and snow, thus protecting the seedlings from drying and frost damage. Meadows and forested ranges in the western United States are fall seeded. In general, the cool-season grasses do best with fall seeding.

Spring seedings are advisable where the major rainfall occurs in summer and where warm-season grasses are planted. These areas include the central and southern Great Plains, the prairies to the east, and the southwestern mountains. Sandy and well-drained soils can be worked early in the spring, and hence, spring seedings of both warm- and cool-season grasses are generally satisfactory. Heavy or clay soils cannot be worked early in the spring; therefore, they are fall seeded.

Site Preparation for Seeding

A well-prepared seedbed that is free of weeds, brush, and other plants enhances the chances for successful seeding. If the site is worth seeding at all, the extra effort required to remove competing vegetation will be justified in the results. The ideal seedbed for grass has a firm soil. If one's heel sinks more than one centimeter into the soil with normal walking, the soil is too loose and should be packed, which improves the soil-moisture conditions for the seedlings.

Methods of seedbed preparation include mechanical and chemical tilling and growing a crop of grain or some other annual plant, removing brush which frequently amounts to tilling the soil, partial tilling in contour or strip applications, constructing microridge relief, pitting, and specially treating road cuts. Disking and broadcasting the seed resulted in the best establishment for *Andropogon gerardi* var. *paucipilus* and *Schizachyrium scoparium* in the Nebraska sandhills (Kocher and Stubbendieck 1986) and *Eragrostis* spp. in the greatly different *Larrea* sites in Arizona (Cox et al 1986).

The preparatory-crop method uses wheat, sorghum, or another annual crop to prepare the land for seeding perennial grasses. The aim is to produce a crop that pays part or all of the expense, reduces weeds, and provides a firm seedbed. If needed, disking will reduce excessive fall weeds, part of the litter, and loosen baked soil. However, stubble and litter are not to be reduced completely because they provide moisture holding capacity, reduce erosion, and serve as protection to newly established grass seedlings. The protection from sun and wind afforded by the nurse crop may not balance the competition for soil moisture on most rangeland sites. A quick growing nurse crop to reduce blowing sand is an exception.

Studies of seeding into closed communities of *Bromus tectorum* and *Artemisia tridentata* in Utah and Nevada found that the early, thick growth of *Bromus* used the available moisture and thereby prevented the establishment of perennial grass seedlings (Robertson and Pearse 1945). *Artemisia* stands reduced insulation, wind movement, and evaporation from the soil surface. They also retained snow, hastened infiltration, and retarded surface runoff, but snow disappeared from them as much as two weeks earlier than from the grasslands. Dissipation of the limited supply of stored soil moisture commenced earlier under *Artemisia* than in brush clearings. Successful seedings into closed communities of *Bromus* and *Artemisia* are the exception rather than the rule.

The presence or absence of heavy stands of *Bromus tectorum* in the northern intermountain area usually is a prime factor determining the method of site preparation. Areas without dense stands of *Bromus* usually can be drilled without cultivation, cropping, or chemical tillage. Ranges heavily infested with *Bromus* need treatment before seeding to eliminate the competition. The *Bromus* may be eliminated with a lister or double-moldboard-type drillhead that scrape or turns back a five- to ten-centimeter-wide strip of soil including the *Bromus*, other plants, and existing surface seed. The new seed is planted in the middle of this narrow cleared strip. Cheaper methods such as burning, harrowing, and spring-toothing have not been successful. Cultivation should be done in the late fall after most of the *Bromus* has germinated or in the early spring before new seed is formed. Freshly plowed land must first be packed with a cultipacker before seeding so that rapid drying is prevented. Drilling is the favored method of seeding on plowed ground, although broadcasting ahead of the cultipacker has given many excellent stands of perennial grass.

Mechanical brush control operations leave the soil stirred, often with few competing plants. Seed broadcast onto the rough and loose soil lodges in the cracks and depressions and soon is covered as wind and rain smooth the surface. Burning, either accidental or planned, provides reasonable seedbeds for grasses and legumes in spots of white ash.

Large amounts of litter and mulch on the ground, for example where stands of timber have been cleared, need to be removed or incorporated into the soil before grasses are planted. Grass seeds must be in close contact with the mineral soil. However, moderate amounts of litter, as from the aftermath of most harvested grain crops on land to be converted to range, are beneficial to seedling establishment and reduction of wind erosion. On problem soils such as moving sands, special effort may be needed to reduce erosion.

Seeding Rate

Rates of seeding rangeland are low in comparison with seeding cultivated crops and must be modified to suit many variables, including number of seeds per kilogram, purity, germination, conditions of seedbed, growth habits of the grasses, objective of the seeding, and cost of seed. Five to ten kilograms of seed per hectare of large seeded plants and as little as 30 grams of the small seeded species (*Eragrostis, Panicum, Poa,* and most legumes) will suffice. Seding rate is important for erosion control with a dense stand immediatly after planting. After 3 or 4 years most stands will reach a density that the site will support.

A commonly used guide to seeding rates is enough seed for ten established plants per square meter of land. A safety factor of 10 necessitates planting 100 pure live seeds of each species per square meter. With 10,000 square meters per hectare and seed numbering 500,000 per kilogram, the amount of PLS to plant is 2 kilograms per hectare. If the lot of seed has 80 percent purity and 57 percent germination, there is 0.456 kilogram of PLS per kilogram of material. For seeding 2 kilograms of pure live seed per hectare, 4.4 kilograms (2/0.456) of material as it comes from the bag would be seeded. **These procedures must be modified to meet local conditions where thick stands are required, where the site will not support ten plants per square meter, or for other purposes.** The average number of pure live seed per kilogram may be found in United States Department of Agriculture Yearbook (1948).

Seeding Methods

Many techniques have been used to distribute the seed in such a manner that the stand will be even and the seedlings will develop into a closed community of valuable plants. A modified grain drill and a specifically made rangeland seeder are the commonly used machines for sowing. Drilling ensures uniform distribution and covering of seed. Where the drill must cut through perennial sod or kill annual vegetation to reduce competition the furrow drill with disk openers has a decided advantage. A large/small double disk opener is superior to the usual double disk (Lawrence and Dyck 1990). The furrow may be shallow, with 2.5 to 5 centimeter strips scraped bare on either side of the seed row. The scraped or scalped strip may be turned back for 10 to 15 centimeters on each side of the seeding furrow, in which case half or more of the land surface is cleaned of vegetation. Examples of the use of the wider strip are the seeding and rejuvenation of *Agropyron smithii* sod. The furrow may be a full lister cultivation with rows 1 meter apart and furrows 15 to 25 centimeters deep, as often used in dry climates to reduce competition and to concentrate the water where the new grasses are planted. A disk in front of the drill spout prevents clogging of the scalper with litter.

The scalper furrow may be used for interplanting to increase yield of forage, nutritional quality, palatability, and plants preferred by wildlife. Examples are strips of *Artemisia* and/or *Atriplex* into existing stands of *Agropyron desertorum*. Another is interplanting *Medicago* into grass and shrub stands.

Special attachments for the drill include bands on the disks to control planting depth, agitators in the seedbox to prevent tunneling as the seed feeds into the drill spouts, and plugs on drill spouts to space the rows. Narrow row spacing produces a stand closed to annuals and weeds. Wide spacing permits planting of small amounts of seed per hectare. A rule to follow is that large seed or sandy soil require deeper planting than small seed or clay soils.

A cyclone broadcast seeder continues to be a favorite hand-operated machine for seeding small areas of disturbed soil, such as those on road shoulders, contour furrows, dams, and brush burns. Cyclone spreading of seed may be done by a person on foot, horseback, or in a vehicle. An extension tube and spreader attached to the cyclone, seeds narrow strips such as contour furrows. Fertilizer broadcasters have been used. Spreading the seed from aircraft is highly practicable for seeding large areas of land that have been burned over, cut over, and brush controlled land. Broadcasting results in high losses of seed due to theft of seed by animals and desiccation of the radical tip before it can enter the soil.

Nearly all range grasses are planted less than 2.5 centimeters deep. Small-seeded species require a planting depth of 1 or less centimeter. The *Eragrostis* spp., with several million seeds per kilogram, probably should be broadcast onto a rough surface and the seed not covered. Many will be buried by rain. **Planting and covering of seed of grasses and shrubs is a requirement for successful seeding, but the depth must be shallow enough to permit establishment.** Any soil disturbance will plant broadcast seed on light and medium textured soils, but heavy cattle trampling and most mechanical treatment can plant them too deep (Winkel et al 1991, Winkel and Roundy 1991). Seedlings from planted seed are not as susceptible to pulling by livestock and to environmental extremes at the soil surface as are seedlings from broadcast seed. A brush drag, trampling by animals, or a light harrowing may be used to cover broadcast seed. The advantages of drilling over broadcasting for the years 1939-1941 near Brookings, South Dakota, are shown in Table 24-2, and the effect of planting depth on the final stand is shown in Table 24-3. Drilled stands of *Agropyron cristatum* in southern Idaho produced ten times more seedlings than did broadcasting (Hull and Klomp 1967). Imprinting of broadcast seed firms the soil and may be a viable alternative to drilling on loose soils as left by some mechanical treatments. The imprinter leaves small depressions that gather water and shield seedlings from wind. Wilkins et al (1990) have shown that broadcasting and imprinting is more expensive than using the rangeland drill.

Small quantities of seed weighing between a few grams and a kilogram, which are enough to seed a hectare, are difficult to handle in large seeding equipment. Tiny, hard seeds tend to settle out of the seed mixture, calibration of amounts through the drill is inaccurate, and many grass seeds do not flow easily. A common procedure is to increase the bulk of the seeding mixture with rice hulls, sawdust, or other inert material that will feed through the drill and maintain the mixture.

In the tallgrass area, when native species are to be seeded, native hay cut at the time of seed maturity, may be spread at about 500 kilograms per hectare. Disking, cultipacking, or otherwise incorporating this organic material into the soil, plants the seed and adds mulch to the seedbed. When the earliest seeds are ripe and the major crop is in the hard dough stage are two guides to proper cutting time of seed hay. All the seeds will mature in a week or ten days. Because compacting and molding can be problems with green straw, the hay should be spread soon after the material is cut to reduce loss of shattered seed.

The extensive use of stoloniferous grasses and sodgrasses in revegetation operations requires raking or scalping the sods and planting the debris. *Buchloe dactyloides, Panicum obtusum,* and *Cynodon* spp. have been successfully established at a pasture scale by planting of pieces of stolons and rhizomes or by mashing of small pieces of sod or plugs into moist soil.

REGIONAL SEEDING PRACTICES

Land Resource Regions (Austin 1965) adequately serve as the basis for brief descriptions of seeding practices on various types of rangeland. The objective of this discussion is to indicate the type of range improvement and the seeding practices for the areas.

Table 24-2 Percentage emergence and survival of three grass species drilled and broadcast in different trials in eastern South Dakota (Franzke and Hume 1942)

Species	Emerged, %		Survived, %	
	Drilled	Broadcast	Drilled	Broadcast
Agropyron cristatum	54	22	23	12
Bromus inermis	31	10	30	9
Agropyron smithii	43	15	67	23
Average	43	15	40	15

Table 24-3 Percentage survival of five species in relation to planting depth on clay soils in eastern South Dakota (Franzke and Hume 1942)

Species	Percentage survival at planting depth		
	Broadcast	5-12 mm	18-25 mm
Agropyron cristatum	None	78	34
Agropyron smithii	None	82	43
Bouteloua gracilis	60	74	None
Bromus inermis	12	86	30
Panicum virgatum	None	65	20

The Pacific slope located west of the Cascades and extending into Northern California is wet and has yearlong rainfall. The area is forested but has many cleared hectares planted in fruits, crops, hays, and improved dairy pastures. Perhaps 10 to 20 percent of the land is used for range sheep and cattle, as well as by deer, elk, and many other wild animals. Seedings may follow logging or cultivation, and they emphasize

Festuca, Bromus, Dactylis, Phleum, Lolium, and *Trifolium,* all cool-season and moisture-loving species.

The northwestern sagebrush and grass area between the Cascades/northern Sierra Nevada and the northern Rocky Mountains, sometimes called the "Cold Desert," is about 75 percent rangeland. Irrigated crops, timber, and dry-land grain are the principal crops. Several species of *Agropyron*, a *Festuca*, and *Poa ampla* were the only ones that could be recommended after 30 years of observation on the same plots in eastern Washington (Harris and Dobrowolski 1986). They are seeded following brush control, abandonment from farming, or wildfire. A number of seedings have been established to reduce sugar beet leafhoppers and *Halogeton glomeratus.* Planting of some 600,000 bare root shrub seedlings, mostly *Purshia tridentata*, were made from 1976 to 1982 on the Arrowrock Front of the Boise National Forest (Carpenter 1983). Perennial grass should be alternated with the *Purshia*, but at least two feet away from the shrubs.

The California region is Mediterranean in its climatic type and supports thick stands of annual grasses, woodland, and chaparral. After brush control in the chaparral type and in forested areas on the Sierra Nevada foothills, seedings to *Phalaris, Lolium, Bromus, Oryzopsis,* and *Trifolium* are common. Seeding the annual grassland to perennial grasses is not successful, but adding annual *Trifoliums* on the best sites increases production.

The southern Great Basin and Southwestern states constitute the hot deserts in North America. The region is estimated to have greater than 95 percent of the area in shrubs and grasses. *Agropyrons* are seeded in the mountainous areas. *Eragrostis* and *Bouteloua* species are seeded in the south with moderate success, except in areas with very low rainfall.

Seeding in the Rocky Mountains usually aims to rehabilitate both wet and dry meadows, to obtain a forage crop after brush control or timber harvesting, and to protect the soil after wildfire. Seeding mixtures usually contain *Agropyron, Bromus, Poa,* and *Dactylis.*

The Great Plains region from the base of the Rocky Mountains eastward to the Corn Belt has much in common throughout its length from Canada to Mexico. On the drier western side, the favorite species for range revegetation are *Agropyrons, Boutelouas,* and *Buchloe dactyloides. Elymus junceus* is included in the north. To the eastward, these species are replaced by *Andropogons, Panicums,* and *Sorghastrum nutans.* In central and western North Dakota, *Bromus inermis* covers many hectares of land between the *Agropyrons* to the west and the *Andropogons* to the east. Much seeding is done through the region to rehabilitate cropland into grassland. Perhaps 50 percent of the area is cropland, but this percentage varies from near zero on the western side to nearly 100 percent in the true prairie region.

Most seeding in southern and eastern Texas follows mechanical brush control. Various species of *Andropogons, Panicums, Loliums, Cenchrus* and others are planted. To the east and into the Southeastern states, the plantings include *Cynodons, Digitarias, Paspalums, Panicums,* and *Pennisetums.* These species may be used in conjunction with short-rotation timber crops or in rotation with cultivated crops.

Seedings on rangeland in other parts of the world are mainly in tropical and subtropical climates where species of *Panicum, Paspalum, Pennisetum, Digitaria,* and *Brachiaria* are mixed with legumes such as *Phaseolus* and *Desmodium.* Legumes of the genera *Trifolium* and *Medicago* dominate plantings in Mediterranean climates. Varieties of *Cenchrus ciliaris* and *Stylosanthes humilis* cover many hectares of rangelands in Australia and Africa. Shrub species that show value for browse have received increasing attention throughout the world, especially in arid climates.

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Rangeland Fertilization

Fertilization of rangelands has without question increased seasonal and total forage production, improved nutritive qualities of forage, enhanced seedling establishment, and altered palatability. Few trials of range fertilization existed before 1945; many were conducted in the next 30 years, as well as practical pasture-scale applications. Since 1975 both testing and rangeland application have decreased, because of high costs and varied but generally unspectacular increases in forage yield. Few public lands were ever fertilized and on private land the practice has not been highly profitable. However, the fact remains that some combination of soil amendments has increased biomass production in nearly every experiment. Increases in forage production may turn profitable. Fertilization of rangeland is worthwhile and justified for other reasons than grazing by domestic livestock, such as producing attractive feed for wildlife and damaged land rehabilitation.

Nearly all papers on range fertilization report favorable biological results. They also report wide and often unpredictable variations. The objective in this chapter is to review the major responses to rangeland fertilization and to suggest management of fertilized rangeland within the ranch or firm context.

WIDESPREAD FERTILIZER PROBLEMS

The major causes of uncertainty about responses to range fertilization appear to be the variation of soil deficiencies from place to place and the fluctuation of responses with changes in rainfall and temperature. Other irregularities relate to differences in stage of plant maturity at the time of sampling, kinds of fertilizer, rate and season of fertilizer application, and economic analysis. Many permutations of these and other causes of variation remain unmeasured.

Nutrient Deficiencies in Rangeland Soil

The growth of the range forage crop within each range site best indicates the available plant nutrients in the soil. Addition of nutrients to the soil and the plant responses measure the deficiencies. While these deficiencies may be indicated by soil test, greenhouse trial, and tissue analysis, a field test gives results directly usable in specifying fertilizer practice. The bulk of information obtained from experience and testing on North American rangelands shows that the major soil-nutrient deficiencies are insufficient available nitrogen, phosphorus, and sulfur or any combination of them.

Nitrogen deficiency seems universal. A wide review of many papers showed that, in most instances, herbage growth increased as a result of nitrogen fertilization. Lack of phosphorus clearly came second and sulfur third in importance. Both nitrogen and phosphorus were required in many areas, where supplying one without the other was of little value. Potassium, calcium, and magnesium amendments to soils under crops and pastures commonly increase production, but these elements appear only of local importance in rangeland fertilization. The trace elements--zinc, iron, boron, manganese, molybdenum, and copper--have given an even smaller response than potassium and calcium in rangeland trials, although they are included in the mix of most soil amendments. Widespread deficiencies of the trace elements occur in Australia, New Zealand, and other world rangelands.

The fertility of rangeland soils probably varies more than the fertility of agricultural soils. This is particularly true when the definition of soil potential embraces soil physical characteristics, moisture content, organic matter, and the living inhabitants as well as the amount and availability of chemical elements. While a narrow definition emphasizes the delivery of chemical salts to plant tissues, management of soil fertility must include the factors controlling that delivery. In this respect, rangelands include widely variant conditions. There are uncontrollable extremes in dryness, wetness, texture, acidity, salinity, and alkalinity. Fertilizer use is just one factor in successful rangeland management. Its effectiveness depends upon the degree to which the added minerals correlate with other limits in production. Every range pasture presents a different combination of these soil/nutrient factors. Continuous fertilization may change the soil and develop other problems. For example, 20 years of low level nitrogen applications reduced the soil pH from 6.7 to 5.3, which was enough to reduce growth of some legumes on the Southern Great plains Experimental Range (Berg 1986).

Relationships with Weather

Precipitation, soil moisture, and temperature change daily, monthly, and yearly. The lows, highs, and unusual events cause variation in responses to fertilization. The importance of these factors in fertilizer practice was given by Martin and Berry (1970) for the California annual grassland. In summarizing 54 field experiments during 15 years of work in 20 counties, they placed the limits of profitable fertilization within the 330 to 760 millimeter range of average rainfall. Less rainfall gave insufficient soil water for efficient fertilizer use, and more rainfall leached the applied fertilizers beyond the root zone before they could be used.

Low rainfall limits for fertilizer use have been suggested in other places. Smika et al (1965) mentioned that 380 millimeters of rainfall in western North Dakota produced maximum herbage without added nitrogen but 500 millimeters were required with application of 90 kilograms of nitrogen per hectare. Patterson and Youngman (1960) gave the dry limit of profitable fertilizer use on *Agropyron desertorum* in eastern Washington at 330 millimeters of precipitation. Trials of rangeland fertilization have given discouraging results in the semidesert grassland.

In one dry year the normally flooded meadows in eastern Oregon responded to nitrogen with little increase in yield and quality of forage (Gomm 1982). As the proportion of low-rainfall years increases, so does the likelihood of little response to soil amendments. The critically low precipitation appears to be near 300 millimeters per year. Seasonal rainfall and growing season may alter that limit.

Forest sites with moderate rainfall usually give favorable herbage yield responses to soil amendments, as illustrated with *Calamagrostis rubescens* in British Columbia (Freyman and van Ryswyk 1969) and on pine woodland in the southern United States (Hughes et al 1971).

Recovery of the applied minerals in harvested forage may also be in part a function of weather. As recovery increases so does the efficiency of applying fertilizer. Although the yield increase was high for *Cynodon dactylon* and *Eragrostis curvula* in south Texas when fertilized with nitrogen and phosphorus, only 20 and 16 percent respectively of the minerals were recovered in the forage. Precipitation varied from 543 to 979 millimeters for the five years of the study suggesting losses by leaching (Wiedenfeld 1988). In Alberta, Canada, yield and protein increased for 7 seeded grasses with nitrogen application. The recovery of nitrogen varied from 12 to 31 percent with one application and 8 to 14 percent with yearly treatments. These returns were too low to be economical (Lutwick and Smith 1979).

However, the apparent loss may be stored minerals in unavailable form in the soil and in plant sinks. Black and Wight (1979) working in eastern Montana, found that crude protein was higher 8 years after a single fertilization than on unfertilized plants, although yield had subsided to that of the controls. A single application of nitrogen was still increasing yield of *Agropyron smithii* after 10 years in eastern Montana (White 1985). Numerous reports of carryover effects in different vegetational types have shown similar results and suggest that responses in dry areas can persist for many years. Carryover of sulfur and phosphorus occurs more commonly than retention of nitrogen.

Variations in response to fertilizers have been suggested. Cosper et al (1967) reported about 130 percent yearly difference in herbage yield from both fertilized and unfertilized mixed prairie in Wyoming; the yearly variation amounted to 2,051 and 953 kilograms per hectare, respectively. Rauzi and Fairbourn (1983) state that variation of concentration of phosphorus, calcium, potassium and magnesium in leaves of mixed prairie grasses in southeastern Wyoming was due to weather. Wide fluctuations in production characterize all native forage-producing areas, with and without fertilization.

RESPONSES TO FERTILIZATION

The major benefits from rangeland fertilization center on increased amounts of seed and herbage that have higher nutritive qualities than the same feeds grown without fertilization. Feed may be produced earlier with fertilizers than without them. Secondarily, or more locally, fertilization is used to promote seedling establishment and distributional control of animals.

Increases in Herbage

Nearly all reports of fertilizer trials describe increases in herbage production. A trial with 12 seeded species combinations, 4 fertilizer treatments, 2 harvest dates, and for 2 years had fertilizer responses varying from depressed yields to more than double within the same species (Schultz and Stubbendieck 1982). A different sort of variation occurred in mixed prairie of western North Dakota where a significant response to phosphorus did not occur until the fourth year of treatment (Lorenz and Rogler 1972, 1973).

Application of nitrogen increases the production of forage in the northern mixed prairie in the United States and Canada (Rauzi 1979, Wight and Black 1979). Nyren et al (1983) found that yield was increased

46 percent with nitrogen and phosphorus fertilization. Their results were cited as similar to 13 other papers. By using climatic and site data, Wight and Godfrey (1985) have shown that yield response of native range to nitrogen fertilization can be reliably predicted.

The California annual grassland is a region where research and fertilizer application on rangeland have been common. Wide herbage increases and variations have prevailed and fertilization has not consistently lengthened the green-feed season (Wolters and Eberlein 1986). The wetter and more fertile range sites did not respond to sulfur, but production increased on upland sites by 28 to 51 percent (Caldwell et al 1985). Seeding with *Trifolium subterraneum* and fertilizing with phosphorus and sulfur every two or three years gives a high yield of quality forage from many sites in the California annual type. This practice is recommended rather than annual nitrogen and phosphorus applications.

Fertilization of the true prairie increases herbage production by stimulating cool-season species, undesirable forbs, or both at the expense of warm-season species (Owensby and Smith 1979). However, cool-season species and weeds were not encouraged in a Nebraska test (Rehm et al 1972). Cool-season application of nitrogen nearly doubled the yield of *Festuca arundinacea* overseeded into a native tallgrass hay meadow in northeastern Oklahoma. The tall grasses showed little change (Mitchell et al 1985).

Although herbage increases resulting from nitrogen applications have been reported for Palouse prairie and other variants of the western mountain bunchgrass type, recommendations for rangeland fertilization generally are less than enthusiastic. In a few trials fertilization has stimulated the annual *Bromus tectorum* and other annuals less than the perennials, especially *Agropyron spicatum*. Increased yield of *Bromus tectorum* varied unpredictably over 11 years (Kay 1966). In general annual grasses respond more than perennial grasses in mixed stands.

Fertilization of seeded cultivars of introduced *Agropyron* spp., *Elymus junceus*, sod bound *Bromus inermis*, and a few other species appears to be a practical means of increasing herbage production in the northern Great Plains, in the sagebrush-grass type in Oregon and in Utah, but had no practical results in Nevada (Eckert et al 1961). *Agropyrons* in the pine zone responded with increased yields in Arizona and with no significant increases in northeastern Utah.

Increased yields of *Cynodon* cultivars and other introduced species commonly occur after fertilization in the southern United States (Gonzalez and Dodd 1979). Planted stands of *Cenchrus ciliaris* gave marked increases in forage production with nitrogen, but increases by the

Pretoria 90 cultivar of *Dichanthium annulatum* were minimal (Wiedenfeld et al 1985).

Sewage sludge has been applied to rangeland and has increased nitrogen, phosphorus, and potassium in the soil as well as a number of the micronutrients. Fresquez et al (1990) found that application of sludge to depleted rangeland in New Mexico decreased plant density and diversity but cover and yield increased. Organic amendments provide mulch to the soil surface and are more environmentally acceptable than the chemical fertilizers. *Andropogon virginicus* showed increased crude protein levels 4 years after liquid digested sludge was applied to a *Pinus caribaea* plantation (Dunavin and Lutrick 1983). Heavy metals in sludge may be a problem.

Increases in Forage Quality

Many papers on effects of rangeland fertilization report that improved forage quality results from additions of nitrogen to the soil. In a few locations, phosphorus and sulfur, in addition to nitrogen, were needed. Duncan and Hylton (1970) reviewed the subject, showing that increases in yield and quality relate directly to each other. Quality in this context refers to percentage crude protein as determined by plant nitrogen quantities.

Increased crude protein levels due to fertilization may not be particularly beneficial since the increase occurs when crude protein levels of unfertilized forages are adequate for efficient animal growth. As the plant growth cycle advances, the protein level in fertilized herbage normally drops to near the level in unfertilized herbage. Improved curing of feed on the ground comes more readily from improved botanical composition and more legumes rather than from fertilization alone.

Uses of fertilizers include correction of deficiencies for animal nutrition, such as phosphorus fertilization to relieve phosphorus deficiencies in range cattle (Reynolds et al 1953) and to reduce the ratio of potassium to calcium and magnesium where grass tetany occurs (Azevedo and Rendig 1972). Nitrate poisoning may result from massive nitrogen fertilizations over 100 kilograms per hectare (Gomm 1979). Fertilizing of five deer browse species in Texas with nitrogen and phosphorus did not alleviate phosphorus deficiency in the browse (Everitt and Gausman 1986). **For livestock, direct feeding of minerals to prevent deficiencies is more effective than fertilizing the feed.**

The effects of fertilization on digestibility vary. Poulton et al (1957) found little difference in digestibility of either *Dactylis glomerata* or

Medicago sativa with nitrogen fertilizations that ranged from zero to 450 kilograms of nitrogen per hectare. Conversely, hay from fertilized *Bouteloua gracilis* rangeland in New Mexico showed increased digestibility of dry matter, protein, and energy by wether lambs (Kelsey et al 1973). After an extensive review of nutritive values resulting from pasture fertilization, Blaser (1964) suggested that TDN, or digestible energy, changed little with nitrogen fertilization because increases in crude protein digestibility balanced decreases in soluble carbohydrates. Improved quality of feed after fertilization may be related to characteristics such as succulence, increased green period, narrow leaf-stem ratio, and botanical composition of the feed, other than chemical contents.

In a south Texas trial, crude protein content of herbage was increased by nitrogen and phosphorus fertilization in three commonly seeded species (*Cenchrus ciliaris, Chloris gayana, Panicum antidotale*) but not in *Dichanthium annulatum* (Mutz and Drawe 1983). Clearly, fertilization increases forage quality, but not to a profitable degree in all situations.

Changes in Botanical Composition

Fertilization increases biomass production in three ways, by promoting larger size without change in species, by supporting more individuals, and by promoting taller or larger species over smaller ones. Adding soil nutrients actually does all three. One or another of these results may be important for practical reasons.

Additions of phosphorus, sulfur, and potassium on rangeland usually favor legumes and other forbs, sometimes with little effect on grass yield. Nitrogen fosters the grasses and reduces the legumes (Table 25-1). These results occur with warm-season and cool-season species. At the present stage of range fertilization practice, few managers use varying combinations of elements to manipulate balances among legumes, other forbs, and grasses.

Fertilization alters the proportion of cool- and warm-season species in the true and mixed prairies. Management objective may aim for either species-type. In the true prairie, increases in undesirable weeds usually accompany increases in cool-season grasses. Fertilization of northern Great Plains grassland results in a desirable spring response of the cool-season grasses. Increased forbs may improve the habitat for seed-eating birds, as sulfur fertilization and increased legumes have favored quail in California (Shields and Duncan 1966). However, atrazine and spring burning were more effective than nitrogen in increasing the proportion of tall grasses in northcentral Oklahoma (Gillen et al 1987).

Table 25-1 Influence of rangeland fertilization upon botanical composition.

Vegetation type and location	Fertilizer type and amount, kg/ha	Species	Percentage composition without treatment	Percentage composition with treatment	Source
California annual type, San Joaquin Range, 1959	Sulfur-67 nitrogen-90	Grasses Legumes *Erodium* Other forbs	58.2 1.2 39.3 1.2	71.1 0.5 27.1 1.3	Woolfolk and Duncan (1962)
1960	Sulfur-67 nitrogen-90	Grasses Legumes *Erodium* Other Forbs	27.0 1.6 60.9 10.5	40.5 0.1 52.1 7.2	
Annual grassland, Israel	Nitrogen-79	Grasses Legumes Other forbs	33 50 17	65 15 20	Ofer and Seligman (1969)
	Phosphorus-59	Grasses Legumes Other forbs	33 50 17	20 74 6	
	Nitrogen-79 Phosphorus-59	Grasses Legumes Other forbs	33 50 17	70 15 15	
Palouse prairie, Washington	Nitrogen-45	*Agropyron inerme* *Festuca idahoensis* *Poa secunda* *Bromus tectorum*	66 4 17 13	14 4 25 58	Patterson and Youngman (1960)
Mixed prairie, Wyoming	Nitrogen-37	*Bouteloua gracilis* *Poa secunda*	76 19	60 37	Rauzi et al (1968)
Mixed prairie, Alberta	Nitrogen-336 phosphorus-168 potassium-336	Grasses	48.0	57.4	Smoliak (1965)

Rumburg and Cooper (1961) found meadow hay in eastern Oregon to be mostly *Hordeum brachyantherum* and *Elymus triticoides* where fertilization was 448 to 672 kilograms of nitrogen per hectare. The clovers disappeared and the sedges started decreasing at 224 kilograms of nitrogen per hectare. *Centaurea maculosa* in western Montana increased more than the other plants with nitrogen added to the soil (Story et al 1989). Fertilization should be avoided where the undesirable species respond quickly and dominate the vegetation.

Legumes, mostly cultivars of *Medicago*, seeded on rangelands are well known for increasing the quality of the feed and the growth of associated grasses. Fifty clonal lines of Hycrest crested wheatgrass showed significantly higher nitrogen content and yield when grown with alfalfa (Asay and Mayland 1991). This result supports the findings of others and suggests that where possible legumes should be seeded on rangeland as a substitute for fertilization. Native lupines have been shown to increase nitrogen near their roots (Kenny and Cuany 1990) and another that fixes nitrogen is *Hedysarum boreale* (Johnson et al 1989).

Rehabilitation of Depleted Areas

The use of fertilizers to rehabilitate rangeland, that is, to increase seedling establishment and reduce erosion, seems to be a questionable practice. Most studies of the central North American grasslands have found fertilization at the time of seeding to have no effect or a detrimental effect on the seedlings of perennial grasses because weed growth was stimulated. Conversely, fertilizers should be applied if soil amendments are needed to correct deficiences or chemical imbalances in newly exposed subsoil.

Palatability

Animals commonly prefer fertilized areas, and many plot results have been lost because the fertilized plots were selected and overused. Here are some examples of exhibited preferences for fertilized areas: Beef cows in northcentral Oklahoma and the degree of utilization increased 15 percent for each 1 percent increase in crude protein (Baker and Powell 1982); Cattle on shortgrass in southeastern Wyoming (Samuel et al 1980); Deer in the Black Hills of South Dakota (Thomas et al 1964); Selection of *Calamagrostis rubescens* in British Columbia (Freyman and van Ryswyk 1969); Reduced differences between palatable and unpalatable species on the Santa Rita Experimental Range (Holt and Wilson 1961); Cattle walked less, took bigger bites, picked fewer acorns, and spent less time grazing in California oak woodland (Green et al 1958); Fertilization away from water gained better distribution on mountain rangeland (Hooper et al 1969); Increased palatability of forbs on blue grama range in southern

New Mexico (Krysl et al 1987); Increased winter elk use in southeastern Washington, but only during the first winter (Skovlin et al 1983); Pronghorn in Alberta, Canada were attracted until the forage matured (Barrett 1979).

Seasonal Growth

Fertilization changes plant growth rate during certain seasons. The most striking and consistent result from many fertilizer trials on the California annual grassland has been increased fall, winter, and early-spring growth from nitrogen applied in the fall. Phosphorus and sulfur must be adequate. The result is feed composed mostly of grasses and it occurs during the seasons when little grass is expected. A common result of fertilization is earlier and greater spring growth. The length of the green-feed season is extended by earlier range readiness but not extension of green feed into the dry season because of soil moisture depletion.

Growth in the semidesert grassland begins with the summer rains, and fertilization cannot advance that time. Apparently fertilizers need to be applied near the beginning of growth when rainfall will take the minerals into the soil. Application of fertilizer on different dates beyond that stipulation has not given large differences in results. Manipulating the times of range readiness, leaf drying, and plant maturity obviously has an important relationship to rotation of grazing.

IS RANGELAND FERTILIZATION PROFITABLE?

Whether fertilization of rangeland produces sufficient increased forage to be profitable remains an unanswered question under most conditions. Research papers often express confidence that fertilization yields a profit, but the authors' evaluations apply to their plot results, not results in the total firm operation. Evaluation of costs and benefits should include budgetary analysis in the full context of the ranch operation.

Most attempts to analyze fertilization inputs for profitability have given costs for additional feed produced in comparison with costs of buying feed. For example, Mason and Miltimore (1969) found that fertilization of *Agropyron inerme* on nine sites for four years in southern British Columbia yielded forage costing between $6.40 and $98 per ton. That suggests great risk and that the price may be controlled more by the price of purchased feed and fertilizer than on the ability to produce grazeable feed.

A fact often forgotten is that **the increased forage produced by range fertilization must be used by additional animals. Forage from fertilized rangeland abounds at nearly the same time that unfertilized range reaches its peak in quantity and quality.** If the manager does not increase the number of animals on the whole ranch at that time, the result is likely to be exchange of one feed for another--a higher feed cost for one that is less expensive.

Significant weight-gain differences of animals on properly managed fertilized and unfertilized ranges are unlikely. More likely, increased numbers of animals and kilograms of product per hectare, rather than increased individual weights, generate the profit. The manager must integrate fertilization into the whole-ranch program and invest where inputs will be most profitable. The biological basis for range fertilization lacks many details, but the managerial aspects have for the most part been overlooked by the range profession and need to be approached with care.

MANAGEMENT OF FERTILIZED AREAS

Major points in rangeland fertilization and management are as follows:

- Rangeland fertilization appears to result in major increases of forage within an annual range of precipitation from approximately 300 to 700 millimeters.
- Fertilize with the correct element or combination of elements that are deficient in the soil and needed for the intended crop. Local experience usually has this information.
- Only apply fertilizers to the best sites. They are the most likely to produce profitable returns.
- Where expedient, encourage legumes that fix nitrogen by fertilizing with phosphorus and sulfur.
- Do not apply fertilizers that will increase undesirable annuals and toxic plants.
- As fertilized rangeland forages mature and dry they lose nutritive value and may become little different than the unfertilized feed.
- Direct feeding of deficient minerals to livestock is more effective than fertilizing the forages.
- Do not invite grass tetany, nitrogen toxicity, and ground water contamination by overfertilizing.
- Fertilize whole pastures or units to prevent problems of livestock distribution and overutilization.

- Be prepared for fluctuations in yield. They are about the same on fertilized and unfertilized rangeland.
- Use a complete analysis procedure to determine profitability. Integration analysis of a fertilization program into the whole-ranch system may show that the money should be used for other investments.

Range fertilization seeks a managerial ideal: the ability to furnish each plant with the nutrients it needs on each particular site as required within the vagaries of weather; the ability to control species composition of the forage; and the delivery of that forage to animals in ways that produce profit for the ranch enterprise. These are the problems, the objectives, and the challenges of rangeland fertilization.

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Soil and Water Conservation

Soil science, including soil water, is a large and complex subject, too much so for a review in this book. The intention here is to present the management of rangeland soil and water as a practical subject with emphasis on erosion and its control, and development of water for use, loosely called "water harvesting."

RANGELAND SOIL CONDITIONS

Rangelands the world over have experienced more extensive damage by wind and water erosion than is normally expected from geological causes. This acceleration of damage is a result of overgrazing, indiscriminate burning, direct harvesting of fuel wood in deserts and forests, cultivation where it should not have been, and severe droughts. The situation is so desperate in some areas and some years that people have starved and fear of expanding deserts has resulted in the United Nations Environment Program to stop the crawl of deserts into more moist regions.

The distinction between erosion as a normal process and as accelerated destruction is difficult to determine. However, normal geologic erosion is severe when water cuts new "badlands," when climate changes, when land has risen or subsided rapidly, and when new landscape is formed, as by a volcanic eruption or cutting by glaciers. Where crops are grown and vegetation covers the land, geological erosion is barely detectable. Severe erosion often follows a change in land-use, for example abandonment of farmland and clearcutting of forest. No soil would exist on sloping land if geological erosion were faster than soil formation. With the right climatic conditions and substrate materials two or three centimeters of soil can form in a couple of decades.

Much erosion has been attributed to burning. Certainly, increased erosion is likely to occur immediately following destruction of vegetation by any means. Fire or any other factor that reduces foliage also reduces interception, transpiration, and cover, thereby increasing the amount of water available for surface flow. But fire has been a factor in most vegetational types of the world far longer than humans have been exerting influence. If fire effects were permanent or greater than could be repaired between burns, soil and vegetation would disappear. Fire effects on erosion are temporary and a few vegetational types depend upon burning for their existence.

Accelerated erosion results from (1) lack of knowledge about its causes and cures, (2) belief in an unlimited land resource enabling people to move to a new site as an old one is destroyed, and (3) uninformed land regulations and customs. Notable exceptions occur mainly in arid lands because people learned to live with geologic erosion.

The rock terraces in the Middle East illustrate the fact that soil management and erosion have been problems since cultivation began. Neatly contoured rock walls are abandoned and hold little soil. We do not know if they were used to keep soil in place where it was originally formed, to hold soil hauled from the lowlands by the donkey load, to catch soil eroding from above, or a combination of these purposes. Nor is it clear whether loss of soil from these terraces caused the downfall of civilizations or came after wars and pestilence had forced the people to leave, abandoning the land for short or extended periods. However, it is certain that human-made structures require maintenance. They are soon reduced by the forces of nature when abandoned. This is equally true of modern soil erosion control structures.

THE EROSION PROCESS

Soil erosion relates to the movement and resistance of soil to the forces of water and wind. Erosion control protects against those forces. Water and wind have two actions: dislodgment of soil particles and their transport. In many respects, water and wind are similar in these two actions. Occasionally water and wind interact, as with driven rain, and seldom does a range area show erosion by one force and not the other.

Erosion by Water

The impact of falling raindrops is the most widespread of the dislodgment forces. Five centimeters of rain per hectare deliver enough force to lift eighteen centimeters of soil to a height of 1 meter (Nichols and Gray 1941). If the raindrops are large, the force is delivered in blows that dislodge soil particles and splash them in all directions. When the raindrops are tiny, little dislodgment of soil particles occurs. On level land with rain falling vertically, splash is equal in all directions and there is little net loss of soil, but the greater the slope, the more downhill the creep of material.

Splash effects following a rain show as muddy walls and as flattening of a pile of sand. On a 10 percent slope, the downgrade splash is about three times the upgrade movement. A violent storm could splash as much as 250 tons per hectare (Ellison 1950). Accumulation of soil within a healthy bunchgrass plant is in part due to this action.

Splash erosion destroys soil structure, places particles in suspension, and mixes water and soil. This action of mixing water and soil commonly is called "puddling." As muddy water infiltrates the soil, the suspended particles tend to plug the soil pores, sometimes completely preventing further intake of water. A dry, unstructured soil, such as dust, traps air, which also prevents wetting except on the puddled surface. When the sealed layer dries, it forms a crust. All this tends to waterproof the land and to increase surface runoff. Total splash of soil can be used as a soil erodibility index (Yamamoto and Anderson 1973).

The overland flow of water transports soil materials dislodged by raindrops and further loosens soil particles by abrasion. The beginning sheet erosion may not be noticed, but it results in concentration of water and increased scouring action that soon is evidenced by rills and grooves in the land. The deeper water-cut channels become gullies, the worst of which often occur toward the bottom of watersheds. Gullies gradually work headward as soil sloughs from the steep sides and is carried away. Gully head cutting can produce a significant portion of the sediment loads (Osborn and Simanton 1986). Large gullies often are objects of concerted schemes for action, such as the treatment of the gullied areas in the United States in the 1930s.

The slope of the land makes a great difference in erosion rate. Multiplying the slope by 4, roughly results in twice the velocity of flow, 4 times the eroding power, 32 times the material carried, and 64 times the size of material that can be moved. The force of running water is dependent on volume and rate of flow, which are related to intensity and duration of rainfall.

Loss of nitrogen, phosphorus, potassium and other elements in runoff water is a form of erosion and is directly related in magnitude to the sediment load. However losses of both nutrients and sediments are not excessive on good condition rangeland. A 3- to 5-year study across the southern plains in Texas and Oklahoma emphasized that losses from well-developed grasslands were less than 5 kilograms per hectare for both nitrogen and phosphorus. More nitrate was received in precipitation than was lost. Sediment and nutrient losses increase quickly if runoff losses occur soon after fertilization or fire (Smith et al 1983).

As a principle, surface water flow, or runoff, should be reduced as much as possible by soil and vegetational management that promotes maximum infiltration where the rain falls. Splash or puddle erosion, fertility erosion, and sheet erosion may be as damaging to productivity as large gullies, but the damage is difficult to assess and seldom determined. Measured soil loss is usually that scoured from gullies and channels. Good vegetational management of the watershed must be the first practice. It will lessen potential erosion in crisis areas and promote healing on most of the watershed. Those few areas that do not respond may be treated with dams, terraces, or other practices.

Since runoff is inevitable and necessary and erosion is a natural process, the reasonable approach is to manage runoff and erosion according to the productivity objectives of an area. These may vary from promoting as much runoff as possible with no erosion for maximum water yield to preventing both runoff and erosion completely, even preventing or minimizing geological erosion.

Susceptibility of Soils to Erosion

Soils that do not rapidly absorb water may be subject to high runoff and erosion. Clays and calichi layers with low percolation rates reduce deep drainage thereby increasing evapotranspiration and runoff. High intensity storms in arid regions produce more sediment from clays than from sands. Soils with low absorptive capacity and low organic matter are highly erodible. Stability of soil structure influences erodibility. Aggregated clays tend to be difficult to erode until the structure is broken.

Sediment yield as a measure of erosion increases with increasing runoff. Situations and influences such as bare ground, soil moisture, soil bulk density, grazing intensity, and rock pavement are positively correlated with runoff and sediment amounts. The negative relationships include cover by vegetation and litter, soil roughness and depth, soil organic matter and aggregate stability. Therefore, to reduce erosion use methods that increase cover, soil surface configuration, and soil organic matter (Blackburn et al 1986).

Nonwettable soils have been reported in several western states, Florida, New Zealand, and Australia (DeBano et al 1967). Hydrophobic conditions may be associated with microorganisms or chemical substances in live plant materials and mulch. Nonwettability can be intensified by fire, as shown in California chaparral and desert scrub (Adams et al 1970). It seems to be associated with a range of 200 to 425 degrees Centigrade in the soil temperature gradient during a fire. Wetting agents can increase infiltration, decrease runoff and erosion, and increase grass establishment. They are expensive for large-scale application.

Erosion by Wind

Wind erosion is similar to water erosion in causes, results, and cures. It occurs where the soil is exposed to the dislodging force of moving air and varies with structure of dry soil; surface roughness; slope; cover on the soil; and velocity, angle of incidence, and duration of air movement. A 40-kilometer-per-hour wind has four times the power to pick up soil as has a 20-kilometer-per-hour wind. Dune sands begin to move with wind velocities of 15 to 25 kilometers per hour. As soil particles are moved by air, they have an abrasive action that dislodges more soil. Control can be attained by decreasing exposure to wind with tillage practices or by planting vegetation that covers the soil and adds organic matter that promotes improved soil structure.

In arid and semiarid regions, where much bare soil exists, maintenance of shrub types of vegetation is the principal way to control soil erosion by wind. Shrubs occupy area, reducing exposure of the soil to wind. The most efficient shrubs for this purpose are the ones that have their greatest width at ground level. Shrubs present a frontal or vertical silhouette from any direction, thus reducing wind velocity. Windtunnel experiments suggest that relatively narrow shrubs with a low diameter-height ratio less than 2 give sufficient roughness to reduce wind erosion and provide an herbaceous grazing resource between the shrubs (Marshall 1970).

RECOGNITION OF EROSION

Anyone working on rangeland needs to be able to recognize erosion. Perhaps the first obvious signs are pedestaled plants with roots showing and movement of soil away from rocks and burned woody stems. The newly exposed rocks and stem bases usually are different in color, thereby indicating the depth of soil that has been removed. Often fine debris will have accumulated in small nearby contour ridges and lodged at the uphill side of any obstruction to water flow. Rills or small grooves of V shape will be present, and pebbles or gravel may be accumulating on the soil surface during early stages of accelerated erosion. More or less level areas are sites of soil accumulation when gentle slopes begin to erode. More serious are subsoil and bedrock exposure, mud flows from slopes, mud bars along streams, channels gorged with creep of dry materials, floods with higher peaks, undercut stream banks, lowering of the water table, and large gullies that are head cutting. Any of these should be recognized as a warning that erosion is active. It is always important to recognize erosion when it starts, to appraise its causes, and to take remedial steps.

EROSION CONTROL WITH COVER

Erosion is prevented and eroded areas healed mainly in proportion to the amount of soil surface protected from raindrop impact with a cover of mulch, plants, and stone. Wilcox et al (1988) found that lack of cover, biomass, and steepness of slope in that order were the most important causal factors, therefore control factors. In New Mexico, Wood et al (1987) agreed that cover was most important and favorable soil characteristics (texture, organic matter, bulk density) also contributed to reduced erosion. A cover composed of vegetation and surface organic material contributes to a favorable soil and directly intercepts and dissipates the beating energy of rain. Indirectly, cover keeps the surface soil moist longer than does bare soil, improves soil structure by adding organic matter, and protects the soil from wind (Simanton et al 1991).

Vegetation and plant residue reduce the rate of water flow across the surface by damming it and continually breaking larger volumes of flow into smaller volumes. Even unattached organic material that may float and move with runoff water tends to lodge, making tiny debris basins. Thus, more time is taken for flow from hillside to channel, resulting in lower flood peaks, more water infiltrating into soil, more storage of water in the soil, and gradual release of water for later channel flow.

Amounts of Cover Needed

Although cover and amounts of mulch or organic residues have been used to suggest proper utilization of ranges, there still is little specific information about the relation of quantity of plant materials and cover to the condition at the soil surface. Expressions of cover may be quantity or percentage of ground covered by plant litter, stubble height, plant residue, and live vegetation.

Soil texture, soil structure, slope, and rainfall are, to a degree, beyond the manager's direct control. Effort is usually indirect through management of the amount and kind of plant cover on the soil. For example, Ellison (1950) suggested from widespread studies in Texas and Oklahoma that a grass stand with 7 tons of herbage and litter per hectare yielded only 1.2 tons of splashed soil per hectare. Infiltration of water into the soil was 60 millimeters in 15 minutes. Nearby, on bare soil, 170 tons of soil per hectare were splashed and water intake was 2.5 millimeters in 15 minutes. From similar work, Allred (1950) suggested that approximately 2,800 kilograms per hectare of plant material is adequate to keep splash erosion below 15 tons per hectare, which he considered adequate protection. Soil algae and lichens in the soil crust reduced the amount of mulch needed to hold soil in light storms, but the crust was broken by heavy rain.

Protection requirements for granitic soils in southwestern Idaho appeared to be 70 percent cover of soil with plants and mulch in perennial wheatgrass (*Agropyron inerme*) and 90 percent cover in annual grass (*Bromus tectorum*). On the average, these requirements mean that spots of bare soil should be no larger than 10 centimeters in diameter in the wheatgrass type and 5 centimeters in the annual type. Runoff was most closely related to cover, and erosion to the size of bare soil patches (Packer 1951). Plant and mulch cover accounted for 52 to 80 percent of the explained variance in erosion in a number of studies (Packer and Laycock 1969). This suggests the importance of cover and the need for the manager to develop local standards.

Effects of Changing Cover Type

Environmentalists and managers of rangeland are concerned with changes in vegetational type and the effects these changes have on runoff and erosion. In the chaparral type of southern California, removal of the shrub cover by fire leaves the steep slopes highly susceptible to erosion. Some slopes, steeper than the angle of repose, immediately begin to show creep as material rolls downhill. Even where slopes are not steep, increases in surface runoff and erosion often occur during the bare-soil period between destruction of one vegetational type and establishment of the next. Significant drops in runoff and sediment production occur as vegetative cover becomes reestablished.

Where grass replaces woody plants on deep soil and adequate rainfall exists to wet the whole soil profile, increased water in aquifers will occur. Grasses, normally being less deep-rooted than woody plants, remove water from only the upper parts of the soil profile, resulting in less needed to recharge the profile and more runoff or deep penetration. Rowe and Reimann (1961) suggested that the soil must be at least 1 meter deep for significant differences in water yield to exist between grass and chaparral types. Kittredge (1954) stated that on deep soil a grass cover will give about the same erosion loss as pine, but five times the runoff.

Where rainfall is light and soils are shallow, the type of plant is of little consequence to the water budget.

Following a cover-type change, adjustments in the hydrological regime may take only a year or it may take decades to achieve complete soil and slope stability. For example, deep woody roots take several years to decompose. When they do and only grass roots remain, land slipping may occur as the deep soil support is reduced (Rice and Foggin 1971). Land slippage may occur several years after the surface vegetation has been converted to grass.

In semiarid areas where cover is always sparse, slope gradient may be the major factor controlling erosion. Even there, as cover by plant materials and rocks increase, erosion by runoff generally decreases.

MECHANICAL STRUCTURES TO CONTROL WATER EROSION

Thousands of soil and water conservation structures were built by the Civilian Conservation Corps and other agencies between 1934 and 1942. In 1949 and 1961, about 900 such structures in the Gila and Membres River basins in Arizona and New Mexico were examined for structural soundness, erosion- control effectiveness, and vegetational response. Half of the structures had been breached within a few years after construction, and the total quantity of trapped sediment amounted to less material than was used in the original construction of the structures. Failures were due to poor siting, improper design, faulty construction, and lack of maintenance (Peterson and Branson 1962).

Erosion-control structures such as sizable dams or gully plugs often are bypassed with new gullies. Terraces and contour structures, which aim at controlling surface water flow may fill with silt or be breached by a burrowing animal. Contour terraces are not effective in preventing downhill splash erosion, because the splash tends to flatten them. Any furrow-break concentrates flow, which cuts a new gully in its downhill rush of water.

Gullies may be especially active in different positions along their length. At the head of a gully, grass and other herbaceous cover often hold the top few centimeters of soil with a mass of fibrous roots. Woody plants and taprooted species hold a thicker layer of soil than do the grasses, but gullies deeper than approximately 1/2 meter grow by undercutting the soil and slumping along the sides and head.

Other gullies may be cutting fastest in their lower elevations. Young gullies that are growing both upstream and downstream need control measures at these critical points. Older gullies that are continuous with the main drainages should be attacked first where they are most active, normally in the lowest segments. Control measures that do not treat all critical points are likely to fail (Heede 1970).

Mechanical structures are necessary to control gullies or large flows in emergency situations. Examples of such structures would be a series of small dams used to raise the water table in a mountain meadow that had been cut with a gully. Dams of this type may be constructed from materials available at the site or from prefabricated, interlocking metal strips. These dams are placed so that the water held by each nearly reaches the dam above. These gully-filling projects must not exploit nearby topsoil and expose subsoil. Watershed management above them is essential. Other examples that illustrate erosion control lessons are as follows:

The Vlekpoort Reclamation Scheme

Several erosion-control principles are illustrated by the extended program to control deep gullies in the upper reaches of the Vlekpoort River, South Africa (Labuscagne and de Villiers 1966). The first step in 1946 was to build dams in the larger gullies. One 4.3-meter high dam, as an example, had sedimentation to the dam overflow in one year but did not fill to a stable gradient until 1953. At that time, sediments extended 915 meters upstream from the dam. During 1959 and 1960, extensive plantings with *Phragmites communis* and *Sorghum almum* were made in the sediments farthest from the dam and along the stream banks. Revegetation resulted in renewed sediment deposition both downstream and upstream from the plantings. By 1963, sediments reached 1,617 meters upstream, where they were 7.5 meters above the spillway level. After a stable gradient is achieved, normal bed-load or eroding material will cross it. Another dam may be needed but the final solution is to reduce erosion from slopes above the gullies.

This example shows that relatively large dams are necessary to initiate deep-gully control and that vegetation planted in the accumulated sediment increases the dams' effectiveness. Shaping of gully sides was not done in this scheme, although frequently it is recommended. Sedimentation builds the V-shaped gullies into U-shaped ones and eventually into flat valleys with ever-increasing width.

In Malawi, an opposite situation occurs. There the spectacular erosion is in the uplands. Broad, often water-logged valleys are holding the sediments and actually increasing in size. The few eroding spots in the valleys are small in size and are healing at the lower edges as rapidly as they are head cutting. Although an initial erosion-control scheme may aim its efforts downstream, the major problems and final solutions usually are on the headwater slopes.

Control of Bank-Cutting

Streams that are cutting their banks on the curves during peak flows may be controlled, but the necessary procedures are expensive. The banks need to be shaped or sloped so they will hold riprap of rocks or heavy materials. Plantings of *Salix* spp., *Alnus* spp., and other riparian woody plants above and in the riprap add stability. Finally, fencing to prevent grazing and to promote a tangle of growth on the stream bank is advisable.

Contour Terraces and Furrows

In 1930, following disastrous summer floods from the western slopes of the Wasatch Mountains in Utah, several watersheds were closed to grazing, and fire control was intensified to prevent further depletion of vegetative cover. On selected highly eroded spots labeled flood source areas, about 700 hectares in extent, deep contour terraces were constructed and seeded to interrupt the gully system and to keep rain where it fell. Specifications for the terraces included zero-grade, spacing and depth sufficiently close to hold 4 centimeters of rain, and check dams at 8-meter intervals across but slightly lower than the terrace dike. Success of the whole rehabilitation program was evident in 1936 and 1945, when storms of greater rainfall rates than the storms of 1930 occurred with no flooding (Bailey and Copeland 1961).

As the above example showed, increased vegetation on the slopes and terraces reduced the need for special structures in the drainages. Where gradients are less than 15 to 20 percent or 7.5 to 10 degrees, an out-sloped type of terrace is recommended. The in-sloped type may be used on steeper land, to about 35 degrees. However, any manipulation of soil and vegetation on land inclined greater than 20 to 25 degrees should be approached with caution, lest soil disturbance cause even greater erosion.

Contour-basin terraces of the in-sloped type constructed after fire on the San Dimas Experimental Forest in southern California failed when unaided by barley plantings. The barley plantings alone, as contour-row plantings, proved to be the best erosion-control measures tested (Hill 1963). These examples suggest that terraces on steep land can be effective if they result in improvement of vegetative cover. They should be applied only where quick development of cover is absolutely necessary, normally in small areas to give a measure of relief to larger areas that will recover without expensive treatment.

For terraces to succeed on mountain lands, they need to be on deep soil (>75 centimeters) with mass stability or no slumping, be of ample size, and have an infiltration capacity that will accommodate the ponded water without overflow. Seeding and terracing are likely to be mutually beneficial to each other and to watershed stability, especially in areas of low rainfall.

Contour Furrows and Plantings

Other mechanical structures or treatments of rangeland for the purposes of eliminating, reducing, or deflecting runoff and controlling erosion include contour furrows, plowed strips, plantings, or ridges. These structures, although used widely on rangeland in the past, are seldom used today. Ranges in excellent condition do not need them since control of runoff and erosion by the vegetational cover is adequate, reliable, and permanent.

Seeded contour furrows made with a lister with native shortgrass strips between proved to be the best rehabilitation method on sandy soils in eastern Montana. This treatment increased soil water recharge and production was high for at least 6 years after treatment (Wight and White 1974). Contour furrows and seeding increased production on fine textured soils. Snow trapping, reduced snowmelt and runoff increased soil water recharge in the same area (Wight et al 1978).

SAND CONTROL

The objectives in sand control are to lower dune crests, to reduce slopes to at least a 3:1 horizontal-vertical ratio, and to spread the sand as evenly as possible. When these objectives are accomplished, vegetational control is most effective and, except in a few situations, snow-type fencing or other devices to control sand become temporary. Fencing, proper use, and other animal-management practices are continually needed on unstable and vulnerable sandy sites if forage production is to be maintained.

Permanent control of sand movement requires plantings of sand-loving plants, such as *Ammophila* spp. along seacoasts or *Tamarix* spp. as used on the sands in Saudi Arabia. The native species, *Calamovilfa longifolia* and *Andropogon hallii*, are used in the Nebraska Sand Hills where matured grass hay is spread as a mulch and anchored by mixing it with the sand. A cover crop of sorghum, sudan grass, or even cereal grain is sometimes raised. Then the sand-loving grasses are seeded directly into the stubble for a more permanent cover. Rhizomatous species were most effective of eight grasses tested in western Nebraska, but they were not as effective as a mulch of prairie hay (Malakouti et al 1978).

Other type barriers, such as snow fencing or slatted wooden fences, as well as plantings, tend to hold sand in place or to stop it from moving. These work well if the sand is in narrow strips or the areas small. Large sand deserts, such as the Great Nafud in Saudi Arabia, can be controlled or stabilized to protect a road or a canal with difficulty.

One approach in such situations is to build structures that tend to channel or intensify the wind into smaller areas thereby causing the wind velocity to increase, as through a funnel (Whitfield 1938). Such channeling has been accomplished by placing sealing strips of asphalt or tar parallel with the prevailing wind. The tendency is for the wind to move the sand from between the strips at a velocity that carries the sand beyond the road (Fig. 26-1). Picket fences at a slight angle to the wind also promote scouring of the dunes. The distance between pickets should be about the same as the width of the picket so that nearly the same proportion of air goes through and over the fence. Bags filled with sand and placed on dune crests lower as wind removes the sand from around them. If the dunes are isolated and surrounded by hard land, listing or roughening the hard land to hold the sand is essential to lowering of the dune profile.

The location of fences for both snow and sand control on irregular terrain determines the pattern of deposition. When the fence is placed on the windward side of a hill crest, the resulting dune or snowdrift will be short and high. Fences on a crest result in long accumulations downhill to leeward. Barriers placed on the lee of the crest are likely to be covered (Schmidt 1970).

WINDBREAKS AND SHELTERBELTS

Windbreaks and shelterbelts have had a long history in the control of wind erosion. **The windbreak itself may be a single row of trees along the windward side of a field, or a planting of several species in a dozen or more rows.** Denmark began planting trees in the 1860s to control sand movement after destruction of heather stands and faulty cultivation practices resulted in large areas of moving sand. Russia used shelterbelts even earlier.

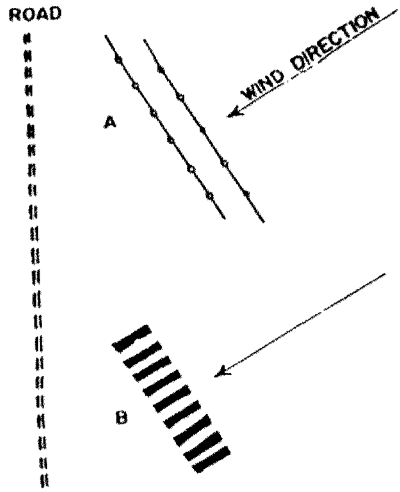

Figure 26-1 Arrangement of barriers to control movement of sand by wind. A: Barriers to stop sand movement by wind before the sand covers the road. If the barriers are irregular in top line, concentrated wind will result in sand blowouts, increasing unevenness of the dune, and difficulty in holding the barrier. A single fence causes a sharp crest, while a double fence properly spaced results in a gently rounded dune crest. B: Barriers or asphalted strips of sand arranged parallel with the prevailing wind will promote increased wind velocity between the barriers and sand crossing the road. Asphalted and bare strips are of the same width.

Experience and research showed that the most effective windbreaks were filters with 30 to 40 percent in holes rather than complete barriers to air movement. Effectiveness was increased with more height and length rather than with more width, since the wider the windbreak planting, the less permeable it usually was. This relationship between the windbreak height and the leeward area it shelters has resulted in windbreak effects being measured in terms of its distance in units of windbreak height. Measurements in the sheltered area at a distance ten times the windbreak height, suggest 20 percent less evaporation from soil, 3 percent higher relative humidity, higher air temperatures, less wind damage, and increased yields of several crops (Zethner-Moller 1968). Twenty times the height would appear to be a reasonable distance between windbreaks which would give at least a little protection to all areas. A windbreak 3 to 10 meters in height should be 30 to 100 meters from the major area to be protected.

Windbreaks are common sights in the plains and prairie portions of the central United States. Cold climate apparently prevents their establishment above 1850 meters elevation as in southeastern Wyoming (Sturges 1983). Most farmsteads and feedlots in the Great Plains have them on the northern and western sides for protection in the winter from severe storms and in the summer from hot winds. Their contrasting colors and shapes provide beauty to the prairie landscape, and they furnish areas for recreational sports and wildlife habitat. Windbreaks supply posts, wood, and protection from cold winds, which reduce fuel costs, but they may harbor pests of various kinds, occupy space, and the land on either side is unsuitable for cultivation because of shade and root competition.

Normally, fewer rows are used in the western, drier areas than in the eastern prairies. Rows should be 3 to 6 meters apart; a distance selected to accommodate shallow cultivation between them for weed control. Spacings within the rows are 1 meter for shrubs, 1 to 3 meters for low deciduous trees, 2 to 3 meters for conifers, and 3 to 4 meters for tall trees. Each row may be a different species, but 20 to 50 percent of the planting should be evergreen. Most windbreaks are planted in straight lines. Contour plantings and irregular shapes, accomplished with groups of different species at the ends and along the sides, enhance soil protection and beauty. Except in single-row shelterbelts, alternating species within a row should be avoided. Other don'ts applying to windbreaks include no placing of tall, spreading species adjacent to lower species; no grazing, burning, or spraying with herbicides; no overpopulations of rabbits and rodents; or planting close to ditches, terraces, and drains. Local and state laws prohibit plantings that result in blind highway corners, grow into or increase maintenance of utility lines, and cause snow to drift onto roadways.

An example of a seven-row windbreak in central Kansas is as follows: (1) *Cotoneaster* spp., (2) *Juniperus virginiana*, (3) *Pinus nigra*, (4) *Morus* spp., (5) *Populus* spp., (6) *Ulmus parvifolia*, (7) *Juniperus virginiana*. This planting gives contrasting colors in leaves, flowers, and fruits for beauty, food and shelter for wildlife, and wind control during winter and summer. Windbreaks vary widely in composition and layout because of wide differences in soils and climates. Before a windbreak is established, local practice should be investigated.

WATER HARVESTING PRACTICES

In arid areas, limited productivity due to limited water supply requires effective management, conservation, and use of precipitation. **Water harvesting means collection from large or small areas and storage in the soil profile for plant use or in tanks of various kinds for irrigation, animal, and human use** (Dodd and Skinner 1990).

A number of practices closely related to those for mechanical control of erosion are used to make more efficient use of water in the soil of semiarid and arid areas. These include contour furrows with leach basins, water spreading, and pitting to increase soil water. **These practices are based on the principle that one way to manage runoff is to increase the depression storage capacity of the land.** Interrupted contour terraces, dams, etc. mentioned earlier, also serve this purpose.

Pitting or Interrupted Contour Furrows

The purpose of pitting, often called interrupted contour furrows, is to increase forage production by breaking soil crusting, encouraging water infiltration, and decreasing water runoff. This purpose may be accomplished even if the pits fill with sand, which has a high infiltration rate.

Range pitting is accomplished by short-distance turning fine- and medium-textured soil with a disk for a length of 0.6 to l meter, to a depth of 7.5 to 16 centimeters, in rows 0.6 to 1 meter apart (Fig. 26-2). Adjacent disks are on separate eccentrics so that as one enters the soil, another is lifted. Pitting with a one-way eccentric disk and scalping with a sod drill proved effective in the western Great Plains beginning about 1939 (Barnes and Nelson 1945). Pitting minimizes wind effects and traps moisture. Pitting should be restricted to areas with less than 20 percent slope.

Pits 1.5 meters long and 1.5 to 2.5 meters wide were found to increase herbage production of *Cenchrus ciliaris* by 2.5 times over the conventional small pits and 5 times over untreated range in the 15- to 20-centimeter summer rainfall zone in southern Arizona. The pits were constructed so that all runoff water passed through them without regular drainage from one to another (Slayback and Cable 1970).

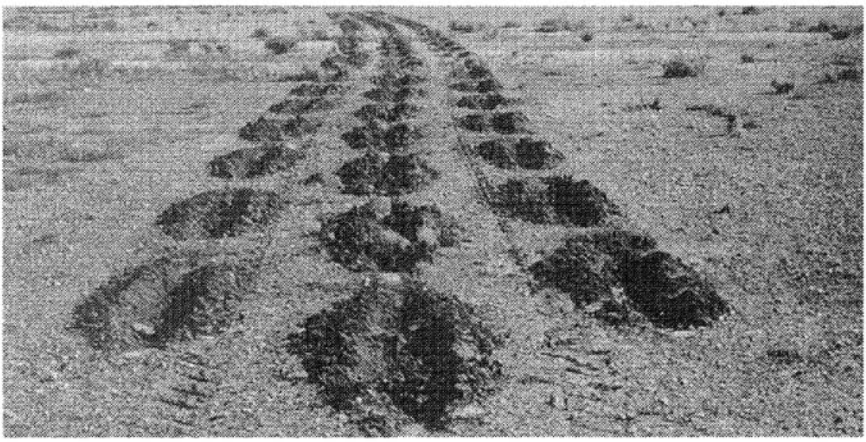

Figure 26-2 Pits on rangeland for the purposes of conserving water and increasing forage production.

Leach Basins

Arid and semiarid areas frequently have lake beds and other extensive areas where various salts accumulated to a degree that plant growth is reduced or prevented. Contour furrows with basins to hold water and allow leaching have been successful in increasing yield of herbage under a wide variety of these soil conditions. In a Montana area with high salts, forage production increased as leaching in furrowed soil reduced calcium, magnesium, and sodium (Branson et al 1966). Favorable results were due to reduced runoff, higher soil moisture, and seeding. The decrease in water catchment in furrows was rapid for about five years, but effects were evident in the vegetation for much longer. Sites dominated by *Atriplex nuttallii* showed the most improvement.

Water Spreaders

A water spreader is a system for spreading flood waters to irrigate land, to reduce and store sediment, and to obtain deep storage of ground water (Fig. 26-3). Native species may be encouraged for hay growth by water spreading in wet or dry meadows in the western United States or the objective may be more AUMs of grazing. Crops of grain, vegetables, fruits, and fiber are planted on land where water is spread in desert climates. Seldom are water spreaders economically justified on western United States rangelands for grazing purposes alone. They are used extensively to replenish ground water for city supplies. Studies in New Mexico (Hubbell and Gardner 1950) showed that sedimentary deposits in water-spreading systems can significantly reduce deposition in channels and reservoirs. Cleaning water of sediments is a worthwhile environmental objective.

Diverting water from large watersheds, 1 square kilometer and larger, requires structures that will contain large flash floods or will divert only a part of the flow. The potential damage from large flows, the greater percentage runoff from small areas than from large watersheds, and the heavy cost of construction and maintenance require that water spreading should be on small areas.

Ancient development of runoff water for local agriculture beginning about 900 BC has indicated a number of "do's and don'ts" in the use of water spreaders. Diversions, simple dikes, and lifted flood water with an upstream dam and canal, often fill with sediments and break, making a deep gully. Small systems work best (Shanan et al 1961).

Ancient water-spreading systems in the Negev Desert divided large watersheds and flows into smaller ones by means of separate terraces, diversions, and pipes that could be opened or closed as needed. The architects of these systems applied the principle that the easiest way to handle flood waters was to keep quantities small by reducing volume of flow near the source. The reason is that water-forces increase exponentially as the volume increases downstream and become correspondingly more difficult to control.

Work in Israel has suggested that a ratio of spreader land (hectares) to watershed should be approximately 1:20-30. This ratio is calculated on the basis of 15 percent runoff from an average of 100 millimeters of annual precipitation and the assumption that the crop needs 400 millimeters of water, therefore:

> 100mm x 0.15 x 20 ha = 300 mm on 1 ha + 100 mm of original rainfall = 400 mm/ha

This ratio can be adjusted as data or experience become available on rainfall, runoff, and needs. The ratio will be narrower, say 1:10 or 1:15 in areas of 250 to 300 millimeters of rainfall.

Another principle that has emerged from the Israeli work is that the proportion of the precipitation which runs off is greater from smaller watersheds (10 to 20 percent) than from larger ones (1 to 5 percent), due to high percolation into the larger stream beds. In other words, small watersheds give a higher percentage water yield and more frequent flows than do larger watersheds (Tadmor et al 1960). This was indicated in the comparisons of flows from lysimeters and watersheds varying in size from 32 square meters to 20 or more hectares. Runoff began after 4 to 6 millimeters of rain in small watersheds of less than 25 hectares, while at least 10 to 12 millimeters of rain were required to initiate runoff from large watersheds (Evenari et al 1961). These are points in favor of keeping the spreader systems as small as possible.

Reasons for failure of water-spreading systems appear to be inadequate design, lack of maintenance, poor judgment, and lack of management of water during each flow. The successful ones today are managed carefully during each flow. Automatic water-spreader operations seem to be beyond economic feasibility. Engineers often have attempted to handle the whole flow of a waterway with structures that have all too often been inadequate in an unusual storm. The results are destroyed dikes, breached check dams, broken terraces, and new gullies. Unless the water checks are extremely large and well protected at flow points, the type of system shown in Figure 26-3 will sooner or later be overtopped and destroyed because the tendency is always for the flow to cut back to its original course. When the break comes, a gully larger than the previous one may be formed.

Harvesting for Concentrated Use

Another type of rangeland water management is collection and storage for irrigation and animals. The term "water harvesting" is sometimes restricted to these purposes. Emphasis is on the modification of the watershed surface, the channel to the collecting basin, the basin, and delivery to the site of use. These systems emphasize collection for a single plant or a tank rather than spreading or irrigating a larger area. They use techniques that minimize infiltration and increase runoff.

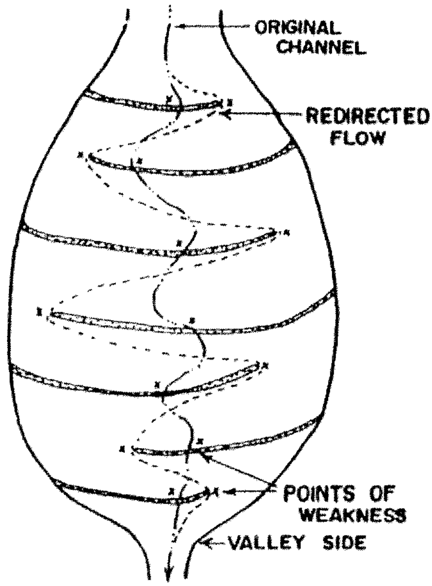

Figure 26-3 Points of weakness are shown in a simple water-spreading system. The greatest pressure of water occurs against the center and at the end of each dike, around which water tends to flow rapidly. No provision, except the height of the dikes, is made to handle large floods. Extremely flat land (1 percent or less slope) is required for the water to spread; otherwise floods will develop a new channel around the dikes. This sketch illustrates a type of water spreading that frequently fails. Ancient systems in the Middle East suggest that the terraces should be tied to both banks and a central, wide, adequate spillway should be used to allow overflow to the next terrace. The basins above each terrace eventually will fill with silt, resulting in a new slope gradient for the whole area. A break then may cause a deep gully where none existed before.

A rough soil surface retards runoff, promotes infiltration, and slows evaporation. Piling of stones so that their cover of the soil surface was reduced from a maximum of 25 percent to 1 or 2 percent increased runoff by 20 to 100 percent in the Negev Desert near Avdat. Increased runoff also increased erosion, but this occurred more during the first rains, after rocks were removed, than later, when the disturbed surface had been wetted several times (Evenari et al 1968).

Water harvesting may be used to increase the water available for individual shrubs or a patch of grass. A small area, a microwatershed, say 10 to 1,000 square meters in size, bounded by low dikes, with finely scratched drainage lines oriented toward a corner collecting basin, will furnish enough water for establishment and production of singly planted saltbushes or grasses. Small watersheds of this type may be paved or covered with plastic to deliver all precipitation to cisterns for watering plants, livestock, game, and birds.

Evaporator-type solar stills are water-harvesting devices for producing fresh water from salt water in desert areas. They are useful in situations where drinking-water needs for animals and people justify considerable expense. A model of one is shown in Figure 26-4. Of course the rain barrel that catches and stores runoff from the farmhouse roof is a system for water harvesting.

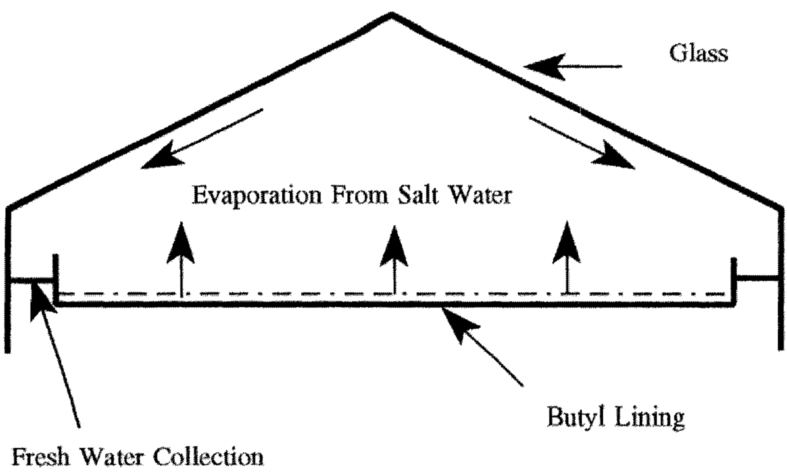

Figure 26-4 Cross section of a greenhouse-type solar distillation unit used to obtain fresh water from salt water in desert areas. Brackish water is led through shallow, Butyl- lined troughs. Heat from the sun vaporizes part of the water, which condenses on the inside of the glass. Fresh-water droplets run down the inside of the glass to the collection troughs. In 1975 this type of solar still furnished fresh water for Coober Pedy in the desert center of Australia, at a rate of 90 to 110 liters per year per 0.1 square meter of still.

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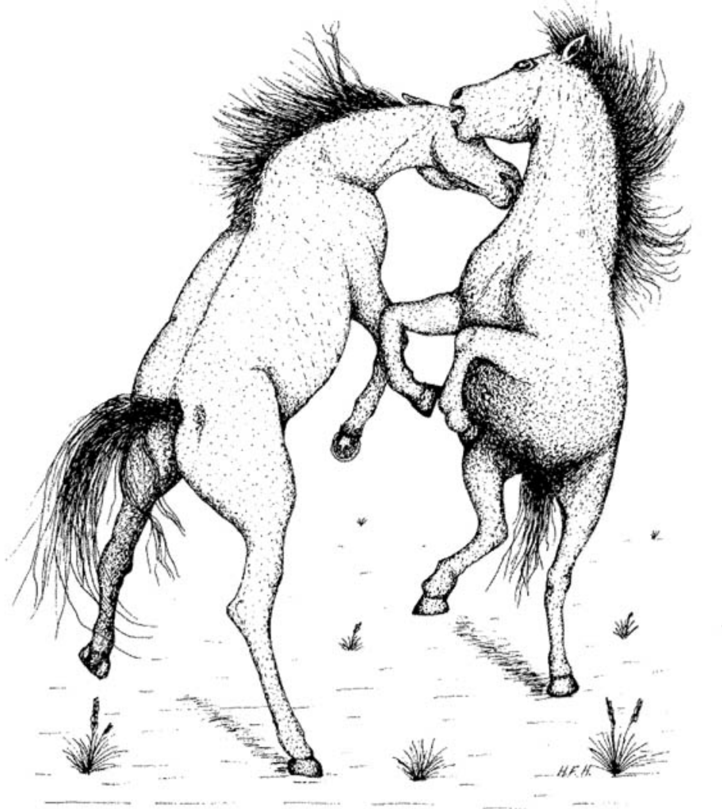
PART FOUR

Managing Rangeland Complexity



27

Reclamation of Damaged Rangeland

In the sense used here, damaged lands are those where the vegetative cover has been largely or completely destroyed and soil, even the subsoil, has been mixed or removed to leave parent material or other substrata that are poor for plant growth. Major examples are the cut and fill slopes in road building, aged mine spoil that remains bare of vegetation, more recent spoil covered with the original soil, and soil damaged in oil-field exploration and development (Smith et al 1988). Other examples are tailings from subsurface mines, bare soil from construction of pipelines and powerlines, and abandoned cropland. Fortunately, most damaged sites are small, but they are important because of unsightliness and high hazards for erosion and pollution.

Effective land reclamation has become legally mandated for many types of land disturbance, but most notably for mining disturbances, and particularly for coal-mining. National policy for coal-mined land reclamation was set forth in Public Law 95-87, Surface Mining Control and Reclamation Act of 1977. A stipulation was to restore conditions capable of supporting the uses which were being supported prior to damage. Based on that authority, responsible federal and state agencies have developed local guidelines for reclamation of coal-mined lands. Where precipitation was less than 26 inches per year, a 10-year responsibility or bonding period was added by publication in the Federal Register in 1983. It included standards for success and stipulation of statistically valid sampling techniques, which required decisions on postmine land use, characteristics to be measured, standards of the characteristics, and method of sampling. Biomass productivity, cover, and species composition have been the principal parameters measured.

OVERLAPPING TERMS

Rehabilitation and care of damaged resources have resulted from regulations set by law, but these vary locally and nationally. One cause may be the irregular use of three terms (DePuit 1988). **RESTORATION often implies exact duplication of predamaged conditions. REHABILITATION returns the damaged land to a predefined condition that is desirable and ecologically sound. The RECLAMATION concept implies return of ecosystem conditions similar to or better than prior to the disturbance.** Obviously the three terms define individual and group preferred positions, span the goals of different interest groups, and are similar in common usage. Although all three terms are synonyms, **"reclamation"** will be used in this book.

"Overburden" is a common term in the descriptions of mine spoil. It includes the material below the developed soil that is removed to expose the seams of minerals or coal. In soil survey, it is parent material.

GOALS

Regardless of the term preferred, three broad reclamation goals are appropriate (1) to insure that society retains multiple-use opportunities of the site, (2) to obtain desired environmental quality through rapid stabilization of soils against erosion and pollution, (3) to develop into diverse and self-sustaining vegetational ecosystems through plant succession.

Such ecosystems provide the widest range of options for changing land uses in the future, and for diversity in physical, chemical and biological resources. The principal item for attaining stability of damaged land is surface cover by living plants and litter. Productive vegetation minimizes erosion, produces forage for wildlife and domestic animals, provides habitat for wildlife, and enhances the esthetic values of the site (Laycock 1980). In short, reclamation strives to rebuild entire, properly functioning ecosystems on disturbed lands (DePuit 1989). Each piece of damaged land presents separate problems or extreme conditions among which are the following:

- A multiplicity of local and difficult-to-follow ordinances
- High saline and/or sodic overburden and spoils
- Mine spoil that erodes exceptionally fast
- Colloidal nature of bentonite materials that seals the soil
- Toxic amounts of molybdenum, selenium, or other trace elements
- Only socially unacceptable plant materials are available

- Drainage of heavy metals from subsurface mines
- Air pollution with dust, SO_2, uranium
- Agreed upon definition of fish and wildlife habitats
- Pollution of groundwater and surface water

The manager of damaged land must meet one or more of such challenges. This chapter emphasizes two examples of damaged land reclamation, mine spoil and cut/fill surfaces along rangeland roads. Damaged rangeland that resulted from overgrazing, brush control, fire, and abandoned cropland have been emphasized throughout previous chapters.

RECLAMATION IN THE ECOSYSTEM CONTEXT

Mine spoil, road fill, and any other damaged land are within a context of climate, topography, the soil materials, and the available plants and animals of the region. These operate together over time and the result is development of soil and vegetation, with and without human efforts. Ecological parlance calls this ecosystem succession. Sometimes the consideration is restricted to plant succession because that is the major part of the ecosystem that can be manipulated. **The manager's approach should be one of guiding, not replacing, the natural processes of ecosystem succession toward societal goals as rapidly as possible.** Each piece of research and example of applied technology is but a small part in the understanding of reclaiming damaged land.

Primary succession begins on bare areas as exemplified by mine spoil and road cut/fill surfaces where soils have been destroyed or nearly so. Few and perhaps no live plant materials remain. The succession begins with migration of organisms to the bare site and continues with their establishment which brings competition for nutrients and space. These reactions among organisms and environment lead to development of soil from parent material. Directional changes in botanical composition gradually give way to more cyclic and random variations that appear stable when viewed broadly. This traditional approach to succession (Clements 1916) is given modern interpretation and evaluation by MacMahon (1987), Redente and Depuit (1988), and Call and Roundy (1991).

For mine spoil, the first step in reclamation is shaping the land surface, which is a one-time step in altering the topography. The new landform cannot be exactly like the original because the mined material is gone. That fact alone requires planning for future land-use and prevents the return of pristine or premining conditions.

The second step is replacement of topsoil, which in most operations has lost at least part of its living organisms, soil structure, and organic matter. However, infiltration and water-holding capacity will be sufficient to support some plants. Mulches are used to encourage soil building and protect seedlings.

Migration, as the third step, is the organisms returned in the restored topsoil, those carried to the site by wind and animals, and those seeded and planted by the human reclaimers. Replacement of microorganisms may be required, as has been shown with mycorrhizal fungi. Extensive experience with a few exotic and genetically improved grasses and legumes provide the technology for relatively rapid development of soil cover. Missing from most situations are the plant materials and techniques needed to establish diverse plant communities that are at least somewhat similar to but perhaps more effective in resource conservation than the premined vegetation.

Fourth, vegetation increases in both number of species and number of individuals per unit area. The resulting competition for a place to live and reproduce becomes more favorable for some and they increase, while others become less prevalent. Continual migration of native species to the site, their establishment, and gradual microenvironmental soil changes have, in a few examples, resulted in vegetation similar to nearby undamaged ecosystems. However, the introduced exotics tend to be reduced but not eliminated by the native vegetation as the species composition approaches stability. Studies of seed mixtures often show little difference in botanical composition after succession proceeds for a few years. For example, after 4 years the native grasses yielded as much as the naturalized species in the Alton and Emery coal fields in Utah (Ferguson and Frischknecht 1985).

The fact that coal-mined land regulations allow 10 years for site and vegetation to attain bonding requirement, suggests that plant succession proceed to satisfactory stability of vegetation and soil in that time period. This is a short time for succession in rangeland environments, but can be ample for soilcover to develop. However, proper manipulation of the successional process on mine spoil and other damaged lands has two purposes. One is to accelerate the process, especially in the first years of reclamation. The other is to direct the succession toward the types of ecosystems ultimately desired (DePuit and Redente 1988). Success depends upon reconstructing a proper physical base, care through working with the successional process, and management throughout.

THE RECLAMATION PROCESS ON MINE SPOIL

Reclamation of mined land in arid and semiarid regions involves many factors. Those over which minimum control can be exercised include climate although irrigation sometimes may be possible. Soil may be amended with fertilizer and organic matter, and physiography of sites may be reshaped as a part of the process. Uses of plants, animals and microorganisms are other major controllable factors in damaged land reclamation. Recovery involves plant succession and soil genesis. It is driven by abiotic factors as well as those introduced and others internal to the vegetation (DePuit and Redente 1988).

Planning

Planning for the reclamation of openpit mine spoil begins before the mine is opened. The topsoil is removed and stored separately. Removal after the vegetation has matured a crop of seed may often be the best time unless the pre-existing vegetation was undesireable. The native seeds may not live through a long storage. Regardless, the top soil fosters secondary succession rather than the much slower primary succession beginning on raw overburden or on parent material. Seeding and planting will be needed. Each of the steps in the reclamation process requires planning in order to successfully meet goals.

Site construction often provides opportunity for new or special wildlife habitats. Site characteristics and the costs of reclamation often restrict the goals to few uses and species. For example, waterfowl and fish habitat can be developed with permanent water supplies. Breeding pairs of puddle ducks need cover and foods such as *Scirpus, Eleocharis* and *Polygonum*. The puddle ducks prefer water about half a meter deep; diving ducks like deeper water. Important to both is a slope above and below waterline no steeper than 3 horizontal to 1 vertical (Rumble 1989a). Rock outcrops and small cliffs are havens for birds and small mammals, some not normally in surrounding grasslands (Rumble 1989b). Habitat for local mammals and migrating birds is a major objective following severe impact by petroleum development (Bromley 1985).

The development of gardens for certain species of particular value, such as threatened and endangered plants or attractive flowers, is possible with early planning. Various habitats may be constructed to enhance wildlife populations for visitor enjoyment. Objectives for these kinds of uses and analysis for their possibility must precede decisions on reconstruction. After these decisions, planning proceeds for the reclamation. The order of activities is indicated by the sequence of the following headings. However, the final objectives of reclaimed land appearance and use must dictate the choice of techniques and intensity of their application in every step.

Site Reconstruction

The first step in successful reclamation of openpit mine spoil is placement of the overburden into the abandoned pit and shaping of the final site according to planned use. These materials are often more erodable than undisturbed soil in the region; therefore, the regraded topography must be conducive to longterm stabilization with slopes not exceeding 3:1 (Farmer and Peterson 1984). Before stockpiled topsoil is replaced, the steeper surfaces should have erosion control and water conservation provided through microrelief features such as deep ripping, chisel plowing, and contour terraces. These will counteract the slumping and settling that normally occur. If possible during the overburden replacement, materials that are chemically or physically undesirable (salty, acidic, high in toxic trace elements) should not be placed near the spoil surface. Without care in replacement of overburden, surface reclamation will likely fail. In any climate, erosion, sedimentation, pollution, drainage, and mineral composition of the overburden can be problems.

Topsoil Replacement

Perhaps the most important single practice in reestablishment of vegetation on openpit mine spoil is topsoiling. After the mining is finished the overburden is placed in the pit and the stored topsoil placed on top. This practice is demanded by law in the process for coal mine spoil reclamation.

The replacement of topsoil on the overburden gives further opportunity to create a variety of sites and microrelief. A level surface and uniform depth of topsoil usually favors pasture-like conditions. Diversity of plants and animals can increase when topsoil depth is varied or a varied microtopography is constructed through such water conservation and erosion control techniques as pitting, furrowing or imprinting. Water harvesting can also be advantageous.

While results of stockpiling topsoil have varied, several characteristics define its value. The soil itself retains part of its structure and organic matter, which the overburden does not have. Although not as high as the original soil, there is soil aeration and water-holding capacity. Topsoil is usually a much better root media than the overburden. Seed and vegetatively reproductive plant parts remain in the topsoil, but usually not in sufficient numbers to develop full stands. Rotation of pit opening and closing may allow direct placement of topsoil on newly shaped spoil. This single handling without storage reduces biological deterioration and speeds reclamation. Whatever the desired final plant community the presence of topsoil gives a start in that direction.

Mycorrhizae

Vesicular--arbuscular mycorrhizae (VAM) are fungi that form symbiotic associations with the roots of higher plants. They are found on the majority of rangeland plant species (Newman et al 1986). VAM enhance water transport in plants, increase absorption of phosphorus, nitrogen, and other minerals, and may be resistant to salinity. VAM are key links in nutrient cycling and energy flow processes. Disturbing soil reduces VAM.

Mycorrhizae as a group probably are representative of other organisms that may be adversely affected by topsoil storage. Call and McKell (1982) found that a majority of plants on new spoil do not have VAM. Recently stored topsoil contained more fungal genera than older material near a coal mine in New Mexico (Fresquez and Wolters 1990). These authors also showed that types of fungal groups were vastly different between disturbed and undisturbed land, although diversity was about the same. The variation of VAM in mine spoil seems to be related to type of parent material and they increase with advancing plant succession (Trappe 1981, Waaland and Allen 1987). Addition of mycorrhizal fungi to steamed soil increased seedling biomass of *Andropogon gerardi* by at least seven fold, suggesting that inoculations on sterile soils may be advantageous (Hetrick et al 1989).

Mulching

Mulch applied during or after seeding has a number of benefits in mined land reclamation. It improves infiltration, reduces wind erosion and raindrop impact, and limits overland runoff. A light straw mulch significantly improved seeded stands on spoil in northwestern Colorado (McGinnies 1987). Schuman et al (1991) found that mulching and irrigation was an effective combination practice for seedling establishment. Light materials such as weed-free straw and grass hay with attached seed need to be crimped into the soil or partly buried to reduce blowing. Other mulches are nets, mats, wood fiber, hydromulches, wood chips, and rock. Seeding into the stubble mulch after a crop of small grain is effective in many situations. Mulch materials like asphalt, that tend to seal the soil surface also reduce infiltration, which increases runoff and erosion. Adequate soil protection is site specific, but 75 percent or more soil cover is recommended to prevent erosion.

With excessive application rates mulch can be so thick that seedlings are smothered and the stand becomes dominated by a few tall-growing species. The accumulated plant residue also increases hazard of wildfire. During decomposition of too much mulch, soil microorganisms use the available nitrogen, robbing some from the terrestrial vegetation. Grazing, mowing, or haying are techniques that can be used to reduce the accumulation and promote vegetational diversity.

Selection of Species to Seed

Species to seed should be selected on the basis of autecological characteristics, which are climatic tolerance, soil tolerance, rapid establishment, growth form, productivity, reproductive characteristics, longevity, and phenology. Synecologically, the expected demography over time, contribution to stand diversity, and relation to threatened species should be predicted for each planted species. Still other characteristics may be critical for certain prestated purposes, such as nitrogen fixation for soil building, forage quality for livestock and wildlife, and for site protection. Choice of species will require compromise because of unavailable seed and because all species have undesirable characteristics. Above all, will it grow and reproduce on the planting site?

Naturalized grasses and legumes that are well adapted (sometimes called "new natives") are lumped together with undesirable weeds by those who want only native plants. While many native species have performed well in damaged land reclamation, many have not. The same is true for the "new" natives. Cultivars of native species seem to be acceptable, but not those of the naturalized species. Protection of critical sites requires that the most adapted available species be used in reclamation.

Seedings should always be a mixture of species to provide plants adapted to site variation and for diversity. Greatly different sites require separate mixtures. Species included should have a variety of characteristics. Disturbed sites are successionally young, so annual and short-lived perennial species are appropriate in the seed mixture. Such species, including most legumes, may give rapid soil stabilization, increase soil organic matter and nitrogen. Less desirable, noxious, and early successional weedy species should be excluded.

Characteristics of Certain Species

The species in the crested wheatgrass complex (*Agropyron cristatum, A. desertorum, A. sibiricum*) may be slow in seedling establishment (DePuit 1986). Although constituting a small percentage of the seed mixture, they will often dominate the stand after a few years. For example, *A. cristatum* at 25 percent of seed mixture was 64 percent of the production in the fourth year. It had crowded out *A. trachycaulum, A. dasystachyum,* and *Pascopyrum smithii* but *Stipa viridula* held its own (Schuman et al 1982). Container plants of several *Atriplex* species and *Ceratoides lanata* were successful in Utah (Ferguson and Frischknecht 1985).

Agropyron riparium and *A. elongatum* do well on saline soils. *Agropyron smithii* and *Bromus inermis* are sod-forming. A native plant mixture of *Agropyron dasystachyum, Bouteloua curtipendula, Agropyron smithii,* and *Stipa viridula* duplicates northern Great Plains grasslands. The crested wheatgrasses are excellent for early spring grazing, but may be poor for erosion control during the establishment period. Local information on seeding practices should be consulted.

The most successful species for seeding in the northern plains on spoil and on road cuts and fills are as follows:

NATURALIZED	NATIVE
Agropyron cristatum	*Agropyron dasystachyum*
Agropyron desertorum	*Agropyron riparium*
Thinopyrum ponticum	*Pascopyrum smithii*
Agropyron intermedium	*Agropyron trachycaulum*
Thinopyrum intermedium subsp. *barbulatum*	*Stipa viridula*
Bromus inermis	*Bouteloua curtipendula*
Medicago sativa	
Astragalus cicer	
Melilotus officinalis	

Revegetation Methods

A number of principles of site preparation and seeding to reclaim damaged land are: prepare the site, drill the seed, plant at the right season, plant on a firm seedbed, shallow planting for small seed, cover broadcast seed, apply mulches, and use the percentage live seed concept to calculate seeding rates for each species in a mixture.

Some of the principles differ for damaged land because the sites are usually severe and success is required by law regardless of cost. Seeding rates are heavier on disturbed land than on adjacent rangeland. Multiple seedings at different dates include a spring wheat or barley crop for quick soil stabilization followed in the fall by the perennial species seeded into the stubble; warm-season and cool-season species are planted separately to take advantage of their adaptation to seasonal growth; species slow in establishing may be planted the first year and others the second year. For soil development use legumes or green manuring or both.

Expensive practices such as transplanting rhizomes, plugs of plants lifted from nearby undamaged vegetation, stolons, potted or banded seedlings, and bare-root woody plants are common to introduce shrubs and species with limited seed availability. Protection of individual woody seedlings from competition and from rodents, rabbits and larger wildlife is occasionally needed. If browsing of small shrubs cannot be controlled, the species should be seeded and protected or not used at all.

Fertilization

Fertilization of mine spoils is often suggested on the rationale that nutrients have been lost and are needed for quick reclamation. Soil amendments as determined by soil tests must be applied to the soil so that postmining fertility levels will support the premining vegetation. However, fertilizer needs of the reclaimed soil, as shown in field trials, do not always correlate with the chemical analysis of soils.

Response to fertilization in the reclamation of damaged land has varied for a number of reasons. Mechanical disturbance, as the stockpiling and respreading of topsoil, releases nutrients but they soon become a part of the system or are lost. Low precipitation often prevents additional plant growth or spreads response ineffectively over a number of years. Fertilization with nitrogen, phosphorus and perhaps other nutrients tend to increase the grasses and annual weeds, which decreases the forbs, shrubs, and legumes as well as the diversity. Fertilizing often has little or no effect on longterm survival and composition of the stand.

If topsoiling is practiced, the use of fertilizers to increase seedling establishment and change the botanical composition seems to be a questionable practice on mine spoil as well as on undamaged rangeland. Fertilization at the time of seeding often has a detrimental effect on seedlings because stimulated weed growth out-competes the seedlings (McGinnies and Crofts 1986). Holechek (1982) found that a light fertilization increased growth of seedlings on mine spoil at Colstrip in southeastern Montana, but he cautioned against increased annuals with heavy fertilization. Mulching and irrigation make a better combined practice for seedling establishment (McFarland et al 1987).

Since mine spoil is often grazed by domestic animals, especially after reclamation is complete, some knowledge about fertilization for forage quality has accumulated. Spoil-grown forages are likely to be deficient in protein, phosphorus and micronutrients. Fertilization of established vegetation will increase cover and production of biomass, but not change the the nutritive value of the species enough to be worthwhile. In one study additional feed for one animal-day grew for each pound of applied nitrogen (Reeder and McGinnies 1989). Annual cereals for quick soil cover usually grow more rank when soil amendments are added.

Extremes in Spoil Chemical Content

Soil amendments help reclaim extreme situations. Perlite and pumice mine spoils in southeastern Idaho have low cation exchange capacity and low water-holding capacity, which require organic matter, nitrogen, phosphorus, potassium, and sulfur for plant establishment and certainly for forage (Williams et al 1990).

High sodium results in little soil structure, surface crust formation, slow water movement to roots, low infiltration and permeability rates, and possible sodium toxicity. These may cause complete loss of seedling establishment. Calcium chloride applied in irrigation water will leach the sodium (Halvorson and Lang 1989). In the northern Great Plains, highly sodic overburden was covered with 50 to 100 centimeters of topsoil. Upward migration of salts, especially sodium at serious concentrations seldom exceeded 30 centimeters, but considerable variation existed.

Uranium mine and mill tailings in New Mexico, Wyoming, Utah, and Colorado present a special problem. They are radioactive and contaminate by wind and water erosion, and by emission of radon gas. Plants in revegetation programs absorb radionuclides that may pass to higher trophic levels. These arid habitats are costly to revegetate. They may need isolation and cover by rock. Local plants have invaded the spoil and tailings, including *Atriplex canescens, Kochia scoparia,* and *Sitanion hystrix* (Yamamoto 1982).

Land disturbed by bentonite mining may be the most difficult to reclaim. The spoil in northeastern Wyoming is old and no attempts were made at reclamation when they were deposited. *Atriplex suckleyi*, a native invading annual, has been partially successful when sawdust and gypsum were applied in the fall (Voorhees et al 1991). Other favorable plant characteristics are to no avail if the species will not grow on the site and any plant that will give cover could begin the succession process.

Work by Smith et al (1986), however, indicated excellent establishment of desirable native and naturalized perenials under intense regimes of wood residue and nitrogen amendment.

Ferguson and Frischknecht (1983) after 6 years found no upward capillary movement from oil shale spoil to the topsoil cover in the arid area of southwestern Colorado. Twelve inches of topsoil were sufficient to support *Atriplex canescens* and *Kochia prostrata*, neither native to the area. Seedings should include the local *Chrysothamnus nauseosus* and *Artemisia tridentata* subsp. *vaseyana*. In New Mexico gravitational movement of water through sandy overburden was much greater than through fine textured material derived from shales (Aquilar et al 1990).

Irrigation

Surface mining operations depend upon a water supply; therefore, water can be available for irrigation in many instances of spoil reclamation. Irrigation even with low quality water for a year or two during the establishment period has been shown to increase establishment of planted species (Ries et al 1988). In a short time after irrigation is stopped only the species that are adapted to the unwatered site will remain. The effectiveness of irrigation in mine spoil reclamation in southwestern Wyoming was only temporarily beneficial and fertilization did not increase effectiveness of the added water (Powell et al 1990). The combined practice of fertilization and irrigation is unnecessary in the longterm with a few exceptions. One exception is the need to leach salt deposited in overburden and oil well drilling fluids. Another is longterm use of irrigation for pasture and recreational area development.

Grazing Management

Grazing of reclaimed mine spoil is not recommended during the establishment of vegetation. At that time, the management is protective, corrective, and aimed at a preestablished goal. Management includes fencing, reduction of small rodents, weed reduction with herbicides, and soil crusts broken by harrowing. When grazing is eventually allowed, the goals may be one or more of the following: (1) to reduce excess mulch, (2) seasonal grazing to foster compositional changes in vegetation, (3) to increase diversity, (4) to thicken the plant cover by promoting tillering of the grasses, and (5) to reduce competition by weeds. Seldom is production of animal products the principal objective for a number of years (Laycock 1989).

Reclaimed areas in Montana were protected for 5 years after seeding, then grazed for three years, except ungrazed controls. Excessive accumulations of undecomposed mulch were reduced by grazing, total live biomass increased, and soil changes included a higher cation exchange capacity and more organic matter and total nitrogen. Diversity increased in the grazed plots (DePuit and Coenenberg 1980). Plant residue can accumulate to a degree that only a few species will survive. **This study showed that carefully managed livestock with little attention to animal production is a valuable tool in mine spoil reclamation.**

RANGELAND ROADS

Range roads, especially those in mountainous areas that were originally constructed for logging purposes, are major sources of runoff and sediment. Many were considered temporary at the time of building, so little care was taken to construct proper roadbeds, drainages, and erosion-control structures. Severe erosion results when new roadbeds are subjected to sudden and severe storms, frost heaving, and snowmelt runoff before vegetation and stable soil conditions are reestablished.

Fillslopes

Fillslopes and cutslopes present different problems. The fillslopes usually contain considerable silt and clay. Rock materials are usually in the middle of the fill. The slope is a little-less than the angle of repose. The fills are frequently over a culvert or some kind of drainage structure. Any material eroded from a fill will be in a drainage very quickly. Another problem is that travelway or road surface drainage causes extensive damage of fillslopes, even more than direct splash and sheet erosion. As on mine spoil, control of sedimentation increases as the cover increases. Mulches are highly important in roadfill reclamation. However, treatments that seal the fill surface against infiltration must be avoided, such as asphalt, spraying on polymers, and over-compacting in construction.

Cutslopes

Depending on type of parent material, cutslopes often show layers of soil, subsoil, and parent rock from top to bottom. Erosion is likely to be dry raveling during the summer on noncohesive tuffs, breccias and coarse sands, and bank sloughing in the winter. Unsurfaced mountain roads may have the cut face on the uphill side and the fill face on the downhill side. The roadside ditch carries sediment that adds to sedimentation problems on and below the fillslopes. Treatments vary in effectiveness because of aspect, elevation, soil type, precipitation events, and frost heaving (Burroughs and King 1989).

Burroughs and King (1989), combining their own research with a review of others' results, showed that without treatment over half of the sediment from a new road comes from the fillslopes while the remainder is produced by the roadway itself, the ditches along the road, and the cutslopes. The sediment becomes highly important if it reaches and pollutes permanent water sources. A rutted unsurfaced road may yield twice the amount of sediment of a smooth unsurfaced road. The grass strips on both sides of the travelway and between the tracks reduce sediment loss considerably. Prevention of transported materials reaching live streams is more important than losses on the fillslopes themselves.

Roadside Reclamation

Careful selection of road locations can do much to reduce drainage and erosion problems. Building of roads on heavy clay soils should be avoided. Attention to both vertical and horizontal curvature largely determines the amount of cut and fill surface, which is directly related to erosion potential. Fillslopes, especially, should be stabilized with planted species. When the road curves are to the natural landscape profiles, the road fits the natural beauty of the landscape, usually with the least damage to landscape stability.

Several practices are recommended to lessen damage to the roads themselves and to reduce sediment in the watersheds. First, the road fill should use rocks and soil with as little organic debris as possible. Second, a drainage system should be constructed which removes water from the road in small streams and keeps water away from fill areas. The discharged water should go onto vegetated slopes; against obstructions such as fallen trees, slash, and brush clumps; and through protective cover before it reaches a major drainage. Third, raw surfaces of cuts and fills should be seeded, mulched, staked, terraced, wattled, or even cribbed to stabilize them initially against heavy rains and runoff. These practices are most effective if established before the first rain. Mulching is the most effective during the first season. The disc-chain can be used to prepare a seedbed on short and steep cut or fill surface.

Seeding on problem sites near the angle of repose, such as road cuts and fills, requires special techniques. Such sites may be stabilized with burlap sacks filled with mixed soil, seed, and fertilizer, or the slopes may be covered with sacking, cut brush, and many other types of mulches.

Wood fiber, fertilizer, and seed are sprayed on the slopes with considerable pressure in landscaping new highways.

State highway departments differ in their specifications for erosion control and revegetation after highway construction. Those of the Texas Department of Highways and Public Transportation serve as an example (McCully 1991). Specifications include ground preparation that provides for seeding, mulching with straw, hay, or cellulose fiber, tillage, a balanced fertilizer at a rate to apply 40 to 50 pounds of nitrogen per acre, and seed mixtures of 4 to 14 pounds per acre of pure live seed. Texas is divided into 24 regions with specified species and seeding rates for each. Thirteen native grasses and 5 naturalized species are on the approved lists. From 2 to 6 of these species and occasionally a legume (*Trifolium incarnatum, Vicia villosa* or *Melilotus officinalis*) constitute a seed mixture.

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28

Riparian Areas and Pollution: Best Management Practices

Joyce (1988) indicated that over 90,000 miles of streams and rivers provide nearly 3 million acres of riparian habitat in the lands administered in the Forest Service and the Bureau of Land Management. Many more acres exist under other jurisdictions, including private ownership. This chapter emphasizes the riparian ecosystem, its condition, and management. That is followed by consideration of pollution and best management practices for quality water. Water from rangeland could become its principle product and the management for water overriding all other considerations.

DEFINITION OF RIPARIAN

"Riparian" as an adjective has been applied to terrestrial and aquatic plant/animal communities, ecosystems, and species that are obligate to free water and more soil moisture than the rainfall alone provides (Jacoby 1989). Riparian as used here includes small water courses; the areas near shores of large water bodies that support aquatic vegetation, the banks and adjacent wet soils; moist areas near springs, seeps and areas of high water table; and other habitats that provide a moister soil than the surrounding uplands. **The riparian area or zone is identified by soil characteristics and vegetation that tolerates or requires free water for at least part of the year.** The aquatic communities near shores of large streams and lakes are excluded in some definitions, but management of fish populations, waterfowl habitat, and other elements of aquatic ecosystems cannot be excluded. Riparian well-being depends upon the uplands.

Characteristics of riparian areas in addition to the presence of water include easy access by people, appealing landscape for an outdoor experience, high density and diversity of plant and animal species, fishing and hunting opportunities, and migration corridors for game animals and birds. **Riparian ecosystems are the focus of multiple-use values, therefore, of primary concern in multiple-use management. Repaired damage from overuse by people and livestock and reduced water pollution are leading goals of riparian management.**

RIPARIAN CONDITIONS

Primary production on riparian areas resulting from the moist habitat lasting well into the dry season or all summer in some, increases grazing capacity to well above the surrounding non-riparian lands. In the part of the year when the uplands are hot and dry, livestock and wildlife seek the riparian areas to find succulent forage, water, shade, and an environment to their liking. Severe heavy forage utilization and soil compaction in riparian areas have resulted. Many miles of riparian zones are in exceedingly poor condition and are increasingly used by people.

Soil eroded from stream channels reduces the support for upper slopes, which begin to erode or to seek new stable gradients, sometimes taking years or decades to do so. Geologically, this is base-leveling, which is the level of the stream outlet into another body of water. **An objective in riparian management is to attain the least possible base-leveling process.**

Overuse and intentional removal of phreatophytes unquestionably increases water yield, 43 percent in one case (Rowe 1963). That also increases channel scouring and watershed instability. Other impacts that increase water flow and base-leveling include changing the vegetation from perennials to annuals that transpire for only a part of the year, encouraging shallow rooted species, and defoliating transpiring vegetation.

The vegetation and soil ecosystems of most riparian areas differ from adjacent rangeland areas. Many plants in riparian zones are adapted to some degree of waterlogging, or to a degree of anaerobic condition seldom present on the uplands (Green and Kauffman 1989). Denitrification and phosphorus immobilization characterize the waterlogged conditions. Therefore, making the soils more xeric through overuse changes the cycling and availability of nutrients.

While much has been written about riparian areas, the health and trends of the uplands or watersheds in which they occur must be considered. The impact of overgrazing has been blamed for riparian deterioration, but wildfires, heavily used trails, and poorly planned and constructed roadways are also the causes of damaged stream channels.

These disturbed upland soils cause sediment-laden flows with high erosive power that scour the channel system (DeBano and Schmidt 1989). **Management solutions to riparian zones must include consideration of the interdependence between the hydrologic processes operating on both upland and stream channel.**

Indicators of Riparian Conditions

Degraded riparian conditions are indicated by low successional vegetation that is unstable, the disappearance of woody streamside plants, and by soil dried to the point that xeric plants grow adjacent to the stream channel. Indicators in streams include trampled banks without overhangs that protect life in the stream, broad channel morphology, sediments covering extensive areas of the channel bottom, shallow water, wide streams, and high summer water temperatures. Woody plant communities along the streams have been more susceptible to longterm damage than the herbaceous vegetation (Clary and Webster 1990, 1989).

An improved riparian area will show the following changes from the same area in degraded condition: The vegetation has increased in diversity and cover, and the composition has changed; root systems have stabilized the streambanks; and the stream is under increased shade. The water temperature will fluctuate less between summer and winter, the flow will be more uniform between the wet and dry seasons, and the water table will be higher adjacent to the stream. The result is improved aquatic habitat for invertebrates and fish, improved terrestrial habitat for herbivores and birds, and increased quality and quantity of water and forage.

Impacts of Grazing Animals

Excluding livestock and light grazing when compared with heavy use are showing the nature of the damage as well as indicating that riparian vegetation has a high potential for recovery. In northcentral Colorado at an elevation of 2500 meters, a 30-year cattle exclosure and an area grazed at approximately 65 percent utilization is an example (Schulz and Leininger 1990). Inside the exclosure the total canopy cover, willow cover, litter cover, cover of *Poa palustris,* and peak standing crop were greater than outside. Cover of forbs, *Deschampsia caespitosa, Carex nebraskensis,* and *Carex rostrata* were little different in and out of the exclosure. *Poa pratensis* and bare ground increased with grazing. Grazing causes some species to decrease and others to increase. The light to moderate utilization did not destroy the ecosystem but did change the species composition.

Riparian areas can be safely grazed. Medin and Clary (1991a) found no difference in bird density, species richness, and species composition between an 11-year exclosure and adjacent grazed land in a *Populus tremuloides/Salix* habitat. In another study (Medin and Clary 1991b) did not find pronounced differences in small mammal richness and diversity between a grazed and ungrazed *Salix* riparian habitat. However, the structure of vegetation (height, thickness, depth) may be different on grazed and ungrazed areas with the same plant species composition, resulting in different animal and bird species, but no difference in diversity (Schulz and Leininger 1991).

Improved riparian conditions under grazing have been described in numerous papers. Stuber (1985) found improved trout habitat in Colorado; and Platts and Nelson (1989, 1985) in Utah showed that riparian habitats will improve under careful grazing management. A common key to improved cover is reestablishment of the *Carex* communities.

Carex nebraskensis is a widespread and major riparian species. It is resistant to defoliation and trampling. The sod formed by its extensive root system resists breaking and many shoots live a second year (Ratliff 1983). The presence of this species in abundance indicates a healthy meadow and perhaps a more stable streambank than one lined with *Salix*. Planting of *Salix geyeriana* in streambeds was successful under moderate grazing in northeastern California (Conroy and Svejcar 1991). Rickard and Cushing (1982) reported that without grazing *Salix amygdaloides* became established within 10 years in southcentral Washington. Other species increased with light grazing.

GRAZING MANAGEMENT OF RIPARIAN ZONES

Riparian area management is a complex exercise for multiple users working together. The acreage is usually long strips of land belonging to private and public ownerships, often in small parcels. They may have the only available water for human, livestock, and wildlife use. More and more the public is demanding use without domestic animal grazing. Traditional rangeland inventory techniques are not always sufficient for riparian zones. The ecological functioning is not completely understood. That most have been damaged by overuse is the only point about them that is widely accepted. Research has shown that riparian zones can be grazed without undo damage. The question is "What managerial techniques are best?"

Streamside shrubs and trees are usually more palatable and their contribution more critical to riparian health than the more xeric upland shrubs. The presence of shrubs and sedges is a key to the prevention of streambank erosion caused by peak flows and cave-in from trampling. Many species in the streamside herbage have rhizomes, a long growing season, and respond to defoliation with new growth as long as soil moisture is available to them.

The cardinal principles of grazing management applies to the riparian areas as well as the drier uplands. However, vegetative response in the riparian areas is faster than the bunchgrasses on the hillsides because of the favorable riparian soil moisture.

The first principle is proper degree of forage utilization. Stubble heights should indicate no more than 65 percent utilization in the spring and livestock removed in time for plant regrowth; 40 to 50 percent in the summer; and no more than 30 percent utilization at plant maturity. A stubble height of 10 to 15 centimeters at the end of grazing is needed to catch sediment until the next growing season (Clary and Webster 1989). Critical sites must be used to a lesser degree. For example, Sedgwick and Knopf (1991) found that an occasional flood was more damaging to South Platte River floodplain vegetation in northeastern Colorado than grazing.

The role of beaver in riparian ecosystems follows the same rule as proper numbers of livestock. The creation of ponds and meadows develops habitats, greater diversity of plants and animals, and desirable aesthetics. This is attractive landscape. Conversely, too many beaver will destroy all the nearby woody vegetation and their habitat will succumb to flood and erosion. If a beaver colony is planned for riparian improvement, their numbers must be managed for eventual habitat protection (Clements 1991).

The second principle and for riparian zones the most important is distribution of animals that gives uniform use of both upland and riparian zones without trampling damage and loss of water quality. Without special distribution management, animal behavioral preference for green summer forages and riparian locations result in overutilization. High costs of fencing long and narrow riparian ecosystems prohibit their separate fencing. Increasing the number of upland pastures for rotation grazing with parts of the targeted riparian zone in each one reduces the need for fencing stream corridors.

The third principle is grazing on a rotational basis so that each piece of the riparian zone receives a rest from grazing during a part of the growing season. Early season grazing usually gives the most even distribution of forage utilization between riparian and upland. Palatability differences are not as great as later. Severson and Boldt

(1978) in North Dakota and Goodman et al (1989) in southwestern New Mexico found that cattle tended to congregate on riparian areas in the summer. During the late summer and dormant seasons they spend more time on the uplands (Roath and Krueger 1982). As with many range forages, nonuse from early summer until plant growth is mature permits regrowth and vegetational conditions that stabilize stream channels and banks. Spring grazing had less effect on channel morphology than summer and fall grazing in north central Wyoming (Siekert et al 1985).

Traditional seasonal rotational grazing systems need careful attention to design for combined upland and riparian vegetation. For example, a riparian zone should be divided so that portions of it occur in two or more pastures. Providing more pastures through reducing their size increases the opportunity for periods without grazing, more uniform utilization of the forages, and relief from grazing when physical damage might be greatest. Gillen et al (1985) in northeastern Oregon and Marlow et al in southwestern Montana (1989) found that several grazing systems on riparian areas showed few differences after the first year. Rest rotation systems appear to foster more riparian improvement than other systems (Bohn and Buckhouse 1985, Kauffman and Krueger 1984).

Light grazing, late season grazing, deferred/rotation, and rest/rotation have provided riparian improvement. A few riparian areas can be grazed in the early growing season without harm, but wet soils in the streambanks are more subject to physical damage at that time. Late season and winter grazing may be harmful to the *Salix* community. Repeated seasonal grazing for a part of the growing season may be practiced but overutilization should not be allowed.

The fourth principle is to graze the right kind and class of animals. Herded sheep are easier to control than cattle and thereby can be less damaging on riparian ecosystems. Habitat preferences of sheep lead to less damage to riparian areas because they tend to prefer the hill land more than cattle. However, reduction of sheep numbers on rangelands and their replacement by cattle has all but eliminated sheep from riparian grazing, at least on public lands.

The time needed for vegetational recovery under good management may not be long because of the irrigation effect of increasing ground water. Degraded streambank recovery usually takes more time than the nearby meadow, because that must occur before the aquatic community within the stream can approach expected conditions. The choices for grazing management of riparian zones center upon combinations of fencing for improved distribution of grazing on the upland and riparian zones and for changes in the seasonal use with rotation systems.

MECHANICAL STRUCTURES TO IMPROVE RIPARIAN HABITATS

The catchment above channel structures in small streams crossing mountain meadows soon fills with sediments, raises the water table, stabilizes the channels and enhances the meadow vegetation. The dams are placed so that the water held by each nearly reaches the dam above. These low dams should be constructed so that fish can move through or over them. Streamside planting of riparian shrubs and trees helps stabilize the channels. Dams will alter the water flow pattern, raise the water table and the vegetation will respond.

While structures may be necessary to stop cutting of banks and to begin the reconstruction process, they treat the symptoms of degradation caused by improper grazing, logging, improper road construction, and other factors. Effort and material may be wasted without proper grazing and watershed management. The required life of the structures in small streams need be only until vegetation stops the channel erosion; however, leaving the structures in the stream channel increases aquatic habitats. If a meandering stream is straightened, velocity of flow will increase, and serious erosion will occur.

SUCCESSFUL RIPARIAN MANAGEMENT

Riparian sites can be restored without eliminating grazing. Reduced stocking rate alone is seldom effective. Yearlong relief from grazing and seasonal periods without grazing in various rotational systems have been successful and more types will be as experience accumulates. Establishment of grazing systems almost always requires one or more additional pastures by fencing, development of off-stream livestock water, upland brush removal, seeding along the streams, and daily herding of animals to the uplands. Establishment of these practices leads to improved overall management. Like all grazing management systems they must be designed for the site, flexible to meet climatic and operating variables, and monitored for evaluation of success. Repair of small upland riparian areas usually requires increasing vegetational cover on the watershed, channel structures or both. Healthy riparian areas reflect sound watershed management (DeBano and Schmidt 1989).

POLLUTION

As point sources of pollution, principally urban and industrial, were gradually improving, interest shifted toward nonpoint sources (NPS) from cropland, forests, and rangelands. The Federal Clean Water Act

(CWA) as amended in 1987 established a major national goal that the quality of the Nation's waters would provide for protection and propagation of fish, shellfish, and wildlife, and provide for recreation in and on the water. The Act established administrative and procedural elements for control of NPS pollution. **By definition, all pollution from rangeland is nonpoint regardless of cause.**

The Environmental Protection Agency (EPA) oversees the Act at the Federal level, has delegated authority for administration to the states, and retains the powers of review and veto. The states have or are in the process of developing their separate and individual authorities, responsibilities for water quality standards, and programs that will achieve the CWA goals, as approved by EPA. In effect, this Act gives the states direct regulatory control over grazing and range management practices on public and private land that they did not previously have.

Types of NPS Pollution from Rangeland

The pollutants are sediments, herbicides, fertilizers, minerals, animal wastes, drainage from home septic systems, and microorganisms in runoff and ground water. Baseline data on pollutants as well as changes on the land caused by people and their animals are not always available. Research is being done concerning the kinds, sources, movement, and concentrations of nonpoint pollutants on rangeland. This information and additional studies on nutrient cycling will aid in the establishment of baseline standards from which deviations caused by rangeland users can be measured. Acceptable pollutant standards are gradually evolving.

Rangeland receives minerals from the atmosphere and weathering of parent rock. For any specific site these natural inputs need to be known as well as the fluxes in and out of the mineral and biological pools. Pollution in reference to that base or standard signifies either of two conditions. One is higher or lower concentration than the normal established standard and the other is amounts or conditions dangerous to humans.

Sediment in runoff is widely believed to be the main pollutant that affects the quantity and quality of water from rangeland. The soil material may be broken loose by raindrops, hoof action, road building, and by unusual climatic events. Destruction of cover by fire and overgrazing intensify these actions.

Research frequently reveals unsuspected sources of pollution. For example, water harvesting techniques in Arizona to supply water for animals and humans showed a high potential for contamination by deterioration of the materials used in constructing the system. Water samples from galvanized steel tanks often contained iron and zinc concentrations higher than allowed. Arsenic was consistently at potentially hazardous concentrations for domestic water (Frasier 1983). Others elements that on occasion exceed standards are chromium, cadmium, lead, and mercury. The water in eight of 32 coal and bentonite surface mine impoundments had sulfate, total dissolved solids, lead, or cadmium levels that equaled or exceeded safe levels for livestock (Rumble 1985). Changes in water temperature, carbon dioxide, and oxygen can lead to poor water quality.

Nutrient enrichment of reservoirs and lakes, called "eutrophication," can increase nuisance algae and other plants eventually causing high decomposition and loss of oxygen. Water taste and odors become unpleasant and fish may be killed. Reduced nutrient inputs is required. Addition of oxygen, dredging of sediments, and increased flushing rate have been tried.

Pollution may be diseases and some of them may be transmitted by water from one warmblooded animal to another. Examples are salmonellosis, leptospirosis, and fecal coliform bacteria. Giardiasis, a protozoan parasite of the small intestine, infects rangeland users who drink contaminated water. Cattle, sheep, and wildlife have been implicated when high coliform bacteria have been found in the water but most studies have not indicated a public health hazard (Buckhouse and Gifford 1976).

In a study near Laramie, Wyoming, Skinner et al (1984a) found that counts of fecal coliform and streptococci could be partially explained by beaver damming stream flow. Results were confounded with grazing treatments. Within each stream, counts varied with season, because increased flow stirred bottom sediments that had high bacterial counts (Stephenson and Rychert 1982). Bacterial populations indicated that fecal pollution was low and probably derived from animals (Skinner et al 1984b). In northeastern Oregon elevated fecal coliform concentrations were related to the presence of cattle and where they congregated (Tiedemann et al 1987), but did not affect chemical water quality (Tiedemann et al 1989). Total coliform and streptococcal numbers and losses of nitrogen, phosphorus, and chlorides were no different on adjacent grazed and ungrazed watersheds (Jawson et al 1982a, 1982b). It appears that domestic animals do not raise bacterial counts above acceptable standard on rangelands. Pollution below a ski area was high in winter but returned to baseline in summer (Hussey et al 1986).

BEST MANAGEMENT PRACTICES (BMP)

A BMP is a practice or combination of practices that is the most effective and practicable means for preventing or reducing pollution generated by a NPS. Pollution from rangeland is most effectively managed by reducing the initial generation of the discharges attributable to land-use. A comparable example for air pollution is the regulation of burning on agricultural and rangelands to lower air pollution in centers of population. EPA (1990) has described pollution abatement for cropland in the Rural Clean Water Program that began in 1981.

BMP Development

The objective of a BMP is application of the most effective and practicable means for preventing or reducing the amount of water pollution generated by a NPS. The objective is not to enhance grazing or any other use.

The procedure for development of BMPs on rangeland includes consideration of legislative and regulatory needs, administrative and financial needs, monitoring, enforcement procedures, assistance programs, and plans for continuous updating of the process. A number of characteristics distinguish BMPs from commonly used range management practices as follows:

- Traditionally, range practices have been based on biological, physical, and economic factors. To those factors BMPs add consideration of clean water standards, legislative and administrative regulations, perhaps financial assistance, monitoring, enforcement procedures, and plans for continuous updating.
- In developing and applying BMPs, consideration is given to natural limitations and feasibility within political, social, economic, and technical constraints.
- Legally, a practice is not a BMP until it has been certified by the designated state authority and approved by the EPA.
- BMPs are of three general types. One is **prohibitive**, for example, no grazing or road building at that location. The second is **process**, specifying the steps to rectify a pollution problem. The third is **performance**, requiring that a certain degree of water quality be attained in a stated time.
- The state may require that BMPs be developed at different levels. They may be general and given as a master list for the entire state; they may be for regions of a state; by broad-scale vegetational type; or

site-specific, stipulating the most effective practices on a stated range site at a given time.
- Usually BMPs are applied as a system of practices rather than a single practice.
- Absolutely rigid compliance can be demanded by the state administration and has been tried, but that has resulted in complaints. A more flexible approach permits management in concert with uncontrolled variables of climate, social demands, political influences, and economic conditions. Rigid specifications are attractive in some quarters because any deviation can be proof of violation.
- Application of BMPs, for example by a rancher on private land, is stated as "voluntary," but that has an unclear meaning. Apparently, the rancher may voluntarily enter the program but must state what will be accomplished in a specified time. If later monitoring finds noncompliance, legal action may take place.

Differences Between Public and Private Land

For public land the responsible Federal agencies have manuals of rangeland management procedures and practices. Their effort is to gain state and EPA approval of BMPs organized according to the manual specifications. Differences in terminology and procedures occur among agencies, but in principle they are very much alike. In effect BMP approval is state concurrence with federal land management procedures.

Private rangeland presents a different problem in the development of BMPs. Responsibility lies with the many landowners, the ranchers. Their management is individually oriented toward the ranch and they make their own decisions. Existing state or regional organizations with authority for rangeland development, regulation, monitoring, and review of private land-use emphasize zoning and environmental protection. Private landowners influence regulations through pressures applied by their own interest groups.

For technical help, the rancher depends upon the Soil Conservation Service, Associations of Soil Conservation Districts, and State Agricultural Extension Services. The infrastructure for technical assistance already exists for service to rangeland management. Missing are monitoring and compliance procedure for control of NPS water pollution on private land.

Administration by States

State administration of the BMP program requires an infrastructure covering both private and public rangeland conservation management. These organizations do not exist or are only partly developed. The private landowner should be able to enter into contract that water pollution will be controlled by reasonable effort and checked by monitoring. Watershed models and research gather information on the effectiveness of management practices. Cooperative effort among interest groups in coordinated resource management programs combines the technical information on watersheds with the practical application of it. Watersheds where such cooperative groups exist could be an excellent approach to reduce water pollution and improve water management on the natural resource lands.

The Seriousness of Pollution from Rangelands

NPS pollution on rangelands has been effectively reduced in many instances by improving range condition with management practices. A forest example of reduced NPS pollution and enhanced wildlife habitat is strips of trees retained along intermittent streams and roads when adjacent stands are harvested (Dickson 1989).

Soil conservation on rangeland has many facets and it is an objective of range management. Whatever the technique the aim is usually prevention of soil erosion through maintenance of cover on the soil. The loss of sediment in water is not frequently measured; hence the seriousness of that pollutant is not always known. If it is measured, distinction is seldom made between that natural for the site and how much sediment is reasonably controllable. The problem is lack of information on the scale of entire watersheds. Accumulating the needed information for better rangeland management is required before BMPs can be effective. When information is available, its use through education is more likely to be successful than through legislated results.

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Multiple-Use

Multiple-use of rangeland is defined as the use of the land for more than one product or service. Implicit is that the land has multiple resources and that damage will not occur. For public-lands, multiple-use also implies for all the people. Many uses and values are largely indirect and socially determined. Multiple-use of public-lands has been public policy by law for many decades. In addition to biological production, multiple-use has elements of planning, politics, law, economics, sociology, and an explicit commitment to public involvement in decision making (Behan 1981).

In contrast, multiple-use of private lands depends more upon the landowner's choice and the profit produced by the alternative uses than on public pressure, but that pressure is increasing. Biologically based decisions are giving way to conflict resolution and socially acceptable management practices on private land.

Listed alphabetically, the land uses could be as follows: aesthetics, livestock grazing, mining, national heritage preservation, occupancy, recreation, water, wildlife, and wood or timber. Some, mining and timber for example, have products that proceed through market channels from land to consumer and thereby are competitively priced, unless fees are set by Congress. Recreation, aesthetics, wildlife, and water on the other hand are not marketed as such, have values difficult to determine, and greatly contribute to the enjoyment of living and local economies.

The so-called social values of the rangeland resources can be categorized as cultural, societal, psychological, and physiological (Joyce 1989). An example of the **cultural** is the "western way of life" that is often attached to the ranching business. **Societal** values have a community focus, which is illustrated by the close relationships between the small western town and the surrounding ranching area. **Psychological** values are those perceived by individuals and interest groups such as the pleasures received from a visit to a waterfowl refuge or just knowing that the refuge exists. **Physiological** refers to values that serve the human body, for example the health benefits from exercise in clean air.

Range forage, domestic animals, and wildlife as commonly listed multiple resources have values determined in the marketplace as well as nonmarket social values. Forage may be market-valued as feed for domestic animals as well as nonmarket values as feed for wildlife and for the conservation of soil and water. Models showing the tradeoffs among these values must include many assumptions. However, Bastian et al (1991) showed by linear programming of substitution rates that a wide range of combinations of pronghorn and cattle yield more economic benefits than either animal alone. Modeling is helpful in analysis of tradeoffs.

CHANGES IN LAND USES

The principal uses of the public-land in times past were for mining, the production of wood, and forage for livestock. Until the Federal Land Policy and Management Act in 1976, public domain lands could pass to private ownerships. Pressures for public use of the public-land and for less livestock use, began to dominate in the 1960s.

In 1969 Congress reinforced provisions of the multiple-use and sustained yield policies by passing the National Environmental Policy Act (NEPA). It required management on an ecological basis and the analysis of impacts that every use and management input might have upon other uses and upon the natural resources. The resultant studies and reports are the Environmental Impact Statements (EIS).

The EISs were used as strong pressures to change the types and degree of uses on the public rangelands. NEPA signaled the increasing importance of wildlife, clean air, water quality and quantity, open space, scenic quality, threatened and endangered species, genetic material, plant diversity, community stability, and environmental quality. These brought conflicts for resource protection, acquisition of open space, access, information, liability, allocation, funding, and regulation (Cordell et al 1990). The change in importance was indicated by high economic values, more political muscle, and in widespread voter support. **The management of vegetation for the multiple outputs and the mediation of user conflicts among them is rangeland management** (Heady 1990).

The technical document supporting the 1989 Resources Planning Act assessment of range forage (Joyce 1989) shows that the Nation's demands for outdoor recreation, wildlife and fish, timber, and water have grown rapidly since NEPA, as an approximate beginning of the environmental movement. More specifically these demands are for such items as wilderness, water quantity and quality, threatened and endangered species, historical sites, and most aspects of outdoor recreation. In effect they have outstripped the more slowly increasing demands for domestic animal grazing. Because of economic and population factors, these trends were projected to continue (Joyce 1989).

The changing demands have resulted in competition and conflicts among the land users themselves as well as between user and those who want no use at all. Perhaps of greatest importance to traditional Range Management is the conflict between those who graze livestock on the public rangeland and those who campaign for no domestic animal grazing on the Nation's natural resources. This conflict is nationwide in scope. Extreme examples on small pieces of land are frequently selected by either side as "proof" against the opponent. Conflicts among the proponents of single uses have often been settled through court decision. Social, economic, and political pressures change priorities for public-land use (Heady 1981).

Twenty years after NEPA, the Clean Air Act, the beginning of the Environmental Protection Agency, and on the 20th anniversary of Earth Day many impacts of the environmental movement on rangeland management are evident. Examples are such actions as regulation of prescribed burning because of air pollution, reduced application and even elimination of certain pesticides, land-use restriction because of threatened and endangered species, as well as domestic animal elimination in favor of recreation and wilderness. Many users of the timber and forage resources now select what to retain--which trees, how much grass--rather than how much to harvest. Conservationist attention to the uses of rangeland, while still increasing, has been broadened to correct the effects of human activity on far-reaching environmental issues (Reilly 1990). An increasing public acceptance of the need for environmental safeguards is making them economically feasible.

MULTIPLE-USE PRINCIPLES AND CHARACTERISTICS

The first principle is that demands by society for the different rangeland resources change and therefore their values change. This affects the multiple-use management of public rangeland and increasingly on private rangeland as well.

Another important principle concerning multiple-use is that most persons probably accept the concept that many goods and services are produced on the National Resource Lands. However, competition for the numerous resources causes conflicts.

All user types cause damage to natural resources; cattle, pack horses, wildlife, people, and pets included. Commonly people cause damage along trails, in campsites, spread litter, crowd each other, pollute water, and leave human waste. Multiple-use management must minimize all damage (Cole 1989).

The different uses of rangeland may be concurrent, sequential, or contiguous. Examples are; forage and water cannot be excluded from each other; a campground may be used sequentially by families in the summer, hunters in the fall, and skiers in the winter; and concessionaire facilities and recreational use of a lake are usually contiguous. These are differences in situations, not causes of incompatibility. Conflicts usually occur because of increasing demand for space and time.

A highly important principle is that renewable resources are reversible; that is, they can cycle and different uses follow the change. For example, logging and fire open a forest giving wide views, a forage resource develops, large ruminant animals increase in number, but these new resources are soon reduced as the new forest develops. Minerals and mining, occupancy by homes and engineering structures, and loss of endangered species are considered nonrenewable and their use not reversible. Substitutes for the nonrenewable resources should be sought wherever possible. Use of the renewable resources should foster their return.

A restraint on the multiple-use of rangelands is the diverse ecological features of the landscape, often on a very small scale. Each unit produces differently and responds differently to identical uses and management. This variety in scale leads to multiple-use as well as to limiting all uses.

A fact of multiple-use is that federal, state, and local statutes control uses and even limit some land areas to a single use. Environmental conditions and societal pressures change but regulations usually remain in effect beyond their usefulness.

Multiple-use terms have proliferated. One set indicates the degree of dominance of a use: thus the adjectives of exclusive, primary, dominant, secondary, and incidental are applied.

MULTIPLE-USE PRACTICES AND MANAGEMENT

Each multiple-use is supported by a clientele: for example, Forestry for forests, Range Management for the nonforested vegetational types, and other uses of the same land by numerous environmental groups. Also, management for the indicated use is supported by a body of knowledge, which may be large. This treatise will not review the individual disciplines, but examine techniques for their working together.

Management of people in their use of the natural resources resembles management of rangeland for grazing animals. Problems and destruction of resources result from the presence of too many people on the land, from their poor distribution, from their presence in the wrong season of the year, and from wrong kinds of use. To these four main problems, behavioral attributes of people cause their management to be especially difficult. In principle, techniques of controlling people and grazing animals give attention to numbers, distribution, season of use, and kind of use.

Land-Use Planning

Planning for multiple-use allows adjustments in response to society's needs. The foundation for multiple-use planning is inventories of the physical resources of soil, vegetation, water, etc. Their condition must be evaluated; that is, are they badly damaged or producing at the maximum the site will allow; and what were the causes of any problems? In a general way, planning multiple land-use follows a number of steps (Child et al 1984):

- Ecological information is accumulated and analyzed.
- Goals and objectives of the mix of uses are set.
- Problems of establishment and management are analyzed.
- Severity of impacts and alternative solutions, as in an EIS statement, are established.
- The results are monitored and the steps are repeated as new information develops and impacts change.

Highly accurate longterm predictions of changes in the use of rangelands are impossible, but a practical measure of accuracy is found in the continual cycle of planning. Uses probably will change little and be predictable in the shortrun, say 5 years. The safeguard at all times is use that does not damage soil and vegetation; hence the importance of basic resource inventory and monitoring.

Economic Factors

Increasing direct use of private rangeland for recreational services such as hunting, fishing, camping, snow sports, motorcycle events, and shooting clubs give rangelands new values. The manager can make these activities profitable through land development and the collection of fees or sale of use privileges. Hunting rights and campground rentals are notable examples of leased services. Fees provide for profit and expenses such as insurance, guide services, horses, riding equipment, food, and camp cooking facilities. Consultants and corporations are available to manage these types of new enterprises. The recreational pursuits finally picked for development survive the same profit motives and competitive processes as do other land developments and uses.

Cost often prevents a ranch manager from changing animal species and adding new types of operations to a long-established productive system. The costs of change include the risk of loss in selling one species and purchasing another and in the capital changes in equipment and facilities. The latter do not add to capital values if they replace undepreciated facilities.

Among the economic considerations of producing a mixture of multiple-uses are several different kinds of decisions. One presumes that the manager has a limited amount of money to spend on development. The need is to spend that money on the animal or practice in a most effective way. The manager must choose the best combination of products and apply the practices in a planned order and at optimum intensity.

Personal Factors

Managers give personal preference as a major reason for their particular mix of multiple-uses. Cattle and sheep owners normally remain in the same business as long as they stay on the same ranch. They may have been trained at a university, by family tradition, or by their own experience to manage one species. Whatever their individual background, they often do not have confidence with a second kind of animal or another type of use.

Groups of people or communities commonly select the same type of use. While this choice seldom results from a vote, neighbors do influence each other's decisions. They find that problems of transportation, marketing, and health diminish when faced on a community basis. The manager of a minority use can be at a competitive disadvantage within the locality. Simply, a person may like one kind of animal or use better than another and be satisfied with it alone, so forgoes profits that could be produced by changing.

SELLING A MULTIPLE-USE MANAGEMENT PROGRAM

Hancock (1989) listed six steps that were successful in selling a resource management program in central Oregon. They are:

- Identify the benefits from proper management such as increased forage, less erosion, better wildlife and fish habitat, clean water, and more uniform stream flow.
- Guarantee yearlong access where grazing management has accomplished resource improvements.
- Bring leaders from all affected landowners, permittees, and interest groups together on sites that are improving as well as those that are deteriorating to observe results and to agree on goals and plans for other areas.
- Monitor the progress with collection of data.
- Keep all parties involved and communicating.
- Remain flexible as progress and demands change.

Other cooperative groups with similar objectives are the Oregon Watershed Improvement Coalition of environmentalists, ranchers, and range professionals (Hanson 1989) and the Muleshoe Ranch reserve in Arizona (Nedeff 1989). The state of Washington passed a Forest Practices Act in 1974 that regulates practices on state and private forest lands. Many controversies arose, causing the regulations to be revised in succeeding years, Intensive effort resulted in endorsement of the Timber, Fish, and Wildlife Agreement increasing resource protection beyond forested lands (Phinney et al 1989).

EXPERIMENTAL STEWARDSHIP PROGRAM

Section 12 of the Public Rangeland Improvement Act (PRIA) of 1978 directed the Secretaries of Agriculture and Interior to develop and implement an experimental stewardship program (ESP). Local groups were established at Challis in Idaho, a second called "Modoc/Washoe" in northeastern California and adjacent Nevada, and the "East Pioneer" program in western Montana (Floyd and Mealey 1989).

The Challis ESP responded to court direction for environmental impact statements because of serious conflicts among interests in livestock grazing, wild horses, anadromous fish, and bighorn sheep (Sharp 1982). In time, the relatively small local group together with representatives from the Federal agencies and the Governor of Idaho overcame conflicts. The result is cooperative multiple-use management of the local problems and this came into being when all could agree on the action program. The ESP process has lived beyond the original Congressional term of experimental trial stipulated by PRIA, because it is an effective method of initiating solutions to local problems. The steering groups included those locally interested and representatives of federal and state agencies with local responsibilities. Expertize from others was solicited when needed.

COORDINATED RESOURCE MANAGEMENT PLANNING (CRMP)

Resource problems and conflicts at local levels have fostered a decision making process known as Coordinated Resource Management Planning. CRMP is a process whereby organizations work together to resolve multiple-use and land management conflicts. It brings together representatives of all public and private interests--that is the key to multiple-use management. It is achieved through thoughtful analysis, bargaining, and compromise. CRMP and multiple-use are practiced after there are no dissenting votes. Decisions based on marginal tradeoffs of alternative products are not possible because many resource products are free and values are in the minds of the interested parties (Anderson 1981). CRMP is a successful planning process for problem solving and multiple-use of natural resources.

"Local" for CRMP is at the scale of a county or watershed, but seldom is it a single legal subdivision. The area may be considered a regional ecosystem with common environment and use characteristics. This is not to say that it is uniform. The land within is owned or managed by private, state, and perhaps several federal agencies. The resource products are many including timber, range forage, crops, wildlife, residential development, and recreation. Each of these ownerships and products commonly has the backing of an interest or advocacy organization. These are the players in the CRMP process.

A CRMP begins with a few people and often with a single manageable problem such as a poor condition riparian situation that crosses several ownerships. Another example is an overgrazed winter range for a deer herd. **The players are concerned and have a common goal of correcting the past land management mistake. They are not interested in blame for the past and realize that all must work together to correct the problem.**

The CRMP group should be leaders from interest, management, and ownership organizations. Each member must be qualified and have decision making authority for the group represented. The goal is attainable when extremes are placed in review, with respect for each other, and progress is made toward the middle ground. General public meetings are usually interspersed with those of the planning group.

Organization and discussions that lead to the first decision often take a year or two. That decision is a landmark because it is proof that diverse interests can agree to management practices, and that is by compromise. The addition of other decisions become the coordinated plan, which is subject to updating based on new information.

SUMMARY

During the last two decades, interests in multiple-use, indeed any use of public-land and of private rangeland to a lesser degree, have taken two new directions. The manager must involve the interested publics in a planning process. Second, environmental consequences of managerial actions must be analyzed and predicted before they are initiated. Multiple rangeland resource management can be attained when the opposition is respected. Treat as you would be treated.

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Planning for Rangeland Management

No single management practice is sufficient in and of itself, whether it be a biological control system, brush control system, vegetation management system, schedule of grazing, or range condition inventory scheme. A planning system is needed that brings management options and dynamic-resource analysis together in a way that facilitates setting of goals and maintaining managerial flexibility. These are accomplished by using decision support systems in each step of the planning process. Three frequently heard questions at the beginning of goal-setting are: How do we extend vegetation and/or animal research to problems of vegetation and animal management? If rangeland practices are so good, why haven't they found wider application? How do we direct research toward managerial needs? Process modeling and simulation (chapter 31) appear to be promising tools for planning, because they can predict outcome when several factors interact. Thus, rangeland ecosystems are better understood.

Before modeling can be undertaken decisions must be made concerning the processes and assumptions to be modeled. Range scientists contribute a better understanding of ecosystem processes, especially response to treatments and their longevity. Professionals provide that knowledge to the actual managers and administrators of rangeland. Budgeting generally concentrates on values the changed rangeland vegetation has for different uses and whether benefits outweigh costs (Tanaka and Workman 1990).

Traditions of rangeland use change slowly. Many scientists have neither the interest nor the time to extend their results. Rangeland professionals often are more concerned with what can be done biologically than with what the land managers choose or can afford to do. This Chapter briefly introduces a few of the possible suggestions to extend information to rangeland resource managers and policy makers.

PLANNING

Decision support models assist planning for problem solving by organizing information and reaching the correct assumptions. The planning process consists of a carefully followed order of steps (Child et al 1987):

- Setting of goals
- Analyzing situations, problems, and needs
- Creatively thinking through alternative actions
- Evaluating possible side effects
- Selecting and sequencing the best options
- Executing the planned sequence of options
- Monitoring progress and side effects to ensure attainment of objectives
- Assimilation of results and revised planning

Successful planning begins with goal-setting, a difficult task because the most common goal in rangeland resource planning is to minimize the cost of attaining multiple output targets. The second or analysis step often faces a tradeoff between information needed and how to use the complex quantity of available knowledge (Hof et al). Interdisciplinary efforts that combine the approaches of scientists, professionals, and managers usually yield the best analysis of goals and situations.

The flow of ideas and actions through these eight steps may present problems unless care is taken to review each detail of the plan as it progresses. Olson and Burkhardt (1992) give a number of common errors in planning and the resulting action. The initial review for the plan may identify an issue but leave it stranded by omission from the remaining part of the plan. The reverse is inclusion and action on an objective or goal that is not an issue. Another inconsistency arises when an objective is abandoned during execution of the plan. A different irregularity results when actions and objectives obscure the underlying issue. Monitoring of results, especially trend in rangeland resource conditions, seldom occurs.

THE OPERATING ECOSYSTEM

The ranch, federal land grazing allotment, game reserve, or other social and political rangeland units operate as entities. The manager makes decisions allocating land, labor, and capital. Most ranches are also households concerned with consumption of products, profits, and even the principal value during droughts and economic depressions. In addition to the physical products, the consuming part of the ranch ecosystem requires numerous intangible items to constitute a good family living. **The rangeland unit or ranch combines the business administration of an operating firm, the social concerns of family living, and the politics of a community. All have economic tenets.**

This book examined rangeland practices one at a time and one following another. A few attempts at cost/benefit analysis showed differences among techniques, as among mechanical brush control practices. Further economic comparisons were seldom made. Choices among practices have little meaning when they emphasize a single technique, one pasture among many, or a few livestock without including all animals. **The unity of the whole operating firm, including alternate uses of resources and complementary effects throughout the system, must be the framework for practices and their intensity of application. The selection of a practice should not be limited to analysis of value within the practice itself.**

Evaluating range practices follows a common pattern: A single pasture or a single range site within a pasture is selected for improvement, and the technique is applied. Careful cost and production records of forage and livestock are maintained. After a year or two, a balance sheet is produced showing that the range improvement practice was profitable. An example of this type of results showed that prescribed burning on tallgrass prairie increased net present value on a 10-year return basis and that burning is risk-reducing (Bernardo et al 1988). Most published case histories of this type suggest that ranchers can increase net income by using the described practice. The data and analyses are accurate for the single pasture, but extension of the conclusions to the whole operating ecosystem may not be justified. **The single practice needs to be placed into its relative position with other practices and alternate uses of money to produce profit (Workman 1986).**

It is well to restate that **no two places are exactly the same nor is a place the same at different times.** Individual technologies may be offered with insufficient analysis of where or when they should be applied. The result is that the manager applies new practices based more on judgment than fact. **Decision support systems improve judgment by increasing accuracy of extending data beyond its collection-point and predicting the results.**

SELECTING THE PARTS OF A RANGE IMPROVEMENT PROGRAM

Each range site, pasture, and ranch will respond to several techniques. The major grazing tools are controlling animal numbers, improving animal distribution by fencing and water development, planning the sequence of grazing, and altering the mixture of animal species. Increased forage production may be attained by noxious plant control, seeding, and fertilization, which have many variations and may be combined in numerous sequences. Each originates different costs and generates different returns. **The chosen practice should yield the greatest return per dollar spent.** Heady and Jensen (1954) illustrated this point with an example from pastures in Tennessee. Mowing of *Poa* yielded $16 for each $1 spent, mowing plus seeding of other grasses gave $5.70 for each $1 invested, and mowing plus seeding plus fertilization yielded only 49 cents for each $1 spent. Fertilization increased forage production, but the added cost caused the whole set of practices to be unprofitable.

Range improvement generally entails a sequence of techniques in which each adds to the cost and to the return of the whole group. Analysis of costs and returns from fencing, pond construction, spring development, and trail construction on the Cache National Forest in Utah suggested that some of these practices were profitable but some were not (Workman and Hooper 1968). Fertilization may be as valuable to gain better distribution of animals as it is to increase herbage production (Hooper et al 1969). The sequence of events in converting chaparral to grass in California commonly begins with chaining and/or burning, which is followed with seeding to grasses and legumes, spraying with 2,4-D, and improved livestock management (Burma 1970). **A range economics problem is finding the break-even point with sequential practices.** Although improvement costs are easier to obtain than the increased returns and accumulated capital values, techniques are available for analyzing benefits and returns from multiple rangeland practices. Most optimization analyses of intensity of application give a one condition answer; that is one price cost, one product return, one value of return. Van Riet (1991) illustrated the fallacy of this approach when land values and rents, mortgage payments, costs, and prices of livestock change over time. **At one time a practice may be profitable but not at other times.**

INTENSITY OF THE PRACTICE

Range managers must decide the intensity at which practices are to be applied. For livestock alone, all *Artemisia tridentata* might be removed from a pasture, but for livestock, antelope, and sage grouse, 15 to 25 percent of the vegetation should be *Artemisia*. Therefore the application level for *Artemisia* control relates to the improvement objective. Another example of the "how much" question is the conclusion that killing the last 25 percent of *Artemisia tridentata* resulted in 135 percent more grass production than killing the first 75 percent (Hull and Klomp 1974). Tanaka and Workman (1988) presented an analytical process based on the degree of *Artemisia* kill that produced the optimum investment for grass production. Other practices may be analyzed by following the same procedure. **Each range program is a stream of costs and benefits through time that is influenced by intensity of application.**

The value response curve for increased forage with fertilization commonly shows large increases at low fertilizer rates, a point where no increase is obtained with an additional bit of fertilizer, and decreases in production with still more. This situation of **diminishing returns as intensity of application increases applies to most range practices.** Of particular appropriateness to this discussion is the observation that too many experiments in their objectives and range managers in their recommendations aim for intensity of practice that will yield the greatest biological return. However, the point where marginal product equals marginal cost is nearly always at a rate of practice intensity less than the rate for maximum biological response. **Recommendations for intensity of practices should be in terms of the margin as the optimum level, not the high point of biological production.**

Probabilities of risk or failure and uncertainty where probabilities are unknown seldom can be stated for range practices. Very few papers describing research, practical experiments, and actual range practice analyze the risk and uncertainty of success. Yet everyone talks privately about the causes of failure, and that land managers must live with failures, much as they do with variations in weather. The usual approach is to average returns over a number of years. **However, the manager must always face the question of the level of application next year. The need is to know the consequence of too little or too much when a fence is built, watering point constructed, fertilizer applied, and seedings made.** These answers seldom are available.

The economic significance of risk is to lower the rate of practice intensity to a point below where marginal product equals marginal cost. This constitutes a form of insurance against loss. If the manager demands a certain percentage return on investment in range improvement practices, as most managers do, the level of application is further reduced below the marginal point.

Sound range recommendations require analyses that give the biological maximum, the point of increase in product value equal to the cost of producing that value, quantified risk and uncertainty, and reasonable returns on investment. When the rancher examines a new practice in all of these terms, the application rate may be zero. Ranchers are conservative in accepting range practices for many reasons, one of which is that full economic analysis often has not been made. They are reluctant to do trial and error testing when profit and loss are at stake. Systems analyses of various types are being applied to range practices, and they promise to yield improved evaluations.

SELECTING RANGELAND PRODUCTS

Rangelands throughout the world produce forage and habitat for domestic and wild animals, recreational opportunities for people, water for downstream users, and places of abode. Some rangelands may be changed to timberland, changed to cultivated land, or covered permanently by houses and highways. Other lands may be switched from timber and agricultural uses to rangeland uses. The public determines the uses of the land and the trends in changing use largely through the marketplace but also by extensive court decisions and legislation. These time-honored forums for resolution of disputes between private rights and public interests will continue as legitimate players in land-use decisions (Kourlis 1992).

The consequences of these changing demands are increased land values, higher taxes, and statutory regulation of rangeland use. Production costs increase, and the manager often finds the need for choosing among new or different combinations of products in order to stay in business. For example, ranch operators find that they must alter fence construction to meet the public demand for game protection, leave brush for animal habitat, and provide access to their land to maintain public confidence. In order to make the most of these changes, they may charge for camping, hunting, and other recreational uses of the land.

Over time the flow and the probability of income from livestock function in accordance with current and future stocking rates (McConnen 1965). **Any function of timing must consider variations in climate, economic environment, and altered public regulation.** Impending changes in public demand for rangeland products cause managers to postpone new practices because they fear uncertainty and undermining of longterm stability. A rancher's resources are limited. Expansion toward a new product requires limitations of other products. Opportunity costs of sacrificed products are costs to any new program. The rancher's scarcest resource is labor. Livestock often give the highest returns because alternate products may require relatively more labor. **The rancher who changes products, must choose practices that give the greatest returns per dollar spent.** The inclination is to stay with tested practices rather than embark on unknown new products. The dilemma over substituting new for old rangeland products slows acceptance of all management techniques.

SUMMARY

Rangeland managers accept recommended practices slowly. The following points support this view and offer suggestions or opportunities for more effective understanding. **The major problem is establishing the intensity and timing of each practice within the framework of the rangeland ecosystem, considered in its largest sense: biological, social, political, environmental, and economic.**

- Recommended practices should be considered in their full managerial and economic contexts.
- Analysis of costs and returns of a practice on a particular piece of land must place the practice in an operating system.
- Maximum economic return seldom accrues from maximum biological return.
- Maximum rangeland profit for the longterm may be well below the point where marginal product value equals marginal cost.
- Risk and uncertainty costs reduce profit and increase conservative attitudes toward change.
- Planning systems assist in making decisions when:
  - A. Data and economic analyses are insufficient to justify choices among alternative range practices and among a sequence of practices.
  - B. Comparisons of costs and returns from alternative rangeland products are unknown.
  - C. Change might undermine longterm stability.
  - D. Rapidly changing social, political, and economic structures lead to uncertainty and continued use of established procedures.
- Goals of each rangeland manager differ. Some managers aim for large profits; others give first preference to a good life with little

concern for accumulating wealth, and still others aim for protection of the rangeland ecosystem. Range management accommodates all these views.

- Powerful and rapid computing give opportunity to analyze multi-factor relationships as an aid in decision making.
- Decision support systems assist planning for problem solving by organizing information and indicating the best assumptions and goals. Field testing of assumptions may be needed.

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Decision Support Systems

The appalling quantity of intertwined relationships in rangeland resources requires information analysis to become understandable and for prediction of linkages between cause and effect. The many systems suggested are generally known as Decision Support Systems.

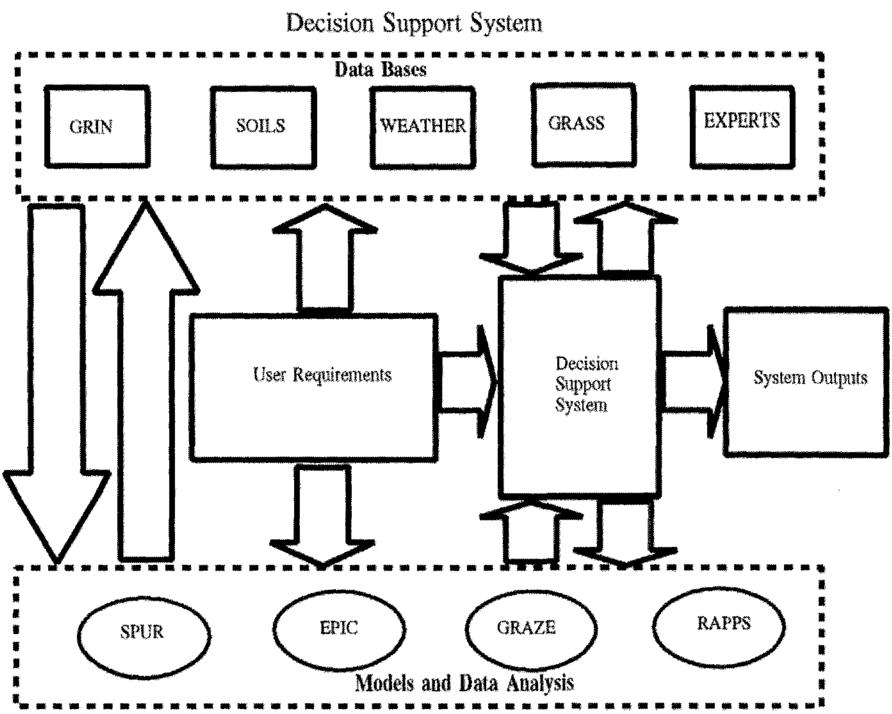
The development of computers, perhaps beginning with the abacus, has made the analysis of complex interacting processes available. The electric hand-operated calculators before and after World War II permitted rapid calculation of variance and regression with relatively small amounts of data. The next stage was the computer composed of an air-conditioned room full of vacuum tubes requiring a separate program for each situation. Computers developed in speed and became smaller in size when transistors and microchips were developed. The use of computers in natural resource management has become widespread as "canned" software and application packages became available.

Those used for rangeland resource management generally include mathematical models capable of simulating relationships among abiotic factors, plants, animals, economic and technical inputs. They must be able to simulate and/or optimize the outcome of time and space dynamics of ecosystems in response to climate, disturbance, management, plant succession, and economic needs.

Decision support systems are planning aids at every step for managers, researchers, and administrators. By using "best guess" assumptions when data are not available, the planner has a powerful tool for predicting effects of alternative management strategies. Another principal objective in the use of models in rangeland resource management is to evaluate the effects of habitat alteration on species, groups of species, and ecosystems. **Models assist the manager in the evaluation of large data sets more accurately than intuitive judgment** (Holthausen 1986).

Extensive computing ability allows analysis of "what if" questions when the analyst puts assumptions into the calculations to determine relationships. Decision support systems allow managers to test different strategies that have not been previously implemented in the field and that go beyond the current base of experience. However, data are accumulating and solid results will become known for more and more ecosystem processes.

A simple diagram that illustrates how models, data sets and other information sources can be linked in a decision support system for rangeland management follows:



The use of decision support systems along with other modern technology is illustrated by the development of computer-controlled farming equipment. Digitized maps of a field or pasture are first obtained from satellite images, multi-band video cameras mounted in aircraft, or from maps developed from field data. Global position satellite signals are then linked to a computer in a tractor to locate the tractor in the field within 3 to 5 meters. Models then analyze the digitized maps for differences in soil, soil moisture, pest infestation, biomass, or other characteristic to automatically vary the application rates of fertilizer, pesticide, or seeding amounts. The use of this equipment has reduced inputs and increased yields in test locations.

As technology continues to advance, innovative applications will be developed for rangelands. Most models concerning rangeland resources have been designed for research purposes. Decisions in rangeland resource management will increasingly depend upon such procedures as simulation, sensitivity analysis, linear and curvulinear analysis, and optimization operating within computer managed decision support systems. The greatest limitation will be the imagination of the human mind.

MULTIPROCESS MODELS

Capability for organizing information has far outdistanced analysis of two or three treatments on one crop. Multiprocess models combine many individual processes needed to address rangeland systems. **A process model is a system of equations whereby state variables can be linked. To build and test a multiprocess system usually requires many scientists from different disciplines.**

Integrated Pest Management

An early development of resource models occurred in traditional biological control of plant and animal pests with insects, fungi, bacteria, protozoa, rickettsiae, and viruses. It became an integration of chemical pest control methods with machines, fire, grazing animals, farming techniques, and chemical pesticides in addition to the traditional biocontrol agents. Formerly known as Integrated Pest Management (IPM), it has become a part of Integrated Farm Management Systems (IFMS).

From the beginning the system applied ecological and economic principles to the management of farm and ranch systems. It originated when chemical control of pests on single agricultural crops became ineffective. Pest insects became resistant to insecticides, and many reproduced on one crop or vegetation and then moved to a different crop. Managers realized that eradication was impossible and that reduced pest levels required integrated farming practices with several crops, a variety of cultural techniques, biocontrol agents, and appropriate herbicides. Other issues were environmental pollution, the cost of developing safe pesticides, and the economic threshold where reduced damage justifies action (Capinera 1987). This is complex integrated analysis to attain crop management.

Determination of economic threshold is an evaluation of damage that justifies the cost of IFMS. Factors in the evaluation are (1) potential for damage, (2) population dynamics of the target pest animal or plant, (3) efficacy of the proposed treatments, (4) cost, and (5) potential return on market and nonmarket values. The outcome of this analysis varies from "You cannot afford integrated management." to "You cannot afford not to use IFMS." Economic thresholds for rangeland improvements, grazing management, pest control, seeding, etc., are fraught with assumptions that need careful analysis. The perception of the need for manipulation of certain rangeland vegetational and animal populations may not become reality until multiple resource analysis is accomplished.

Erosion Productivity Impact Calculator (EPIC)

Another widely used decision support system for crop and rangeland is the Erosion Productivity Impact Calculator in use by the Soil Conservation Service and the Extension Service. The processes and datasets (100 or more) included are within the broad fields of hydrology, erosion, crop growth, irrigation, waterways, nutrient inputs and losses, pesticides, pollutants, and budgets. EPIC exemplifies good model characteristics because (1) Several disciplines contribute to its ongoing development. (2) New research results are easily incorporated. and (3) New technology is rapidly integrated into farming and ranching systems (Benson et al 1992).

Models for Rangelands

Scifres (1987) described a decision support system for analysis and management of natural rangeland resources where the primary problem was excess brush. He described how decision models may be used to select management alternatives. Integrated brush management is but one submodel which can be included when creating comprehensive decision-making models for total resource management.

The SPUR model (Simulation of Production and Utilization of Rangelands) depends upon five basic components: Climate, hydrology, plants, livestock and wildlife, and economics (Wight 1983). Each is divided further. For example, plants have separate categories of species, biomass of several types such as alive, dead, above- and below-ground, and nutrient content. Independent parameters include abiotic environment and species dependent parameters that include tolerance, respiration, mortality, growth, phenology, and water potential. Pasture or community specific parameters include decomposition, dentrification, and drought tolerance. Data banks are seldom available for all these parameters, nor are they all required in every instance. Flexibility in which they enter the model gives the opportunity to emphasize different objectives with newly developed submodels. Reasonable answers may be obtained with "best" assumptions and incomplete data. For example, one objective of SPUR is to simulate the responses of a vegetational system in terms of production and longevity under different managements where hard data are not available.

In general SPUR developed with tested information and adaptation of multiprocesses available in a number of agricultural models. One version of SPUR for a grazing unit simulates plant growth, grazing, and animal production. Another for a watershed retains those simulations and adds runoff and sediment yield. SPUR is driven by daily inputs of rainfall, temperature, solar radiation, and wind. Sensitivity analysis indicates that SPUR as a whole gives no more variation than the ecosystem it simulates (MacNeil et al 1985).

A number of rangeland resource models have been designed and published. Purposes and designs are as varied as the many authors. Here are some of interest to research and management.

- **AFRICA, BLUE GRAMA, ELM, LINEAR, RANGES, ROOTS, SAGE, SHEEP, and SPUR.** Plant growth models based on photosynthesis, growth, carbon allocation, plant death, and germination as compared and reviewed by Hanson et al (1985).
- **COPLAN.** An early linear programming based model that was used for ranch planning. Specialists used portable terminals in ranch homes to link them to large mainframe computers (Child 1975, Child and Evans 1976).
- **CREAMS.** Used to simulate evapotranspiration (ET) (Wight et al 1986).
- **DEERCC.** (Unnamed in publication) A computer program based on quantity and quality of feed and nutritional requirements to determine carrying capacity of black-tailed deer (Hanley and Rogers 1989).
- **ERHYM.** Ekalaka Rangeland Hydrology and Yield Model for simulating soil water status and ET (Wight and Neff 1983).
- **KINEROS.** Did well in estimating runoff after contour ripping a rangeland watershed (Osborn and Simanton 1990).
- **OVUNST.** (Unnamed in paper, OVerstory/UNderSTory) A spatial simulation model that allows examination of herbage yield at the

community level following manipulation of woody cover (Scanlan 1992).

- **PASTORAL.** Simulates forage availability, preference, and degree of utilization (Hart and Hanson 1990).
- **RAPPS.** A single plant model that simulates growth and response to climatic, environmental, and managerial influences from a plant physiological basis (Sims et al 1993).
- **SMART.** Simple Model to Assess Range Technology simulates the effects of stocking rate and rotation on herbage production and steer performance (Hart 1991a, 1989).
- **SPAW.** Soil-Plant-Air-Water model for soil water status and ET (Saxton et al 1974).
- **SPUR.** The hydrology component of SPUR (Renard et al 1983).
- **STEERISK.** This spreadsheet is a tool to estimate chances in variable forage production, to test marketing and management strategies, and to estimate economic returns from them (Hart 1991b).
- **UNNAMED.** Bosch and Booysen (1992) presented a model designed for assessment of rangeland condition and carrying capacity. Blackburn and Kothmann (1991) used palatability, preference, and availability to simulate diet selection.

COMBINING RANGELAND RESOURCE MODELS

Integration of separate decision support systems into a larger framework is illustrated by the Field Office Computing System framework (FOCS) (Soil Conservation Service 1992) for the approximately 2500 county offices of the Soil Conservation Service. Models being incorporated include Grazing Land Applications software (Stuth et al 1990) for forage and livestock inventories, site descriptions, grazing schedules, and economic analysis. FOCS also includes information systems on public information, administration, planning, policy, field office operation, and natural resource technology (Soil Conservation Service 1990). The goal is a decision support system that filters the land manager's objectives, field resources, and public concerns into a practical land management plan (Carlson 1993). Importantly, the plan applies to a pasture, a ranch, or other field unit and information in the system is additive for national and international perusal by policy makers.

PRECAUTIONS IN APPLYING MODELS AND SIMULATION

Models based on density of the species have been used to find optimal habitat quality for wild animals. About 50 percent of these simulations have failed. Laymon and Barrett (1986) offered that models failed because they excluded predation, disease, herbivory, competition, assumed linearity between animal and habitat, and use of simple analysis when multivariate analysis is needed. This example illustrates the importance of correct and complete assumptions in models. The assumption that species density indicated habitat quality was true only in part. **Use of a model without full understanding of its goals and assumptions can lead to false conclusions.**

Models for wild animals, principally birds, have been used to estimate the needs of each species, response to successional changes in vegetational composition and structure, to predict response to disturbance, to predict interactions with abiotic factors, and responses to patch size and fragmentation of habitats. Accuracy or testing of model prediction is seldom given, but is essential. **In most situations models based on habitats, abiotic environment, and animals should be considered submodels of ecosystem models if the purpose is for decision making.**

ACCUMULATION OF DATA-SETS

Lack of adequate data-sets on ecological processes responding to interacting abiotic and biotic factors is a major present deficiency. The future will bring an increasing volume of time-related process data from research, inventory, and monitoring. Expansion of the data-sets accumulated in the space-related Geographical Information Systems continues at a rapid rate. Integration of the time and space relationships for the field technician is close to reality. Successes with process modeling indicate that storage, analysis, and retrieval in appropriate form for decision making are imminent.

ISSUES AND VALUES OF MODELING

Issues in rangeland resource modeling usually center upon (1) the correct biological assumptions, (2) accuracy of input effects, (3) testing of the model, (4) suitability and cost/effectiveness of the intended application, and (5) the required kinds and availability of data sets for the intended purpose (Verner et al 1986). Salwasser (1986) wrote that models should be easy to operate, run on commonly collected data, be reliable, provide information on the objectives of concern, and be based on major relationships.

Integrative modeling of multiprocess systems has added a better understanding of ecosystem functions. Modeling and simulation are a tremendous aid to managerial decision making. More values have been listed (Bosch and Booysen 1992) as follows:

- An interdisciplinary approach to model building ensures that most aspects of the ecosystems are covered.
- Integration with computer technologies optimizes efficiency.
- Present-state data sets and experience can be used.
- Inclusion of qualitative and quantitative data invites participation by specialists from various disciplines.
- New knowledge can easily and inexpensively be accommodated.
- Wide or universal application can be attained regardless of adequacy of the quantitative data pool.

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Appendix One

Scientific and Common Names of Plants

The following alphabetical list includes the genera and species of plants mentioned in the text. Names are based on the following literature as well as common usage:

Beetle, A. A. 1970. Recommended plant names. Univ. WY Agr. Expt. Sta. Research. J. 31.
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Note that the list includes both new and replaced scientific names. For example, Ceratoides lanata and Eurotia lanata are winterfat. Many others, principally in Agropyron and Andropogon, are given. The reader is cautioned that the list refers to usage in the literature, some of it old, and does not attempt up-to-date taxonomic treatise. The lag time between revision of species and acceptance in field usage may be many years. Interestingly, common names may be more lasting than scientific names for field application.

SCIENTIFIC NAME	COMMON NAME
Acacia	acacia
Acacia aneura	mulga
Acacia constricta	mescat acacias, whitethorn
Acacia farnesiana	huisache acacia
Acacia greggii	catclaw acacia
Acacia karroo	karroo
Achillea lanulosa	yarrow
Actinomyces	bacteria
Adenostoma	chamise
Adenostoma fasciculatum	chamise
Agropyron	wheatgrass
Agropyron cristatum	crested wheatgrass

Agropyron dasystachyum	thickspike wheatgrass
Agropyron desertorum	crested wheatgrass
Agropyron elongatum	tall wheatgrass
Agropyron inerme	beardless wheatgrass
Agropyron intermedium	intermediate wheatgrass
Agropyron riparium	streambank wheatgrass
Agropyron sibiricum	Siberian wheatgrass
Agropyron smithii	western wheatgrass
Agropyron spicatum	bluebunch wheatgrass
Agropyron trachycaulum	slender wheatgrass
Agropyron trichophorum	pubescent wheatgrass
Aira caryophyllea	silver hairgrass
Alnus	alder
Amaranthus	pigweed
Ambrosia artemisiifolia	ragweed
Amelanchier alnifolia	Saskatoon serviceberry
Ammophila	beachgrass
Ammophila arenaria	European beachgrass
Andropogon	bluestem
Andropogon annulatus	Angleton grass
Andropogon caucasicus	Caucasian bluestem
Andropogon divergens	pinehill bluestem
Andropogon gerardi	big bluestem
A. gerardi var. paucipilus	sand bluestem
Andropogon hallii	sand bluestem
Andropogon ischaemum	yellow bluestem
Andropogon scoparius	little bluestem
Andropogon tener	slender bluestem
Andropogon virginicus	broomsedges, yellow bluestem
Aplopappus tenuisectus	burro goldenweed
Arctostaphylos	manzanita
Aristida	threeawn
Aristida stricta	pineland threeawn
Arrhenatherum elatius	tall oatgrass
Artemisia	sagebrush
Artemisia cana	silver sagebrush
Artemisia caudata	field sagewort
Artemisia frigida	fringed sagewort
Artemisia nova	black sagebrush
Artemisia tridentata	big sagebrush
A. tridentata subsp. tridentata	basin big sagebrush
A. tridentata subsp. vaseyana	mountain big sagebrush

A. tridentata subsp. wyomingensis	Wyoming big sagebrush
Arundinaria tecta	switch cane
Aspergillus	mold fungus
Astragalus	milkvetch, loco weed
Astragalus cicer	cicer milkvetch, chickpea
A. miser var. oblongifolius	weedy milkvetch
Atriplex	saltbush
Atriplex canescens	fourwing saltbush
Atriplex confertifolia	shadscale saltbush
Atriplex nummularia	oldman saltbush
Atriplex nuttallii	nuttall saltbush
Atriplex polycarpa	allscale saltbush
Atriplex suckleyi	rillscale
Atriplex vesicaria	Australian saltbush
Avena barbata	slender wildoat
Axonopus affinis	carpetgrass
Azotobacter	N-fixing bacteria
Balsamorhiza sagittata	arrowleaf balsamroot
Betula	birch
Bothriochloa caucasica	Caucasian bluestem
Bouteloua	grama
Bouteloua barbata	sixweeks grama
Bouteloua curtipendula	sideoats grama
Bouteloua eriopoda	black grama
Bouteloua gracilis	blue grama
Bouteloua rothrockii	rothrock grama
Brachiaria	signalgrass
Brassica	mustard
Bromus	brome
Bromus carinatus	California brome
Bromus inermis	smooth brome
Bromus marginatus	mountain brome
Bromus mollis	soft chess
Bromus rigidus	ripgut brome
Bromus rubens	red brome
Bromus tectorum	cheatgrass
Bryophyta	moss species
Buchloe	buffalograss
Buchloe dactyloides	buffalograss
Calamagrostis rubescens	pine reedgrass
Calamovilfa longifolia	prairie sandreed
Carduus	thistle

Carduus nutans	musk thistle
Carex	sedge
Carex filifolia	threadleaf sedge
Carex geyeri	elk sedge
Carex nebraskensis	Nebraska sedge
Carex rostrata	beaked sedge
Cassia	senna
Cassia armata	desert senna
Casuarina	beefwood
Ceanothus	buckbrush
Ceanothus sanguineus	redstem ceanothus
Ceanothus velutinus	snowbush ceanothus
Cenchrus	bristle grass
Cenchrus ciliaris	buffelgrass
Centaurea	starthistle
Centaurea diffusa	diffuse knapweed
Centaurea maculosa	spotted knapweed
Centaurea repens	Russian knapweed
Centaurea solstitialis	yellow starthistle
Ceratoides lanata	winterfat
Cercocarpus	mountain mahogany
Cercocarpus betuloides	birchleaf mountain mahogany
Cercocarpus breviflorus	Wright mountain mahogany
Cercocarpus ledifolius	curlleaf mountain mahogany
Cercocarpus montanus	mountain mahogany
Chenopodium leptophyllum	narrowleaf goosefoot
Chloris gayana	rhodesgrass
Chondrilla juncea	rush skeletonweed
Chrysanthemum leucanthemum	oxeyedaisy chrysanthemum
Chrysothamnus	rabbitbrush
Chrysothamnus nauseosus	rubber rabbitbrush
Chrysothamnus viscidiflorus	Douglas rabbitbrush
Cicuta	waterhemlock
Cirsium	thistle
Cirsium arvense	Canada thistle
Claydonia	lichen
Clostridium	anaerobic bacteria
Coleogyne ramosissima	blackbrush
Commiphora	murrh tree, commiphora
Compositae	sunflower family
Condalia spathulata	knifeleaf condalia
Convolvulus	bindweed

Convolvulus arvensis	field bindweed
Cotoneaster	cotoneaster
Cowania	cliffrose
Cowania mexicana	Mexican cliffrose
Cretraria	lichen
Crotalaria	crotalaria
Cuscuta	dodder
Cyanophyta	blue-green algae species
Cynodon	Bermudagrass
Cynodon dactylon	Bermudagrass
Cytisus	broom
Dactylis	orchardgrass
Dactylis glomerata	orchardgrass
Danthonia californica	California oatgrass
Danthonia intermedia	timber oatgrass
Danthonia parryi	Parry oatgrass
Danthonia unispicata	onespike oatgrass
Delphinium	larkspur
Delphinium barbeyi	Barbey larkspur
Delphinium geyeri	plains larkspur
Deschampsia caespitosa	tufted hairgrass
Desmodium	tickclover
Dichanthium annulatum	Angleton grass
Digitaria	fingergrass
Discaria	fixes N
Distichlis spicata	seashore saltgrass
D. spicata var. stricta	inland saltgrass
Dryas	dryad
Elaeagnus	elaeagnus
Eleocharis	spikerush
Elymus	wildrye
Elymus canadensis	Canada wildrye
Elymus caput-medusae	medusahead
Elymus cinereus	basin wildrye
Elymus junceus	Russian wildrye
Elymus lanceolatus	Snake River wheatgrass
Elymus trachycaulus	intermediate wheatgrass
Elymus triticoides	creeping wildrye
Elyonurus argenteus	elyonurus
Elytrigia intermedia	intermediate wheatgrass
Elytrigia repens	quackgrass
Elytrigia spicata	bluebunch wheatgrass

Emmenanthe penduliflora	yellow whisperingbells
Epilobium	fireweed
Epilobium angustifolium	fireweed
Eragrostis	lovegrass
Eragrostis curvula	weeping lovegrass
Eragrostis lehmanniana	Lehmann lovegrass
Eragrostis trichodes	sand lovegrass
Ericameria austrotexana	false broomweed
Erodium	filaree
Erodium botrys	broadleaf filaree
Erodium cicutarium	redstem filaree
Eucalyptus	eucalyptus
Eumycophyta	fungi species
Euphorbia esula	leafy spurge
Eurotia lanata	winterfat
Festuca	fescue
Festuca arizonica	Arizona fescue
Festuca arundinacea	tall fescue
Festuca elatior	meadow fescue
Festuca idahoensis	Idaho fescue
Festuca octoflora	sixweeks fescue
Festuca rubra	red fescue
Festuca scabrella	rough fescue
Festuca viridula	green fescue
Flourensia cernua	American tarbush
Frankia	bacteria
Fraxinus americana	white ash
Gale	gale
Garrya wrightii	Wright silktassel
Geranium viscosissimum	sticky geranium
Grayia spinosa	spiny hopsage
Gutierrezia	snakeweed
Gutierrezia sarothrae	broom snakeweed
Halogeton glomeratus	halogeton
Haplopappus tenuisectus	burro goldenweed
Hedysarum boreale	northern milkvetch
Helenium hoopesii	orange sneezeweed
Helianthus annuus	sunflower
Heliotropium	heliotrope
Heteropogon	tanglehead
Heteropogon contortus	tanglehead
Hilaria belangeri	curlymesquite

Hilaria jamesii	galleta
Hilaria mutica	tobosa
Hippophae	buffaloberry
Holodiscus discolor	creambush, rockspirea
Hordeum brachyantherum	meadow barley
Hymenoxys odorata	bitterweed
Hyparrhenia hirta	thatching grass
Hypericum	goatweed
Hypericum perforatum	St. Johnswort, Klamath weed
Ilex vomitoria	yaupon holly
Isatis tinctoria	Dyer's woad
Juncus	rush
Juniperus	juniper
Juniperus ashei	ashe juniper
Juniperus osteosperma	Utah juniper
Juniperus pinchotii	redberry juniper
Juniperus virginiana	eastern redcedar
Kochia prostrata	prostrate summercypress
Kochia scoparia	fireweed summercypress
Koeleria cristata	prairie junegrass
Larrea	creosotebush
Larrea divaricata	creosotebush
Larrea tridentata	creosotebush
Leguminosae	pea family
Lepidium densiflorum	prairie pepperweed
Lepidium perfoliatum	clasping pepperweed
Lespedeza striata	lespedeza
Lolium	ryegrass
Lolium multiflorum	Italian ryegrass
Lolium perenne	perennial ryegrass
Lupinus	lupine
Lupinus caudatus	tailcup lupine
Lupinus sericeus	silky lupine
Lycopersicon esculentum var. minor	wild tomato
Madia glomerata	cluster tarweed
Medicago	medic
Medicago hispida	burclover
Medicago sativa	alfalfa, medic
M. sativa subsp. falcata	sickle alfalfa
Melilotus indica	annual yellow sweetclover
Melilotus officinalis	yellow sweetclover
Mertensia arizonica var. leonardi	tall bluebells

Morus	mulberry
Muhlenbergia montana	mountain muhly
Muhlenbergia porteri	bush muhly
Mycorrhizae	vesicular-arbuscular mycorrhizae (VAM)
Myrica	waxmyrtle
Onopordum acanthium	Scotch thistle
Opuntia	pricklypear
Opuntia fulgida	Sonora jumping cholla
Opuntia imbricata	walkingstick cholla
Opuntia inermis	pricklypear
Opuntia leptocaulis	tesajillo
Opuntia lindheimeri	Lindheimer pricklypear
Opuntia megacantha	mission pricklypear
Opuntia polyacantha	plains pricklypear
Opuntia stricta	pricklypear
Oryzopsis	ricegrass
Oryzopsis hymenoides	Indian ricegrass
Oryzopsis miliacea	smilo
Oxytropis	loco
Oxytropis sericea	silky loco
Panicum	panic
Panicum antidotale	blue panic
Panicum coloratum	kleingrass
P. coloratum var. makarikariense	makarikari grass
Panicum maximum	Guineagrass
Panicum obtusum	vinemesquite
Panicum virgatum	switchgrass
Pascopyrum smithii	western wheatgrass
Paspalum	paspalum
Paspalum dilatatum	Dallisgrass
Paspalum notatum	bahiagrass
Pennisetum	pennisetum
Pennisetum ciliare	buffelgrass
Petradoria pumila	rock goldenrod
Phalaris	canarygrass
Phalaris arundinacea	reed canarygrass
Phalaris tuberosa	bulb canarygrass
P. tuberosa var. hirtiglumis	koleagrass
P. tuberosa var. stenoptera	hardinggrass
Phaseolus	bean
Phleum	timothy

Phleum pratense	timothy
Phlox canescens	hoary phlox
Phragmites	reed
Phragmites communis	reed
Picea glauca	white spruce
Picea mariana	black spruce
Pinus	pine
Pinus attenuata	knobcone pine
Pinus caribaea	slash pine
Pinus contorta	lodgepole
Pinus echinata	shortleaf pine
Pinus edulis	pinyon pine
Pinus monophylla	singleleaf pinyon
Pinus nigra	Austrian pine
Pinus palustris	longleaf pine
Pinus ponderosa	ponderosa pine
Pinus radiata	Monterey pine
Pinus remota	papershell pinyon
Pinus sabiniana	digger pine
Pinus taeda	loblolly pine
Poa	bluegrass
Poa ampla	big bluegrass
Poa arachnifera	Texas bluegrass
Poa palustris	fowl bluegrass
Poa pratensis	Kentucky bluegrass
Poa secunda	Sandberg bluegrass
Polygonaceae	buckwheat family
Polygonum	knotweed
Populus	poplar, aspen, cottonwood
Populus tremuloides	quaking aspen
Prosopis	mesquite
Prosopis glandulosa	honey mesquite
Prosopis juliflora	mesquite
Prunus emarginata	bitter cherry
Prunus virginiana	chokecherry
Psathyrostachys juncea	Russian wildrye
Pseudoroegneria spicata	bluebunch wheatgrass
Pseudotsuga menziesii	Douglas fir
Psoralea tenuiflora	slimflower scurfpea
Pteridium aquilinum	westerm bracken fern
Puccinia jaceae	ruston yellow starthistle
Purshia	bitterbrush

Purshia tridentata	antelope bitterbrush
Quercus	oak
Quercus douglasii	blue oak
Quercus gambelii	Gambel oak
Quercus havardii	shin oak
Quercus petraea	durmast oak
Quercus turbinella	scrub liveoak
Quercus virginiana	liveoak
Quercus wislizenii	interior liveoak
Ramalina reticulata	lichen on oak
Ranunculus occidentalis	western buttercup
Rhizobium	nitrifying bacteria
Rhus	sumac
Rhus glabra	smooth sumac
Rhus microphylla	littleleaf sumac
Ribes velutinum	desert gooseberry
Rosa bracteata	Macartney rose
Rubus	blackberry
Salix	willow
Salix amygdaloides	peachleaf willow
Salix geyeriana	geyer willow
Salix scouleriana	scouler willow
Salsola	Russianthistle
Salsola iberica	Russianthistle
Salsola kali	Russianthistle
Sarcobatus	greasewood
Sarcobatus vermiculatus	black greasewood
Schizachyrium scoparium	little bluestem
Schizachyrium stoloniferum	creeping bluestem
Scirpus	bulrush
Scleropogon brevifolius	burrograss
Sclerotinia sclerotiorum	fungus
Senecio	groundsel
Senecio jacobaea	tansy ragwort
Serenoa repens	sawpalmetto
Setaria macrostachya	plains bristlegrass
Shepherdia	buffaloberry
Sisymbrium altissimum	tumbling mustard
Sitanion hystrix	bottlebrush squirreltail
Sorghastrum nutans	yellow indiangrass
Sorghum almum	Argentine sorghum
Sorghum halepense	Johnsongrass

Sorghum intrans	sorghum
Sorghum plumosum	sorghum
Spartina	cordgrass
Spartina alterniflora	smooth cordgrass
Spartina patens	saltmeadow cordgrass
Spartina spartinae	gulf cordgrass
Sphaeralcea grossulariaefolia	globmallow
Sporobolus airoides	alkali sacaton
Sporobolus flexuosus	mesa dropseed
Sporobolus wrightii	sacaton
Stipa	needlegrass
Stipa columbiana	subalpine needlegsrass
Stipa comata	needle-and-thread
Stipa leucotricha	Texas needlegrass
Stipa pulchra	purple needlegrass
Stipa thurberiana	Thurber needlegrass
Stipa viridula	green needlegrass
Stylosanthes humilis	Townsville stylo
Symphoricarpos albus	snowberry
Symphoricarpos occidentalis	western snowberry
Symphoricarpos vaccinoides	whortleleaf snowberry
Taeniatherum asperum	medusahead
Tamarix	tamarisk
Taraxacum officinale	dandelion
Tetradymia canescens	gray horsebush
Tetradymia glabrata	littleleaf horsebush
Themeda	kangaroograss
Themeda australis	Australian kangaroograss
Themeda triandra	red oatgrass
Thinopyrum intermedium	intermediate wheatgrass
T. intermedium subsp. barbulatum	pubescent wheatgrass
Thinopyrum ponticum	tall wheatgrass
Trichachne californica	Arizona cottontop
Trifolium	clover
Trifolium hirtum	rose clover
Trifolium incarnatum	crimson clover
Trifolium repens	white clover
Trifolium subterraneum	subterranean clover
Tristachya hispida	
Typha	cattail
Ulmus parvifolia	Chinese elm
Veratrum californicum	falsehellebore

Vicia villosa	vetch
Wyethia amplexicaulis	mulesear
Xanthium	cocklebur
Xanthocephalum sarothrae	broom snakeweed
Yucca	yucca, soapweed
Zygadenus	deathcamas
Zygadenus paniculatus	foothill deathcamas

Appendix Two

Common and Scientific Names of Animals

The following alphabetical list includes the common and scientific names of animals used in the text. The references consulted for the scientific names were as follows:

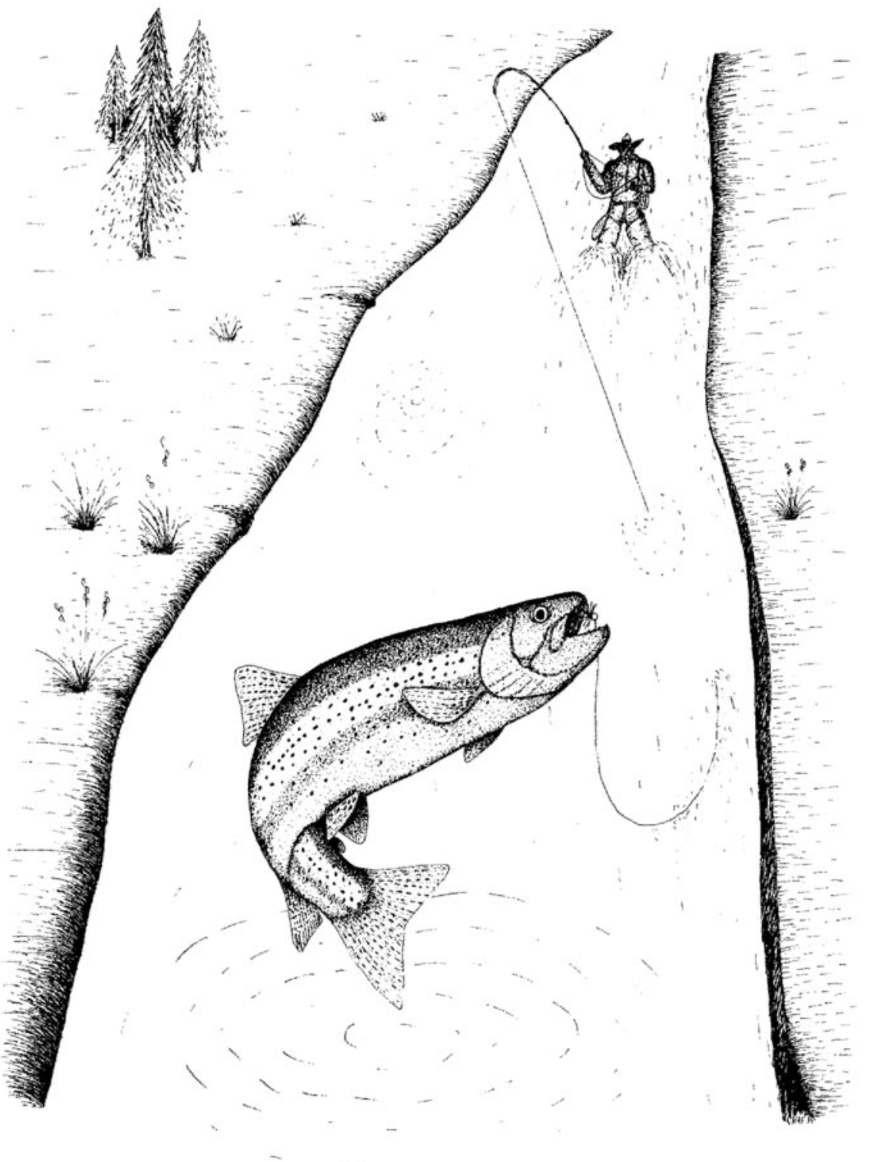
Code	Reference
B	Ehrlich, P. R., D. S. Dobkin and D. Wheye. 1988. The birder's handbook. Simon & Schuster Inc., NY.
D	Borror, D. J. and D. M. Delong. 1971. An introduction to the study of insects. Rinehart and Winston, NY.
E	Larousse encyclopedia of animal life. 1972. Hamlyn, London.
J	Jones, J. K., Jr., R. S. Hoffmann, D. W. Rice, C. Jones, R. J. Baker and M. D. Engstrom. 1992. Revised checklist of North American mammals north of Mexico, 1991. The Museum, Texas Tech Univ. Occasional Papers 146.
L	Laudenslayer, W. F., Jr., W. E. Grenfell, Jr. and D. C. Zeiner, 1991. A check-list of amphibians, reptiles, birds, and mammals of California. CA Fish and Game 77:109-141.
M	Haltenorth, T. and H. Diller. 1984. A field guide to the mammals of Africa including Madagascar. Collins, London.

Common Name	Scientific Name	Reference
ant	Veromessor pergandei	D
ant, army	Eciton	D
ant, mound building	Formica exsectoides	
antelope, blackbuck	Antilope cervicapra	J
antelope, nilgai	Boselaphus tragocamelus	J
antelope, roan	Hippotragus equinus	M
antelope, sable	Hippotragus niger	M
antelope, saiga	Saiga tatarica	E
aoudad, Barbary sheep	Ammotragus lervia	J
badger	Taxidea taxus	J
bear	Ursus	J
bear, black	Ursus americanus	J
bear, grizzly	Ursus arctos	J
beaver, American	Castor canadensis	J
beaver, mountain	Aplodontia rufa	J
bison	Bos bison	J
blesbok	Damaliscus dorcas	M
boar, European wild	Sus scrofa	L
bobcat	Felis rufus	L
buffalo, cape	Syncerus caffer	M
burro, feral ass	Equus asinus	J
bushbuck	Tragelaphus scriptus	M
bushpig	Potamochoerus porcus	M
cactus moth	Cactoblastis	
cactus moth	Cactoblastis cactorum	
camel	Camelus dromedarius	E
caribou	Rangifer tarandus	J
cat	Felidae	J
cattle, Hereford	Bos taurus	
cattle, Indian zebu	Bos indicus	E
cattle, Santa Gertrudis	Bos taurus x Bos indicus	
chamois	Rupicapra rupicapra	E
cheetah	Acinonyx jubatus	M
chicken, domestic	Gallus gallus	
cochineal on cactus	Dactylopius	
cochineal on cactus	Dactylopius tomentosus	
condor, California	Gymnogyps californianus	B
cottontail rabbit	Sylvilagus	J
coyote	Canis latrans	J
crow, American	Corvus brachyrhynchos	L
deer	Odocoileus	J

deer, axis	Cervis axis	J
deer, mule, Columbian blacktailed	Odocoileus hemionus	J
deer, red	Cervus elaphus	E
deer, sika	Cervus nippon	J
deer, whitetailed	Odocoileus virginianus	J
dikdik	Rhynchotragus	M
dingo	Canis dingo	E
dog, domestic, great pyrennes, komonder	anis familiaris	J
dog, hunting	Lycaon pictus	M
duck	Anas	L
duck, mallard	Anas platyrhynchos	L
duiker	Cephalophus	M
dung beetle	several species	
eagle, golden	Aquila chrysaetos	L
eland	Taurotragus oryx	M
elephant, African	Loxodonta africana	M
elk, wapiti	Cervus elaphus	L
elk, Roosevelt	Cervus elaphus	L
emu	Dromaius novaehollandiae	E
flea beetle	Aphthona	
flea beetle	Aphthona nigriscutis	
fly, blow	Calliphoridae (family)	D
fly, tsetse	Glossina	D
fox, red	Vulpes vulpes	L
gazelle	Gazella	M
gazelle, Grant's	Gazella granti	M
gazelle, Thomson's	Gazella thomsoni	M
giraffe	Giraffa camelopardalis	M
goat, Angora, Boer, feral, Spanish	Capra hircus	J
goat, Rocky Mountain	Oreamnos americanus	J
goose, Canada	Branta canadensis	L
gopher, pocket	Thomomys	J
grassbug, black	Labops hesperius	
grasshopper	Aulocara elliotti (many more)	
grasshopper disease	Nosema locustae	
grouse, ruffed	Bonasa umbellus	B
grouse, sage	Centrocercus urophasianus	B
grouse, sharptail	Tympanuchus phasianellus	B
hamster	Cricetus cricetus	E
hare, cape	Lepus capensis	M
hare, snowshoe	Lepus americanus	J

hartebeest	Alcelaphus	M
hippopotamus	Hippopotamus amphibius	M
hog, giant forest	Hylochoerus meinertzhageni	M
horse, domestic	Equus caballus	J
horse, feral	Equus caballus	J
hyena, spotted	Crocuta crocuta	M
hyena, striped	Hyaena hyaena	M
impala	Aepyceros melampus	M
jackal	Canis	M
jackal, blackbacked	Canis mesomelas	M
jackrabbit	Lepus	J
jackrabbit, blacktailed	Lepus californicus	J
jackrabbit, whitetailed	Lepus townsendii	J
jay, European	Garrulus glandarius	E
kangaroo rat	Dipodomys	J
kangaroo rat, giant	Dipodomys ingens	J
kangaroo rat, Merriam's	Dipodomys merriami	L
killdeer	Charadrius vociferus	B
kob, Uganda	Adenota kob	M
kudu (koedoe), greater	Tragelaphus strepsiceros	M
kudu, lesser	Tragelaphus imberbis	M
lemming	Synaptomys borealis	J
leopard	Panthera pardus	M
lion	Panthera leo	M
llama	Llama huanacos	E
meadowlark	Sturnella neglecta	L
moose	Alces alces	J
mourning dove	Zenaida macroura	B
mountain lion	Felis concolor	J
mouse, pocket	Perognathus	J
mouse, whitefooted	Peromyscus leucopus	J
nematode	Nematoda	
opossum, Australia	variety of genera and species	
peccary	Tayassu tajacu	J
pheasant, ringneck	Phasianus colchicus	B
pig, feral	Sus scrofa	J
porcupine	Erethizon dorsatum	J
prairie chicken	Tympanuchus	B
prairie chicken, Attwater's	T. cupido attwateri	B
prairie dog, blacktailed	Cynomys ludovicianus	J
pronghorn	Antilocapra americana	J
protozoa	Protozoa	
quail, bobwhite	Colinus virginianus	B

quail, Gambel's	Callipepla gambelii	L
quail, Mearns'	Cyrtonyx montezumae	B
quail, valley, California	Callipepla californica	L
rabbit, European	Oryctolagus cuniculus	L
raccoon	Procyon lotor	J
rat	Rattus rattus	L
rat, pack, pack	Neotoma	J
reindeer	Rangifer tarandus	E
rhinoceros, black	Diceros bicornis	M
rhinoceros, squarelipped, white	Ceratotherium simum	M
sheep, bighorn	Ovis canadensis	J
sheep, feral, domestics	Ovis aries	E
sheep, moufflon	Ovis musimon	E
skunk, striped	Mephitis mephitis	J
sparrow, house, English	Passer domesticus	L
springbok	Antidorcas marsupialis	M
squirrel	Sciurus	J
squirrel, ground	Spermophilus	J
starling, European	Sturnus vulgaris	L
St. Johnswort beetle	Chrysolina hyperici	
St. Johnswort beetle	Chrysolina quadrigemina	
termite, harvester	Nasutitermes triodiae	D
thar	Hemitragus jemlahicus	J
ticks	Ixodoidea (family)	
topi	Damaliscus topi	M
tortoise, giant Galapagos	Testudo elephantopus	E
tsessebe	Damaliscus lunatus	M
vole	Microtus	J
vulture, turkey	Cathartes aura	L
walkingstick	Diapheromera velii	D
wapiti, elk	Cervus elaphus	J
warbler, Kirtland	Dendroica kirtlandii	B
warthog	Phacochoerus aethiopicus	M
waterbuck	Kobus ellipsiprymnus	M
wildebeest, whitetailed	Connochaetes gnou	M
wildebeest, blue	Connochaetes taurinus	M
wolf	Canis lupus	J
zebra, Burchell's	Equus burchelli	E
zebra, mountain	Equus zebra	E



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About the Book and Authors

Over the last two decades the science of range management, like many other resource disciplines, has embraced and integrated environmental concerns in the field, laboratory, and its policy. *Rangeland Ecology and Management* now brings this integrated approach to the classroom in a thoroughly researched, comprehensive, and readable text. The authors discuss the basics of rangeland management—including grazing and practical management of animals and vegetation—and place those basics within the context of decision making for damaged land, riparian and water conservation, multiple-use, and modeling. Concepts such as succession, stability, and range condition are examined and their effects discussed. Fire is considered as an environmental factor. Appendixes provide scientific and common names of range plants and animals. These and many other issues crucial to the understanding of successful range management combine to make the finest text for upper-level undergraduates now available.

Harold F. Heady is professor emeritus at the University of California–Berkeley. He was awarded the Berkeley Citation in 1991 in recognition of his long and preeminent career in range management. **R. Dennis Child** is National Program Leader, Range, with the USDA Agricultural Research Service in Beltsville, Maryland.