

Grazing Behavior in Ungulates: Current Concepts and Future Challenges

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Abstract: An early focus on ungulate foraging behavior occurred in the 1940's as scientists began quantifying the activities of livestock and wildlife to address production goals. Interest resurfaced in the 1970's and continued as investigators pondered behavior related hypotheses at evolutionary, ecosystem, and plant/animal interface levels. Presently, many grazing land environmental concerns are related to the selective foraging habits of ungulates and their poor distribution about the landscape. These two facets of ungulate behavior serve as the impetus for many of today's research efforts, and scientists in the field need to develop a theoretical framework to address these problems. The theories of optimum foraging and adaptive rumen function were offered to explain evolutionary patterns of forage selection among herbivores, but they lack the specificity needed by range and pasture managers at relevant space and time scales. While post-ingestive feedback mechanisms cause aversions to toxic plants, and some species of herbivores have developed means of neutralizing harmful compounds, the mechanisms stimulating the development of forage preferences in the absence of aversive compounds are not clearly understood. Ungulates also exhibit selective patterns of spatial use about the landscape. In some environments where necessary resources (water, shade, forage, minerals, escape topography or cover) are scarce, areas of activity will be focused about these limiting elements. Many of the herding ungulates, however, repeatedly regrazed certain areas and avoid other equally suitable portions of the landscape. Research suggests these habits elevate the animal's nutritional status by curtailing advances in plant phenology and removing the hindrances of cured forage from the grazed patches. Such a scenario increases landscape diversity and may enhance species richness and accelerate nutrient cycling in the grazed areas by maintaining vegetation in an earlier stage of succession. Recent investigations suggest that ungulates can retain and use spatial memory to expedite foraging, and can associate shapes and colors with the presence or absence of food. These skills have been clearly demonstrated in small, well controlled environments, but patterns of behavior and distribution in extensive landscape settings are poorly understood. The recent advances in geographic information systems and global positioning systems will assist us greatly in our analyses of ungulate behavior at landscape levels of resolution. Pasture and landscape managers are beginning to recognize many of the innate habits and preferences of livestock though, and are exploiting these behaviors to affect plant succession, control weeds, and manipulate forage quality or structure of the plant community. There is much left to learn,

but as we make inroads in these endeavors, the value of grazing animals can only increase.

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Ruminants were first domesticated by humans as early as 10,000 years ago. The earliest archeological evidence comes from Iraq where sheep and goats were raised 8,500 years ago (Fitzhugh *et al.*, 1978). These same authors report that cattle were first raised in Greece about 6,500 years ago. In the New World the domestication of camelids appears about 4,000 B.C. (Bokonyi, 1983). As Europeans colonized the globe, they took their domesticated animals with them. Basically, domesticated animals invaded some lands previously ungrazed by large numbers of wild herbivores, replaced the native herbivores, or competed with the native populations. Today, 35% of the world's land areas are grazed by livestock (Steinfeld *et al.*, 1997). Grazing livestock have altered environments, even continental environments, and have been followed around the globe by weed invasions (Crosby, 1986). Durning and Brough (1991) have stated that poor management of grazing livestock has resulted in degradation of dry lands and destruction of forests leading to proliferating weeds, depleted soils and eroded landscapes. Fleischner (1994) termed livestock grazing the most pervasive land use in western North America and the single most important factor limiting wildlife production. Where degradation has occurred, the reasons are complex, and often both cultural and biological in nature. Most are beyond the scope of this paper. However, the role of grazing behavior remains a primary component in both causing and rectifying land

degradation, competition or facilitation with other grazing animals, and the economic viability of livestock owners. The study of grazing behavior was, is and will continue to play an integral role in the development of ecologically sound grazing management systems.

Today's literature is replete with information on grazing behavior. Stuth (1991) provides an excellent compilation of the complex interacting behavioral factors related to foraging. Senft *et al.* (1987), Coughenour (1991) and Bailey *et al.* (1996) provide excellent reviews of various components of grazing behavior. Previously, Gonyou (1984) for sheep, Arave *et al.* (1984) and Stricklin and Kautz-Scanavy (1984) for cattle, and Squires (1982) and Arnold (1987) for sheep and cattle, have also provided reviews. Most of the citations in all of the above papers are from the 1970's forward. Stricklin and Kautz-Scanavy (1984) and Arnold (1987) provide some sources in the 1950's and 60's. Hancock (1953) reviewed earlier grazing behavior research on cattle. Grazing behavior research seems to be active prior to 1950 and then wanes during the 1950's and 1960's. Perhaps scientists took too seriously Hancock's admonishments that there is a danger of basing practical farm management advice on observations of grazing behavior because it is not possible to predict the extent to which animals are able to alter their habits to meet the exigencies of changing or adverse environmental conditions. He went on to say that cattle will change their habit

to a considerable extent in order to meet changes in their environments, and therefore, grazing behavior studies can rarely contribute to the evaluation of the relative efficiency of various management practices.

The Serengeti Region of Africa provided one location for the rebirth of active grazing behavior research. The work of Bell (1971), and later, McNaughton (1979) have certainly stimulated research worldwide. Likewise, the continuing research of Arnold and others (see Arnold and Dudinski, 1978; Arnold, 1987) have also contributed.

In this paper, we will review current concepts of foraging behavior, emerging science and technology, the field application of research and future challenges.

Current Concepts

Stuth (1991) presented a model, adapted from Senft *et al.* (1987) and Coleman *et al.* (1989), that is useful for conceptualizing the hierarchical linkages within any environment that affect foraging behavior. To harvest the nutrients necessary for their physiological needs, animals must make selections from among progressively smaller components of the landscape. In essence, animals select a particular portion of the landscape, a specific plant community, a patch or identifiable portion of the community, and lastly, a particular plant or plant part to consume. Because grazing alters the flow of nutrients and energy in plants, feedback mechanisms in turn affect the well-being of individual plants, plant communities, and eventually the landscape, soils, and hydrology of an area (Stuth, 1991). The effects of these landscape features on

animals and their foraging behaviors in turn bring the model full-circle.

The greatest frustration in the study of foraging behavior, however, has been the lack of a unifying theory capable of explaining the selective processes of grazers. Perhaps the most widely encompassing and debated concept related to grazing behavior has been the optimum foraging theory proposed by MacArthur and Pianka (1966). In essence, animals are expected to minimize the energy expended and maximize the energy gained in foraging endeavors (MacArthur and Pianka, 1966). This theory was offered to address evolutionary arguments (MacArthur and Pianka, 1966; Westoby, 1978; Belovsky, 1984; Stephens and Krebs, 1986), and its utility lies in predicting the relative amounts of broad categories of foods that animals might consume over evolutionary time. Research has shown that livestock and wildlife frequently employ forage optimization strategies (Schoener, 1969; Charnov, 1976; Pyke *et al.*, 1977; Owen-Smith and Novellie, 1982; Black and Kenney, 1984; Belovsky and Slade, 1986; Putrnan *et al.*, 1987; Astrom *et al.*, 1990), but ruminants do not always optimize intake of any particular nutrient within a meal or even on a daily basis (Booth, 1985; Broom and Arnold, 1986). Optimum foraging theory lacks specificity in that exact diet composition can not be predicted for the short-run (Belovsky, 1986), so tests of foraging decisions by large grazers at relevant temporal and spatial scales have not yet been conducted (Laca *et al.*, 1994).

Because selective foraging often affects the character and composition of rangelands (McNaughton and Geordiadis, 1986;

Crawley, 1990; Brown and Stuth, 1993; Taylor *et al.*, 1993), a substantial body of research has focused on the causal mechanisms contributing to its development. On a broad scale, adaptive rumen function has arguably been proposed as a determinant of forages ruminants might consume. Small, simple stomachs may be adapted to digestion of rapidly assimilated foods, while large, complex stomachs might allow for retention and digestion of fibrous forages (Hoffman, 1968 and 1989; Spalinger *et al.*, 1993; Robbins *et al.*, 1995).

Ungulates, however select diets from arrays of forages furnishing many different kinds and concentrations of nutrients and toxins. Among young ungulates, the social influences of maternal and peer examples contribute greatly to the shaping of an animal's dietary selections (Provenza and Balph, 1987) and one's foraging skills and dexterity improve with age and experience (Flores *et al.*, 1989). Post-ingestive feedback mechanisms, through neural and chemical pathways, also figure prominently in the development of aversions to forages that have toxic effects or cause gastro-intestinal distress (Provenza, 1995). Some species of herbivores, however, can ingest toxic forages, because they've developed some means of neutralizing harmful compounds (Kronberg and Walker, 1993), or they select plants or plant parts that contain less of the toxic substance (Distel and Provenza, 1991; Schmitz *et al.*, 1992). Mechanisms stimulating the development of forage preferences in the absence of aversive compounds are less clearly understood (Provenza, 1995), and researchers or ecologists attempting to model selective foraging

must still rely on demonstrated preferences of animals to project how mixtures of forages might be utilized on the landscape (Hart and Hanson, 1990).

The heterogeneous patterns of distribution exhibited by various ungulates about the landscape have always been of interest to ecologists and resource managers. On a landscape basis, interactions of geology, climate, and elevation have contributed to the evolution of a diverse patchwork of vegetation types. Early observers noted that various ungulates elected to occupy only portions of the entire vegetation array, and proposed that these separations in space facilitated resource partitioning and reduced competition among the various users (Lamprey, 1963). In a given community, seasonal use and feeding at different heights above the ground can also contribute to resource partitioning (Lamprey, 1963) as well as the use of specific plant parts (i.e., leaf, stem, flower) by ungulates sharing a common forage in space or time (Gwynne and Bell, 1968; Bell, 1970). The hypothesis that the partitioning of forages is an evolutionary product of competitive interactions has not been clearly substantiated, however (McNaughton and Georgiadis, 1986).

One product of the heterogeneous distribution of herbivores about the landscape is an uneven pattern of herbage utilization. This is especially evident where large herds of roaming, wild ungulates occur, and it has been arguably demonstrated that with repeated use of specific areas, these animals maintain their forages in an earlier and more nutritious stage of phenology throughout the grazing season (McNaughton, 1984; Westoby, 1986). When grazed and ungrazed

environments are compared, nitrogen cycling rates and urease activities appear to be elevated where grazing occurs (Seagle and McNaughton, 1992; Frank and Evans, 1997; McNaughton *et al.*, 1997a and b). When rangeland condition is based on plant community proximity to climax conditions (Dyksterhuis, 1949), higher numbers of wildlife and a greater diversity of plants may be found on good condition rangelands than on excellent condition areas (Smith *et al.*, 1996).

In extensive rangeland settings, domestic ungulates also create grazed and ungrazed patches about the landscape. On many rangelands, intensively grazed areas may be associated with the presence of scarce but necessary resources (Stuth, 1991), and energy conservation dictates that animals center their activities about these areas (Coleman *et al.*, 1989). Examples include: water, shade, hiding cover or escape terrain, resting areas, and mineral licks. Ability or willingness to negotiate rugged terrain or steep slopes may also restrict ungulate activities to specific areas (Ganskopp and Vavra, 1987).

Even without these limitations, however, domestic stock frequently create grazed and ungrazed patches on the landscape and return repeatedly to these same areas to forage. A preponderance of evidence indicates that livestock prefer to use grasses where they are unimpeded by the previous growing season's reproductive stems (Dumont *et al.*, 1995), and cattle may be cognizant of even one senescent stem in a caespitose grass (Ganskopp *et al.*, 1993). There appear to be nutritional advantages to this selective behavior (Birrel, 1989; Ganskopp *et al.*,

1992) and, if given opportunity, livestock prefer to forage in areas without reproductive stems where they can maximize intake rate (Stobbs, 1973; Ruyle *et al.*, 1987; O'Reagain and Mentis, 1989; Arias *et al.*, 1990; O'Reagain, 1993; Flores *et al.*, 1993; Wallis de Vries and Daleboudt 1994). If excessive numbers of livestock use these areas for extended periods, however, forage health and the productive potential of the landscape can be harmed (Anonymous, 1936; Holechek *et al.*, 1995).

In recent years interest has developed in the processes that herbivores use to guide their spatial decisions and foraging activities. A general consensus has been that the more experience an animal has with a particular habitat and array of forages, the greater its ability to optimize grazing and other survival tactics (Senft, 1989; Stuth, 1991). This brings one to the question of whether or not ungulates can retain and exploit memory of their spatial environment. Some argue there is no strong evidence of cognitive mapping among any animals (Bennett, 1996), but we will not debate that issue here. It has been shown that horses can learn to navigate complex mazes (Marinier and Alexander, 1994) and associate colored cues with food. Sheep can associate food with different shaped objects (Espach *et al.*, 1993), and cattle can pair food with color/structural cues (Kidunda and Rittenhouse, 1992). Ungulates appear to enhance foraging efficiency by using memory to relocate patches of plentiful food and avoid areas with no rewards or where food has been consumed (Bailey *et al.*, 1989; Gillingham and Bunnell, 1989; Lynch *et al.*, 1992; Laca, 1998). Spatial memory may deteriorate after 8 to 12 hours,

however, and the animal may have to explore its environment to acquire new knowledge (Bailey *et al.*, 1989; Bailey *et al.*, 1996). At pasture, cattle appears to graze nearby areas on successive mornings and seldom graze the same area for more than two successive mornings (Bailey *et al.*, 1990). Most research in this arena, however, has involved highly controlled mazes or patch arrangements, and there is much to learn about decision making by ungulates at landscape scales.

Science and Technology

Advances in technology have greatly enhanced our abilities to describe and analyze many facets of ungulate behavior. Animals are always active and it is difficult to completely record the full array of postures, actions, and sounds that accompany their activities. Fortunately, as animal behavior is not random, we can approximate most activities by sampling (Lehner, 1992). The specific hypotheses to be tested helps us establish what relevant activities might be of interest (Lehner, 1987), and one can design of their experiments accordingly.

Earliest efforts at recording behavior typically involved pads and pencils to assemble arrays documenting the relative frequencies of various activities. Tasks can become challenging, however, if one is forced to navigate rugged terrain, observe, and write simultaneously. The advent of small clocks, counting devices, cameras, and portable sound recorders freed observers from the labors of writing, allowed them to watch their subjects continuously, or configure their instruments with trips or triggers so the animals recorded data themselves (Giles, 1971). Vibracorders (chart

recording motion detectors) were one of the first instruments to allow round-the-clock monitoring of timing and duration of foraging activities by free ranging ungulates (Allden, 1962). Inexpensive pedometers can also be used to quantify an animals travel habits (Anderson, 1986).

Early radio-telemetry equipment (Slater, 1963) was first used to define patterns of spatial use by wild or free-ranging animals. With the recent advances in electronics, one can now simultaneously monitor an animal's location, level of activity, and selected physiological variables (i.e., temperature, heart rate, breathing, etc.). Radio tracking equipment, however, remains prohibitively expensive, and it is typically employed as a last resort.

The advent of laptop computers has also greatly enhanced our data gathering and analysis capacities. Observations can be keypunched in real-time, and with proper programing, the sequential nature of the data remains intact, so one can examine the relationships and transitions among events (Demment and Greenwood, 1987; Ganskopp *et al.*, 1997). Computers may also be linked with video cameras and other monitoring equipment to simultaneously integrate behavior observations and information from large numbers of sensors (Laca *et al.*, 1992; Dado and Allen, 1993).

Many of the management problems involving grazing ungulates could be solved if we could stimulate the animals to seek out and exploit large areas of unused resources. A recent integration of computer and space-age technology is beginning to greatly expand our understanding of geo-spatial aspects of ungulate behavior at landscape levels of resolution. Presently, global

positioning systems (GPS units) are available that can rapidly and accurately (1-m resolution) pinpoint one's location on the earth's surface. An integration of GPS data with digitized maps via geographic information systems (GIS) software lets us analyze animal movements and the spatial relationships of habitat resources or characteristics with astounding accuracy and speed (Rutter *et al.*, 1997). The bottleneck in this technology is most likely the development of accurate maps depicting habitat characteristics that guide animal behavior. But in the coming years, GPS and GIS systems should help solve many of the distribution and resource problems associated with both wild and domestic ungulates.

Field Application of Research

The end product of grazing behavior research is an understanding of the variables that influence how an animal uses its environment, and how that knowledge can be incorporated at the landscape level to provide desirable management outcomes. In most current grazing programs, annual management plans do not consider such things as previous year's utilization patterns, current year's precipitation as it relates to forage production, or time of grazing entry in regard to plant phenological stage. Coughenour (1991) stated that ecosystem sustainability was influenced by interactions among animal movements and abundance, plant growth, plant response to grazing and the physical structure of the landscape. These and other factors individually and interactively determine the distribution and utilization patterns of grazing animals. Fixed stocking rates and fixed grazing rotations may lead to areas of overuse as well as

areas of non-use. Over time, ecological degradation of the overused areas can cause deterioration of the forage resource. In many situations management objectives have changed dramatically in recent years. Graziers were once concerned with maintaining sustainable levels of animal outputs from rangelands. Recent concerns for environmental integrity, including threatened and endangered species, watershed function, clean water, weed invasion and aesthetics, have broadened our view of sustainability (Vavra, 1996). Uneven grazing can exacerbate deteriorative processes. However, uneven grazing patterns may be required to maintain early or late seral habitat for different plant and animal species (Bailey *et al.*, 1996). Incorporating grazing behavioral aspects into grazing management plans gives us the opportunity to manipulate utilization patterns or diet selection to accomplish specific management goals.

Utilization is the percentage of the current year's herbage production that is consumed or otherwise destroyed by herbivory. Physical features such as distance to water, slope, and presence or absence of overstory influence the amount of forage consumed and hence, utilization of a given area of a pasture. Various aspects of grazing behavior can also influence utilization and provide implications for management.

In some grazing situations, when grasses are ungrazed in a given year, standing dead stems often persist, and livestock are less likely to graze those plants in subsequent seasons (Norton and Johnson, 1986). Ganskopp *et al.* (1992 and 1993) found that even low densities of cured seed stalks placed in current year's growth of a bunch-

grass greatly reduced the likelihood that the plant would be grazed by cattle. As seed stalk density increased, utilization levels of the grasses decreased when grazing occurred during late boot and anthesis stages of growth. Seed stalks had no influence when treated plants were grazed during quiescence. The landscape management implication is that where stocking rates are light or moderate, preferred grazing areas would receive the heaviest use. Grazed patches would develop and the absence of persistent cured stems the following year would insure that the patch would again be used. Ungrazed patches would be maintained due to the persistence of cured stems. Overgrazed, degraded areas could conceivably occur among ungrazed or lightly used areas. A year of above average forage production might cause grazed patch sizes to shrink and the area of unpalatable, wolfy vegetation to increase.

Gillen *et al.* (1984) reported that cattle in deferred rotation and continuous grazing systems utilized riparian meadows to 75%, while adjacent upland use was only 10%. Riparian areas are normally preferred by livestock and a greater level of use is to be expected. However, south slope grasslands were used the least of all upland communities in the deferred rotation system. Previously, Harris (1954) working on a similar mountain range, found that grasslands were preferred over other upland plant communities. The early entry in this system (Gillen *et al.*, 1984) resulted in only one per cent utilization on the grassland. In the absence of grazing, bunchgrasses that dominate this plant community commonly have previous years' vegetation persisting.

Cattle grazing the late entry pasture with deferred rotation management had the choice of mature, dry grassland forage, forested uplands that were still somewhat green, or the riparian meadows that were green. Late-entry utilization of the dry grassland forage was four per cent. Therefore a large portion of the grasslands was ungrazed with a late entry, and even more mature forage was carried over to the next year. On early entry, even though the grassland was green, the presence of old material made that community essentially cattle proof. Grazing behavior changes due to the presence of previous years' growth probably contributed to both the lack of use on the grasslands, particularly in the early entry; and the intense use noted on the meadows. Stobbs (1973) working with tropical pastures, found that the accumulation of stemmy and dead material was difficult to prevent. He went on to say that removal of the top hamper (of this material) can greatly increase the accessibility of new season's growth and thus improve animal production.

The previous scenario provides an extreme case of how grazing behavior can contribute to the success or failure of a grazing system. All too often managers do not consider the complexities of the environment (in this case, disparate plant communities) and the management system (uneven distribution and residual forage). Bailey *et al.* (1996) stated that distribution of free-grazing herbivores is a major issue facing animal and rangeland managers, and the common theme of this issue of animal distribution is the relationship to nutrient extraction. Uneven grazing often exacerbates ecosystem deterioration processes.

Conversely, Bailey *et al.* (1996) also stated that the same uneven grazing distribution is required to maintain early and late-seral habitat for various species. This should include both animals and plants. We would add that structure of the vegetation, e.g., height of grass, as well as seral stage is important to some species. Sage grouse, for example need tall grass in association with sage brush to provide cover for nesting and brooding. The mountain plover, on the other hand, only nests where there is heavy grazing (Graul, 1975). Some species need areas of undisturbed vegetation for cover and must have disturbed areas supporting early seral forbs for forage close by.

Distribution of livestock across a landscape is influenced by several factors (Coughenour, 1991; Bailey *et al.*, 1996). In this discussion, we focus specifically on foraging behavior aspects. Disturbance is a natural component of all ecosystems and grazing provides a tool to promote areas of varying disturbance across a landscape. This disturbance may be expressed as changes in plant species composition due to decreased vigor or altered competitive ability of the grazed plants.

Severson and Urness (1994) describe four methods that exploit livestock foraging behavior, to manipulate vegetation, modify wildlife habitat, or enhance forage for another species of livestock or for later use by the same animals. Grazing can alter the composition of vegetation, increase the yield of selected species, increase the nutrient quality of forage or increase the diversity of the habitat by altering the structure of the vegetation.

On ranges that contain shrub and grass components where palatable shrub enhancement is a goal, cattle or horses can be grazed, because of their preference for grasses, to effectively reduce vigor of grasses. Grazing should be applied early in the grazing season, when grasses are green and highly palatable, to minimize the possibility of shrub consumption. Grazing in this fashion can increase the stature of bitterbrush (Ganskopp *et al.*, 1999), as well as produce conditions favorable for the establishment of new bitterbrush plants (Neal, 1982). Gambel oak is a shrub that exists as clones that thicken with age. Other shrubs, forbs and grasses are consequently reduced. Grazing by Spanish goats can effectively manipulate oak communities to increase production of other shrubs and to interrupt the trajectory of oak succession (Riggs and Urness, 1989; Urness, 1990). Both above examples depend on having animals that forage on specific components of the plant community.

When dietary overlap is significant among co-occurring species, systems can still be utilized that will effectively increase nutritional value and accessibility to forage (Vavra and Sheehy, 1996). Livestock grazing in late-spring or early-summer during the boot-stage of grasses has proven effective (Anderson and Scherzinger, 1975) if soil moisture is sufficient to allow regrowth after livestock exit. Studies investigating various forage conditioning hypotheses have not been conclusive (Pitt, 1986; Wambolt *et al.*, 1997). However, most studies have only reported values of crude protein for the standing crop and they do not reflect the actual diets of the animals that selectively harvest only certain

plants. Also, diet quality content data should be based on the total amount consumed by the target herbivore over the wintering period since small differences in nutrient content can have important implications across seasons.

Increasing diversity of habitat by altering its structure occurs when herbivores create patches. Bobwhite quail can benefit from small overgrazed areas for feeding sites interspersed with ungrazed areas for cover (Guthery, 1986). Glenn *et al.* (1992) found that grazing animals tended to promote among-site heterogeneity of vegetation, especially when coupled with periodic fire.

An emerging area of interest in foraging behavior is in the use of livestock as weed control agents. Cattle, sheep and goats are being used on range and cropland around the globe (Popay and Field, 1991). Grazers can influence weeds directly by eating or damaging them, and indirectly by conditioning the pasture and making it more competitive and resistant to subsequent weed invasion (Popay and Field, 1991). These authors went on to cite diverse examples from United States rangelands to smallholder farms in Asia. The use of animals as control agents often requires conditioning of the animals to be weed eaters (Walker *et al.*, 1992). Also, success of a weed control program requires using the right species of animal. Walker *et al.* (1994) reported that goats were more effective than sheep in controlling leafy spurge (*Euphorbia esula*). *Long term sheep grazing in Britain causes an increase of Bracken (Pteridium)*. The introduction of cattle into sheep pastures has been suggested as a control agent (Popay and Field, 1991). Likewise, tansy ragwort (*Senecio jacobea*) in-

creases in cattle grazed pasture, and the introduction of sheep can assist in control (Sharrow and Mosher, 1982). There appears to be a global concern over the use of herbicides, so research focused on control of weeds and poisonous plants with grazing animals is an important endeavor.

In most cases, grazing livestock are maintained for one purpose, to provide return (food and/or economic) to the owner. However, in the future, the objective of grazing management may place greater emphasis on manipulation of plant communities (Walker 1995). Therefore, continued research on the application of grazing behavior to management at the landscape level will remain critical.

Future Challenges

The primary challenge to managers of the world's rangelands is to develop grazing systems that are environmentally sound. Walker (1995) predicted that there will be greater emphasis on plant community manipulation with grazing animals, but that maximization of long term economic return will still be necessary. This fits the definition of sustainability discussed by Vavra (1996). Sustainable systems are those that blend what people collectively want, reflecting social and economic concerns, and what is ecologically possible in the long term (Borman *et al.*, 1994). Adequate references exist that describe the detrimental effects of excessive livestock grazing (Durning and Brough, 1991; Fleischner, 1994). Grazing behavior of livestock has long been recognized as one of the major problems associated with rangeland degradation (Hormay, 1956). The challenge then, to managers

and researchers, is to exploit or manipulate grazing behavior for positive results.

In a previous section we discussed the field application of research. In the specific applications mentioned, we are really in the infancy of development. Manipulation of plant communities to enhance wildlife habitat (Severson and Urness, 1994) and weed control (Popay and Field, 1991) are two areas of current emphasis and definite future need. In the former case, Severson and Urness (1994) stated that present knowledge is quite meager, and in the latter, Walker (1995) found that grazing was not yet fully appreciated.

Severson and Urness (1994) describe a problem common to many rangeland situations. Long term grazing by one species of ungulate usually leads to decreased competitive ability of the forage species commonly consumed by that ungulate. Introduction of a carefully timed grazing event with another ungulate of dissimilar food habits affects previously ungrazed plants. The competitive playing field is thus leveled. Sheep are generally recognized as having food habits different from cattle (Vavra and Sneva, 1978; O'Reagain and Grau, 1995). In some cases, sheep can be used to control plants poisonous to cattle. Ralphs and Olsen (1992) used sheep to control larkspur (*Delphinium* sp.), and cited other examples of similar practices. The management practices described by Severson and Urness (1994) have application to multi-species grazing for both domestic and wild ungulates as well as different species of domestic ungulates. Abaye *et al.* (1993) grazed sheep and cattle together and reported that mixed grazing should

increase daily gain, total gain, and weaning weights of lambs and allow target weights of lambs to be reached earlier in the grazing season. Is multi-species grazing ecologically and/or economically more efficient?

Hormay (1956) recognized selective grazing and distribution on rangelands as two of the most important factors in developing successful grazing systems. Work by Roath and Krueger (1982) revealed that cattle on rangeland maintained home ranges and that home ranges persisted from year to year. Can livestock producers cull or select specific animals to address livestock distribution problems?

Not only are animals selective in where they graze, but also in what they graze. Hanley (1982) described how different species of ungulates, because of differences in such things as body size and body mass to rumen volume ratio, developed disparate food habits. Provenza and Balph (1987) provide a review of dietary choice in livestock. The authors concluded that we are not yet able to outline specific diet management plans nor can we maximize or optimize food preferences or avoidances. Walker (1995) suggested that livestock might be genetically manipulated to select diets that are most appropriate for the environment. Can animals be selected, genetically altered or trained to develop dietary choices different from their traditional patterns (Hanley, 1982)?

Given control over grazing behavior, innumerable management opportunities with ungulates exist. Landscapes could be "designed" with grazing. Maximization of such values as biodiversity is possible, or livestock could be used to manage fine

fuel levels for prescription burning programs. Also, we should not forget the livestock producer. Manipulation of dietary choices may allow animals to select higher quality diets, avoid toxic plants, and improve performance. Given the current trends in environmental awareness, numbers of domestic stock will probably not increase greatly on our rangelands. With increased manipulation of gazing behavior, however, we should be able to improve livestock production and enhance the environment as well.

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