APPENDIX M

Range Science – What Are Your Roots?

A Treatise Focusing on the Theories of Forage Utilization

Dave Grider[1]

The "Rule of Thumb" Theory

Rangeland plants evolved 20 million years ago with early herbivores that are now extinct (Manske 2004). About 175 years ago, non-native grazers were introduced onto vast ranges of "wilderness" America. Although the domestic livestock were newcomers to the scene, these lands already had a long history of grazing (Burkhardt 1996). What this paper attempts to do, at a juncture in this long history, is to establish the chronology for the evolution of range science. Particular emphasis is placed on the science behind the determination of how much forage use can be made without damage to the grazed plants.

Early frontiersmen were, for the most part, sturdy, experienced, and practical men -- explorers, trappers, traders-who viewed the countryside with an eye to its ability to supply their immediate needs, and with regard to its potentialities for settlement. A great many of them had reason to give close attention to the forage resource: either directly as a source of feed for the animals which transported and fed them; or indirectly, as a possible means of livelihood through grazing of livestock. Most pioneer range men had only one desired outcome from livestock grazing, and that was profitable production of food and fiber. There was little, if any, awareness of the role livestock play in maintaining the integrity of ecological systems.

Obviously, since there truly was no "body" of scientific knowledge from which these early westerners could tap a set of concepts or ideas that are consistent with how natural processes work, they knew nothing about formal "range science" and little about the effects of livestock grazing on plants. They relied upon their own observations and experience to judge their ranges. The rule-of-thumb guesses of the early range mangers had no basis rooted in tests, experiments, and intensive analysis of the resulting data. But their anecdotal guesses became practices, "tried and true" over time. This paper focuses on the anecdotal philosophy to "take half and leave half" and whether it is supported by any scientific evidence as to its effectiveness. This "rule of thumb" is widely recognized and has been addressed by many authors in the sense of practical grazing philosophy. Because of this extensive application and review, the secondary question becomes, "If the theory was at one time subjected to peer review and published in an accredited scientific journal, haven't better theories with popular acceptance now been proposed?"

This question comes 175 years after the advent of grazing by domestic livestock in the Western United States. Actual studies and experiments, documenting the effects of grazing, didn't occur until after the turn of the 20th century, but, since then there have been nearly 100 years of scientific replication of major concepts and theories, mathematical calculations, and data measurements. The 20th century saw the complete developmental era of the evolution of range management and range science.

In grazing regulation, the United States Forest Service came first. It became a pioneer and leader in the development of management techniques for all types of range stock. Its research efforts sought knowledge about the condition of the range, optimum grazing capacities, and the impact of grazing upon the forest resources. Science makes the Forest Service unique. The ability to conduct scientific research

[1] Author is with the United States Forest Service, Dixie National Forest, Cedar City, UT 84720

in-house, to apply research findings on the National Forest System lands, and to transfer them to others for use on all the nation's forest lands sets the Forest Service apart as natural resource agency. Over the last century, the Forest Service has initiated numerous, innovative products and procedures, as well as led the country and the whole world in scientific forestry matters. The Forest Service now operates 222 research and experimental forests. Long-term records on many of these experiment stations date back to the 1930's when the majority of them were established. The oldest records date back to 1911 (Priest River Experimental Forest in Idaho) and 1912 (Great Basin Experimental Range in Utah).

So…."What is the science behind today's grazing utilization standards?" Most rangeland plants, especially grasses, have evolved and adapted to tolerate grazing by some animal species. Research has shown that most forage plants can tolerate the removal of some percentage of the yearly production of leaves, stems, and or twigs without ill effects. Still, the question ever-present before the range manager and stockman is "How much can the range be grazed without permanent damage to the good forage plants?"

We know more today than we did 100 years ago and we'll know even more 100 years from now. Our answer to the question, "How much grazing can occur without damaging key forage plants?" is compatible with all the evidence we have, and we hope that our ideas will survive the tests of the future. However, as the mysteries and complexities of rangeland communities are continually discovered, we also realize that new evidence will provide continual review and lead to at least somewhat different interpretations.

So what does all this mean? It means that science does not presently, and probably never can, give statements of absolute eternal truth - it only provides theories. We know that those theories will probably be refined in the future, and some of them may even be discarded in favor of theories that make more sense in light of data generated by future scientists. However, our age-old theory, "take half and leave half"—in all its simplicity—is still the best layman explanation of how grazing of forage plants should occur.[2]

Historical Exploitive Grazing

Proper use and management of our nation's natural resources has been a challenge since European settlement of this country began. Columbus brought cattle to this continent in 1521. He dropped them off in ports where he stopped, to ensure there would be something for future expeditions to eat when they got there. Over time, these scraggly cattle evolved into what are known as Texas Longhorn, or Longhorn cattle. They are the only cattle recognized as a breed, which were not manipulated by man.

As late as the eighteenth century, government policies focused on settling the West. This was an all out effort to settle and "reclaim" the nearly 1.8 billion acres of original public domain. Hundreds of laws were

[2] With over a 100 years of studying and testing rangeland management theories, as can be expected, the results have generated many diverging theories, each with its own depth of complexities. What used to be, seemingly, a simple question, now evokes tangential dissertations steeped in a wealth of science. This paper does not attempt to diverge away from simply addressing "is there science to support the 'take half-leave half' theory?". It does not discuss how monitoring or measurements should be done. Currently there is much debate about the value of stubble height monitoring versus utilization measurement. This paper does not make an evaluation. There has been, and still are, issues about utilization not intended to be applied to any one year alone, but that its intent for management purposes is to be an average over several years. This paper does not discuss how utilization criteria are to be applied. Research has shown that greater or lesser use levels can be applied through various grazing systems. No evaluation of that is made here. It is widely recognized that there are three significant elements of grazing that must be addressed to determine appropriate stocking: intensity, frequency, and timing. This paper only deals with intensity of use, specifically the "take half-leave half" rule of thumb.

passed between 1785 and 1878 that were designed to encourage settlement and development of the public domain's vast timber, mineral and forage supplies. Generally, this movement to the West was made with little thought or concern for the health of natural resources. Vast holdings of public lands were converted to private ownership and became headquarters for many western ranches. Free forage on unclaimed public domain lands allowed the building of cattle and sheep empires. The western range livestock industry came into prominence in the decades after the Civil War because capitalization costs were minimal: a ranch headquarters, a few cowboys, and a number of horses. Often, early ranchers had little more than a dugout for shelter and a corral for their horses, for when the adjacent range was eaten off, they simply moved their herds and headquarters to a new location. The animals were left to fend for themselves and were only rounded up for branding and marketing.

Cattle ranching was based on a transplanted Mexican culture that included no fences, corrals, or supplemental feed. With no gauge of how forages could stand up, speculation ran wild. Grazing lands were stocked far beyond their sustainable capacity and as numbers continued to increase, bad weather and human errors worked to bring disaster. The bust came when weakened forage combined with overstocking, blizzards, and drought. Cattle died in great numbers. The boom/ bust phenomena of the 1880's and 1890's characterized the cattle industry, though the situation was aggravated by increased numbers of sheep and the new practice of fencing the range. When disaster struck, cattle couldn't freely roam to avoid storms and search for food.

Other ranchers also allowed their herds to graze freely on the federal lands, but moved their cattle between summer and winter ranges. Cattlemen with Midwestern traditions ranged their cattle on the federal lands during the summer, and before winter, moved their herds close to the home ranch where they could be fed hay. After the harsh winters that occurred between 1886 and 1890, this became the predominate method of ranching in the West. Financed by speculators who were attracted to the impressive profits of the large range outfit, which had minimal capital outlay and a seemingly unlimited supply of free forage on the federal lands, livestock herds grew rapidly on the public rangelands and they were severely overcrowded and depleted by the late 1800's. As the turn of the century neared, forests were cleared, rivers and streams were dredged and dammed and public rangelands were broadly degraded.

Much of the cattle came from Texas, in the form of the Texas Longhorn. The quality of the Longhorn stock was poor, but the cattle proved to be prolific. Left to fend for themselves in the wild, Longhorn numbers skyrocketed. In 1830, it was estimated that there was 100,000 head of cattle in Texas. By 1860, an estimated 3.5 million head roamed the Texas rangelands. It was during the late 1830's that cowboys started herding the wild cattle to other states to be sold. Perhaps the best description of cattle ranching in the West was J. Frank Dobie's remark that, "after the Civil War all it took to become a cattleman in Texas was a rope, the nerve to use it, and a branding iron" (Jones 1996).

During the 100 years following the Civil War, U.S. rangelands were used almost exclusively for livestock grazing. During the 1880's the number of cattle in the 17 western states proliferated almost six-fold from 4.5 million head to nearly 27 million head. At the same time, the number of domestic sheep was also multiplying—from less than one million head in 1850 to 20 million head by 1890 (Mitchell 2000). Buildup of livestock and privatization of the fertile, watered areas occurred, accompanied by lack of regulated grazing management in federal rangelands and forests. Mistakes in grazing practices occurred. The most significant being the exploitive grazing practiced between 1865 and the 1930's. The results of several decades of grazing the western ranges with too many animals for too long and often at the wrong season each year were nearly catastrophic. Most range livestock operators at that time were unaware of the limits of grazing pressure that the vegetation and soil could tolerate. No grazing regulations on federal lands existed until the Forest Reserves were formed. (Krueger et. al. 2002).

1860 to 1900 was a time of exploitation of the nation's natural resources. The public was slow to become aware that these resources were not inexhaustible. Timber and water were the first resources to arouse the largely Eastern public's attention. "Cut and get out" timber barons were stripping the forests of the East. Timber cutting was visually obvious, unlike the insidious loss of forage production. Eventually a public cry to stop abuses to the forests resulted in passage of the Forest Reserve Act of 1891. Whatever benefits came to forage through these conservation efforts did so largely as a by-product of action intended to prevent forest destruction.

Scientific management of rangeland began at the turn of the century, but the accumulation of knowledge and its application advanced slowly. The management aim was to adjust the number, kind, and location of the grazing in such a way as to restore and maintain the natural resources. Range managers and livestock operators found that controlling grazing improved both range condition and livestock production. Development of this new concept marked the end of the exploitive period of grazing and the beginning of managed grazing on the Western ranges.

Early Assessments

President Abraham Lincoln knew when he founded the U.S. Department of Agriculture, in 1862, that it was wise to have stewards for the vast and wild lands. He called it the "people's department" (Jones 1996). Their motto from the beginning, and to this day, is "caring for the land and serving people". One of the ways it serves the people, is by monitoring and assessing the impacts of livestock grazing on federal lands.

Range deterioration was first documented in the late 1800's and early 1900's, about the time of establishment of the national forests. The need for systematic methods of rangeland assessment first became apparent when Jared Smith was sent by the U.S. Botanical Survey in 1895 to study the causes of the deterioration of western rangelands that had been widely reported in the late 1880s. The U.S. Forest Service, which was formed in 1905, recognized the need to develop a scientifically credible and economically feasible method of surveying rangelands to carry out its mandate. Beginning in the early 1900s, experiment stations were developed to help livestock owners understand the deterioration of grazing lands and to learn how to use those lands sustainably. Grazing lands research became a part of the mission at federal experiment stations in the United States throughout the twentieth century. These first assessments were used to determine the suitability of western lands for grazing. Most rangeland monitoring techniques used today are based on one or more of the models developed during the first half of the 20th century. (Rowley 1985)

> "The first recorded surveys of U.S. rangelands are fragmentary comments from the letters and journals of explorers, trappers, members of military expeditions, and missionaries. They are based on visual observations of what were, to them, vast and foreign landscapes. Early military and exploratory expeditions and the medical and scientific plant collectors who accompanied them provided much information about western U.S. rangelands (Chapline and Campbell 1944). Although few of these people described the vegetation or the grazing resource sufficiently for a credible analysis of the soft and plant conditions prior to settlement by Europeans, their records served to entice additional surveys." (Buckhouse et. al. 1994).

> "In the late 1800s, the dramatic expansion of the livestock industry combined with equally dramatic droughts, and severe winters led to widespread degradation of rangelands. In 1895, letters from individuals about the declining range conditions in Texas were sent to USDA, and plans were made for an experiment station in Abilene, Texas. The Division of Agrostology within USDA was created in 1895 to investigate grass, forage, and range management (Wasser, 1977). Although it lasted for only 6 years, this division published a number of reports on the forage conditions and grazing problems of the western United States (Chapline and Campbell, 1944). These surveys were localized descriptions of rangeland vegetation and management." (Buckhouse et. al. 1994)

> "In 1891, the U.S. Congress authorized the President to set aside national forests from the unreserved public domain. This act was the first step in closing America's vast open land frontier. This act also marked a change in the kind of information the government needed about these lands—it shifted from landholding to land management information. The management direction of these forest reserves was not officially set until 1897, when Congress decreed that national forests were established to "improve and protect the forest ... or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber." In 1901, USDA developed principles to regulate grazing within U.S. forest reserves. Grazing was allowed "where it is shown after careful examination, that grazing is in no way injurious to or preventive of the conservation of the water supply" (Rowley, 1985:40).
>
> "In 1905, a letter from the secretary of USDA to the director of the newly created U.S. Forest Service indicated that the rangelands were to be appraised as to their carrying capacity—that is, the maximum limit of livestock numbers that could be grazed on that land—to divide the land and set limits for grazing permits. This need for information to determine grazing capacity led Jardine and others to develop methods of surveying forest reserves." (Rowley, 1985).

The Evolution of Range Management Science

By the time forest reserves were proclaimed, ranchers had become accustomed to unregulated use of forest lands for summer range. At the turn of the century, there were so many livestock grazing the public lands that severe deterioration of the health of western rangelands and grazed forests occurred. There was really not much regulation of grazing activity until 1905 when Congress transferred the forest reserves from the Secretary of the Interior to the Secretary of Agriculture and established the Forest Service. The Forest Service soon became the pioneer grazing control agency and by 1906 to 1907 had established a system of range regulation.

William D. Rowley in his book U.S. Forest Service Grazing and Rangelands—A History, recorded that "Rational use and management of range resources by a government agency required a detailed knowledge of the rangelands. Although stockmen had long relied upon their own observations and experience to judge their ranges, professional managers needed more than a stockman's advice. The rule-of-thumb guesses of the early range mangers had to be replaced by knowledge rooted in tests, experiments, and intensive analysis of the resulting data. The Forest Service needed a research arm to fulfill Pinchot's boast that it could competently manage and protect all of the forest resources." (Rowley, 1985).

> "The objective of range research was the application of scientific principles to rectify range problems. In 1907, the Forest Service in cooperation with Frederick V. Coville, a botanist with the Bureau of Plant Industry, began a basic study of sheep grazing on the ranges. Grazing capacity studies relating to particular range types were begun in northeastern Oregon in the Wallowa Whitman National Forest by Coville and James T. Jardine. Studies of ecological processes, also in the Wallowa National Forest, in plant communities and the impact of grazing on plant species occurred under the direction of Arthur W. Sampson. In 1910, to coordinate and promote range research and the collection and use of technical range management information, the Forest service established the Office of Grazing Studies, naming Jardine as its director. Once in office, Jardine launched a grazing "reconnaissance" of specific forest ranges. In later years, this job was called "range survey" or "range resource inventory". Ultimately, the survey hoped to find a simple, reliable method for empirically (visually) rating the condition of the range and also for determining whether the range was improving or deteriorating." (Rowley, 1985).
>
> "At the same time that Jardine was developing his method for evaluating rangelands, ecologists were developing theories of community dynamics (how plant communities develop and change) that would provide the foundation for new methods for evaluating rangelands. F. E. Clements of the University of Nebraska, Lincoln, was extremely influential in the study of succession in the Great Plains grasslands. His numerous publications on plant succession and ecology formed a major source of information for resource managers. The textbook Plant Ecology, which Clements wrote with his colleague J. E. Weaver (Weaver and Clements, 1938), became a standard in the field. Students from the "Nebraska school of ecology" such as E W. Albertson, E. J. Dyksterhuis, A. W. Sampson, and L. A. Stoddart became leaders in the young science of rangeland management and brought the Clementsian model of community change into the new field. The Clementsian model dominated much of the early literature in the field. Clements developed a theory of vegetation dynamics and a quantitative method to test his theory. To Clements, the

climax theory rested on the assumption that vegetation could be classified into formations that represented a group of plant species that acted together as if they were a single organism. He wrote, "As an organism, the formation arises, grows, matures, and dies.... each climax formation is able to reproduce itself, repeating with essential fidelity the stages of its development" (Clements, 1916:3). Clements developed the quadrat method of quantitative study of plant associations that the Forest Service later adopted as a factor in its research. Clements was the first American credited with giving systematic form to the phenomenon of "dynamic ecology" or succession in plant associations." (Buckhouse et.al. 1994)

"One of Clement's most productive students was Arthur W. Sampson. In 1912, Jardine, Coville, and Sampson helped organize the first experiment station (first called the Utah Experiment Station and later the Great Basin Experiment Station) devoted mainly to range research on the Manti Forest near Ephraim, Utah. Sampson remained there as director of the Experiment station until 1922. His work, Range and Pasture Management (1923), was the finest comprehensive textbook in the field and won him the reputation of "father of range science". In articles written in 1917 and 1919, Sampson related the idea of plant succession to effective range management. Sampson believed that progressive development (revegetation) "may be greatly expedited by cropping the herbage in such a manner as to interfere as little as possible with the life history and growth requirements peculiar to the different successional states." A working knowledge of plant associations could assist in judging what was overgrazing or undergrazing. Grazed animals could then be moved safely toward maximum carrying capacity and "the herbage cropped on the basis of sustained yield". Cropping the herbage should be done in a manner that would not interfere with the maintenance of a desired successional stage." (Rowley, 1985)

The concept of successional change in rangeland ecosystems was to become the fundamental basis of the methods used today to inventory and classify rangelands. "Rangelands would be classified on the basis of differences in climax plant community composition and assessed on the basis of the divergence of the current plant composition from the climax plant community composition." (Buckhouse et. al. 1994).

In 1917 Sampson provided what was perhaps the first published reference on the utility of successional stages in rangeland assessment. Then, in 1923, Sampson wrote about the need to move from the old method of determining grazing capacity, which used palatability factors and visual estimates of forage composition, to a new method based on observation of the succession of conspicuous vegetation, that is, the replacement of one set or type of plants by another (Sampson, 1923). Sampson noted that the use of successional units to develop a rational grazing plan presumed a detailed knowledge of the successional stages in the development of the vegetation (Sampson, 1923). To obtain this information, he recommended the use of quadrats. However, the great amount of tedious work involved in the mapping and the subsequent synthesis of the data led Sampson to recommend that the person working in the field record the percent cover of all plants of each species within each of the 100 cells that divided the chart quadrat rather than mark the specific location of each plant within each cell. This cover estimate was then multiplied by the palatability of the cover to determine forage yield. Sampson's work was instrumental in bringing successional theory and practical grazing management together.

"Sampson's ideas spawned much research into using successional stages as indicators of the status of rangelands. A number of rangeland scientists experimented with methods that could be used to determine the relationship of successional stages to rangeland condition. In 1949, E. J. Dyksterhuis published a landmark paper that was to solidify the contribution of successional theory to the assessment of rangelands. Dyksterhuis refined the climatic climax community described by Clements (1916), proposing that different climaxes coexist as a function of soil or topographic or geographic differences within a similar climate. Dyksterhuis defined those areas that support a unique climax community as a range site. Each site—defined by its climax plant community, soil, and climatic environment—would support a characteristic assemblage of plants, and this vegetation would persist unless it was disturbed by grazing, fire, drought, or other factors. Vegetation would develop toward this climax plant community through successional processes once disturbances (wind, drought, fire) ceased. Grazing drove the plant composition toward the early stages of succession, whereas natural successional processes drove plant composition toward a climax community. By adjusting the grazing pressure or the duration or season of use, rangeland managers could maintain rangelands at any stage of succession." (Buckhouse et. al. 1994).

"Dyksterhuis proposed a quantitative system for assessing whether a rangeland was at an early or late stage of succession by analyzing the behaviors of three classes of plant species: decreasers, increasers, and invaders. As

livestock grazing drove the plant composition toward earlier stages of succession, certain plants were thought to decrease in abundance. These decreasers were replaced by other plants that initially increased in abundance. Those increaser plants were thought to decrease in number and abundance if grazing pushed the plant composition to even earlier stages of succession. The plants that replaced the increasers were called invaders. The successional stage that the rangeland was in could then be determined by what proportion of the vegetation, measured by percent composition by weight, was decreasers, increasers, or invaders. If most of the plants were decreasers, the rangeland was thought to be in a late successional stage; if most plants were invaders, the rangeland was considered to be in a very early stage of succession." (Buckhouse et. al. 1994).

"Dyksterhuis's use of successional stages as the measure of the condition of rangelands had great appeal. His concept not only proposed a systematic way of evaluating the condition of rangelands but also explained the effects of grazing on rangeland vegetation and provided the basis for changes in grazing management. Estimations of livestock carrying capacity were linked to range sites, condition classes, and successional stages. By 1950, the measurement of range condition as the degree of departure from climax plant community vegetation of a defined range site and the succession-retrogression model of rangeland development became the standard concept in U.S. rangeland management. All major inventory and classification methods in use today are modifications of that basic concept. The concept was adopted to varying degrees by the USFS, BLM, and SCS, the agencies with the most responsibility for rangeland management in the United States. Changes in terminology and interpretation since 1950 have resulted in divergences between the site classification definitions and the rangeland inventory methods used by the different agencies." New developments in ecological research have had an influence on specialization and research within the field of range science, but this influence on the diversity of range science research has not yet been transferred to a diversification of the measures used to inventory and monitor rangeland. The fundamental concepts underlying the rangeland classification and inventory methods of all of the federal agencies are based on those proposed by Sampson, Clements, and Dyksterhuis in the first half of the twentieth century." (Buckhouse, 1994)

Grazing Capacity Studies and Determination of Grazing Use

The Forest Service enthusiastically accepted the full administration of the forest reserves in the spring of 1905. Four days after the transfer, the secretary of agriculture informed Chief Forester Gifford Pinchot that the General Land Office had already set in motion a permit-grazing system for the 1905 season. Rangelands were to be appraised and divided according to their capacity and the type of stock to be grazed on them. The range's "carrying capacity", that is, the stock numbers that could be allowed would be determined. The rule-of-thumb guesses of the early range managers had to be replaced by knowledge rooted in tests, experiments, and intensive analysis of the resulting data (Rowley, 1985)

Jardine. The earliest rangeland inventory was made by James L. Jardine on the Coconino National Forest in 1911 in response to a question regarding the livestock carrying capacity of the rangeland. Jardine's range reconnaissance method involved a careful visual examination of the rangeland to provide a written record of the rangeland's resources. On the basis of this reconnaissance data, grazing management plans were written and periodically adjusted for discrepancies. Methodologies for inventorying rangelands have varied since then, but they have primarily focused on the vegetation within allotments (Buckhouse, et. al. 1994).

Clements. In 1916, Frederick E. Clements conceived of the community as a sort of superorganism whose member species were tightly bound together both now and in their common evolutionary history. Clements' theories on communities were also linked to succession. He suggested that a community of plants passed through a cycle of development similar to that of the life of the plant itself. He taught that at the end of a plant's growth cycle, it died just as a vegetational community in a climax condition died out and was replaced by another life form. Clements was the first to designate as the biome, "an organized unit comprising all the species of plants and animals at home in a particular habitat." Clements is considered as one of the "fathers" of ecology and these principles guided the performance of early research experiments. Clements taught that by counting the various species of grasses and forbs in sample plots, an estimate could be made of the vegetal composition and the value of its edible plants for

grazing. Through an analysis of species composition, an understanding of the seral stage in the successional process could be determined. He suggested that strictly from the viewpoint of range science, the amount of grazing that could be allowed should be gauged according to the availability of forage provided by a particular successional stage of vegetation. (Buckhouse et. al. 1994).

Standing. In 1933, Standing introduced the concept of using measured volumes of vegetation rather than visual estimates of cover. "During the 1930s, other modifications were made to the Jardine method, and these were finally standardized as the interagency range survey technique used by the Bureau of Land Management (BLM) and USFS. Although more quantitative than the original reconnaissance method, the interagency survey depended heavily on palatability factors and other subjective criteria for estimating forage production or carrying capacity. This method assessed, almost exclusively, forage production and livestock carrying capacity. Few if any data were collected on soil conditions, wind and water erosion, or other factors that would allow a more comprehensive evaluation of rangelands. More important, the method was not linked to any theoretical base that suggested how the forage composition data that were collected could be interpreted as indicators of ecological conditions on rangelands. Forage production, rather than the state of rangeland ecosystems, was evaluated. (Buckhouse et. al. 1994)

Parker. In 1948, the research arm of the Forest service quietly initiated a study to obtain a method of demonstrating the condition and direction or trend in which the vegetation of a range was moving. The investigative task fell to Range Conservationist Kenneth W. Parker. Parker's method involved three steps: 1) measurement of the essential features of vegetation and soil, 2) classification of these data as to condition of vegetation and soil and estimation of current trend in condition, and 3) general and close-up photographs from permanently located photo points. In 1952, this three-step method was adopted for general use on western national forest ranges. Within the regions and forests where it was implemented, the method became known as the Parker Three-Step method. The method involved establishing permanently marked transects and the collection of samples along these transects from which could be measured forage, type, and species. Comparisons of data taken over a period of years obtained in the three steps could yield an understanding of range condition and trend. (Rowley, 1985)

In 1960, responding to allegations that Forest Service range analysis procedures were impractical and unreliable, Chief Forester Richard E. McCardle pointed out that the range survey procedures had been developed from fifty years of research and practical range experience by the agency and its personnel. The Service emphatically believed that its range analysis method was sound, was adequately applied, and offered a realistic evaluation of range and watershed conditions on national forest system lands. Range analysis, it maintained, was designed, among other things, to determine the grazing capacity of that portion of an allotment that can be used by domestic animals over a long period of time under an attainable system of management. Range analysis was further divided into five areas of investigation, including grazing capacity. The goal of this feature of range analysis was to achieve "indicated grazing capacity". Ideally this is the amount of use in animal unit days or months obtained at the time proper use is achieved. (Rowley, 1985)

The Parker Three-Step method was incorporated in the 1964 Range Analysis Handbook as the recognized Forest Service method for determining long-term trend. The range analysis procedure embodied the following steps: 1) Determine basic ecology, 2) mapping, 3) Determine tentative grazing capacity, 4) Determine trend, and 5) Develop environmental analysis reports and allotment management plans. Determining tentative grazing capacity was based on production and proper use of the forage on the primary range. (USDA Forest Service, 1964)

The Development of Grazing Guidelines

European settlement brought with it the sedentary grazing of the plains and foothills by domestic stock. First, during the brief period of open range grazing in the late 1800's, and later through the early ranching system with pasture units undefined by barbed wire fences. Guidelines for western ranchers were non-existent. Range science and the current philosophy of range management emerged as generations of ranchers observed natural processes and the impacts of their grazing animals, and learned from trial and error.

With regulated grazing, two highly significant guidelines (rules-of-thumb) for forage utilization and range readiness were developed: The rule of thumb for range utilization was "take half and leave half"; the rule-of-thumb for range readiness was to allow six to eight inches of new growth on bunch grasses before grazing (McGinnies, Parker, and Glendening 1941). By applying these rules, a gradual improvement in range condition took place through the first half of the 20th century.

The old theory of "take half-leave half" is based on the physiological needs of the plant. If more than 50% of the current year's production is removed, then root growth stops. Early range investigations (Sampson 1923) showed that not all available material could be harvested annually if the plant was to be maintained. Stoddart and Smith (1943) indicated that by weight volume, a consistent use of over 40-50 percent of the total annual production probably would deplete most plants. In 1941, McGinnies, Parker, and Glendening cited a 1939 study by David Costello (reference unavailable) that determined that removal of leafage is closely correlated with root development, and any abrupt decrease in the amount of synthetic activity of leaves, as occurs with grazing, causes a corresponding slow down in root growth. They also referred to a 1938 study done by Edward McCarty that determined that a reduction in tops results in decreased storage of carbohydrate reserves in the roots. Although they didn't quantify the amount, McGinnies et al. concluded:

> *"The direct influence of grazing on grasses is to reduce the tops. As there is a tendency for a balance to be reached between tops and roots, probably related to the amount of active photosynthetic tissue present, a reduction in tops results in a reduction in roots."*

In 1955, Frederick Crider (cited in Rasmussen 1994) also studied root growth stoppage and determined that if more than 50% of the current year's production is removed, then root growth stops. He found that, based on the assumption that if the root growth was stopped then a plant's ability to continue to explore new environments for water and nutrients would be reduced and the plant would not be as competitive.

In a discussion of "Basis for Determining Proper Use", the 1964 Forest Service Range Analysis Handbook notes that *"Through the years, considerable research has been directed toward an understanding of effects of grazing on numerous plants and soil types"*. The HB then summarized some of those research findings:

1) Effects of herbage removal on the plants (cites Robertson, 1933; Carter and Law, 1948; Branson, 1956; Biswell and Weaver, 1933; Weaver and Hougen, 1939; Crider, 1955; Janti and Heinonen, 1957; Hanson and Stoddart, 1940; Stoddart, 1946; McIlvanie, 1942; Heady, 1950; Blaisdell and Pechanec, 1949; Julander, 1958)
2) Selective grazing habits of the animals (cites Weaver and Hanson, 1941; Dyksterhuis, 1949; Voight and Weaver, 1951; Tolstead, 1942; Jardine and Anderson, 1919; Ellison, 1954; Hormay, 1956)
3) Mechanical effects of grazing on the plants and soil (cites Craddock and Pearse, 1938; Renner, 1936; Packer, 1953; Lull, 1959; Huberty, 1944; Johnson, 1952; Alderfer and Merkle, 1941; Peele, 1955; Rauzi, 1955; Edmund 1958; O'Connor, 1956 and 1957)
4) Vegetal cover as a factor in site stability and its relation to grazing use (cites Packer, 1951; Marston, 1952; Orr, 1957; Packer, 1953)
5) Results of grazing trials on mountain rangelands (cites Johnson, 1953; Johnson, 1957; Beetle, 1956)

The Handbook then states:

> *"Under season-long grazing, which is the common practice at present on Region 4 allotments, 50 percent use of key species is the established maximum. Wet meadows in good condition are the exception. Here, up to 60 percent use can be allowed, provided vigor and production are not adversely affected. Utilization will be graded down from the 50 percent maximum to conform to local range condition, soil stability, and known individual plant requirements. The 50 percent utilization will apply specifically only to forage plants during the growing periods. Dry forage can stand more use so long as mechanical damage to the soil and cover is not a limiting factor. Also, plants can conceivably stand heavier utilization where systems of rest-rotation are being used."* (USDA Forest Service 1969)

Then, in 1975 H.E. Dietz (as referenced by Frazier 1979), tabulated how progressively greater removals of leaf volume during the growing season affect stoppage of root growth, with a dramatic increase occurring between 50 and 60 percent use:

Leaf Removal and its Effects on Root Growth	
% Leaf Volume Removed	**% Root Growth Stoppage**
10-40	0
50	2-4
60	50
70	78
80-90	100
All root growth stops for 12 days with 80% leaf removal and for 18 days with 90% leaf removal	

In 1976, 50 percent use was considered to be proper use or the maximum grazing that the plant can withstand and retain good vigor and production (Schmutz 1976).

Holechek and others (1989 pg 189) noted that the importance of maintaining minimum plant stubble heights for soil, vegetation, and animal resources has been well established. They summarized a wide-range of grazing intensity studies to indicate forage utilization levels associated with moderate stocking rates. These estimates were then considered as best estimates of proper use factors. For sagebrush-grass and coniferous forest types the utilization guide for use of key species at moderate grazing is 30-40 percent. Holechek clarified that the coniferous forest type is easily damaged by grazing because of rugged mountain terrain that causes livestock, particularly cattle, to concentrate in the flatter, more convenient areas. He cites both Johnson (1953) in Colorado and Skovlin et al. (1976) in Oregon in emphasizing the need to keep utilization levels of primary forage grasses around 35 percent.

However, in 2000 Holechek and Galt recognized that:

> *"Considerable controversy has existed over how grazing intensity should be measured over the past 7 years, as researchers and consultants we have had the opportunity to evaluate grazing intensity on several rangeland sites in New Mexico using a variety of techniques."*

In this June 2000 Rangelands article, they provide that revised moderate use guidelines for mountain grasslands should allow 41-50% use of forage by weight. They equate this use level to an approximate 4.5 inches stubble height (an average of stubble heights for six species). Then in 2004, they (Holechek and Galt, 2004) re-define the minimum stubble height for these same mountain species to be an average of 3.0 inches, saying "The critical stubble height guidelines…came from past research, our own studies, and our practical experiences."

Hall and Bryant (1995) documented that "cattle prefer to reach their tongue out of the side of their mouth and draw in the vegetation, tasting it as they do. Thus they limit themselves to those species that taste

best. But this preference begins to change as stubble heights are lowered to 3 inches because the vegetation is too short to be pulled in by the tongue."

Clary and Webster (1989) reported that study data indicates that a 3 inch stubble height compares to an equivalent utilization of 47-51 percent; a 4 inch stubble height is about 37-44 percent use; and a 6 inch stubble height equals a use level of 24-32 percent.

McKenney (1997) also observed the foraging behavior of cattle, and concurs with Brotherson and Brotherson (1983) that a grazing animal does not eat everything in its path, but it grazes selectively, concentrating on the most palatable and desirable species. McKiney noted that "utilization takes place on a plant-by-plant basis as our grazing critters 'visit' their favorite plants". He contends that utilization is measured as an average of the use on the same plants in an area, usually on a species-by-species basis. He explained that in order to measure the utilization level in a pasture we take an average of the plant utilization along a transect line:

> *"This typical transect of 10 plants in an area which averages a moderate use level might show: 6 plants heavy (6x70% = 420); 1 plant moderate (1x50% = 50); 1 plant light (1x30% = 30); 1 plant slight (1x10% = 10); and 1 plant unused (1x0 = 0); We take the average: 420 + 50 + 30 + 10 + 0 = 510; 510 ÷ 10 = 51% average. So our utilization at this area is moderate, while only one out of ten plants was actually used at a moderate level. And that's what we find when we are dealing with rangeland bunchgrasses, then; moderate utilization usually means that most of our plants are munched at the 70% level heavy use); a few are partly used, and a few are untouched."*

He maintains that heavy grazing is not overgrazing; it's just the natural way a large ungulate eats grass plants. He concedes that "overgrazing" occurs when plants are "twice-over" grazed—on the first visit, animals almost never take a plant much below the 70% use level. It's when the animal comes back and "visits" the plant a second time and bites deeper into the plant to get a "mouthful", thus getting some old plant growth along with the new, that harm is done to the plant.

The Total Available Carbohydrate (TAC) Theory

Recent research by Trlica (1999), 4(2000 and 2003), and Briske (1991) has shown that the amount of root growth, which was previously thought to be the most important element for maintaining plant vigor over time, may have a lesser value than protection of plant growing points (apical meristems) and that it is the removal of meristematic tissue that has a greater impact on a plant's ability to maintain vigor and reproductive capability over time.

Valentine (1990) noted that Total Available Carbohydrates (TAC) are a pool of nonstructural carbohydrates, from which plants can get materials that allow them to offset fluctuations in the levels of sugars needed for maintenance, respiration, initial growth, and many other functions. Valentine also mentioned that moderate levels of TAC may be as advantageous to plants as high levels. This indicates that some removal of vegetation is not detrimental to plants. Valentine noted that adequate levels of TAC food reserves:

1. Maintain overall high plant vigor;
2. Support perennial plant function during dormancy, principally respiration;
3. Enable earlier and more rapid regrowth following dormancy or severe defoliation;
4. Promote extensive root and rhizome growth;
5. Increase both vegetative reproduction and seed reproduction;
6. Give higher drought, frost, and heat tolerance;

7. Maintain high resistance to insect and disease injury; and
8. Promote root nodulation in legumes.

Valentine (1990) went on to note that prolonged depletion of TAC by overgrazing or in combination with severe restriction of environmental resources required for growth can result in reduced root growth, tiller bud development, rhizome development, forage yield, and even death (particularly when combined with some adverse environmental factor such as drought).

Manske (2004) explained that the crown of a grass plant is the lower portion of a shoot and has at least two nodes that can produce roots. Before flower development, the shoot consists of several closely spaced nodes. The node at the top, or apex, of the stem is the location of the shoot's apical meristem, an area of new cell formation. The cells in this area can develop into either leaf buds or flower buds, depending on the growth stage of the shoot. Leaves form on alternating sides of the shoot, with the oldest leaf outermost and each new leaf growing upward, protected by the surrounding sheaths of the lower leaves. A leaf bud contains about the same number of cells as a fully expanded leaf. The leaf grows as the cells' size and weight increase, beginning with cells at the tip of the blade. Because grass plants have the oldest cells at the leaf tip, grazing animals can remove portions of a leaf without stopping the growth of the shoot. Leaves may continue to grow from existing buds and from new leaf buds developed in the shoot's apical meristem, or growing point. The apical meristem of most grasses remains close to the ground and below the reach of the grazing animal when the shoot is in the vegetative, or non-flowering, phase. This growth structure, Manske claims, makes grasses well adapted to defoliation by large herbivores.

However, Manske (2004) notes that turning livestock onto native rangeland too early in the spring damages plants and limits herbage production because grazing at this time removes leaf area from grass that has not recovered from winter dormancy. Grass cannot withstand defoliation before reaching the third-leaf stage, after plants have produced sufficient foliage to support growth. The practice of starting grazing before grass tillers have produced three new leaves reduces the forage available to livestock later in the season. The grass shoot's production of three to three and a half new leaves during the growing season is the most reliable indicator of when grazing may safely begin. After the lead tiller has reached the third-leaf stage and been exposed to the triggering photoperiod, the apical meristem changes and begins to produce flower buds rather than leaf buds, although previously formed leaf buds continue to grow and develop. Defoliation of leaf material before the shoot has reached the third-leaf stage can disrupt the formation of leaf buds and the expansion of existing young leaves for the shoot, weaken the plant, and diminish the plant's ability to produce herbage.

In 2000 Manske noted that effective grazing management strategies are based on the phenological growth stage of grasses. Grazing early spring growth before grass plants reach the third-leaf stage and grazing stimulated secondary tillers during periods before they reach the third-leaf stage negatively affect grass growth and result in reduced herbage production.

The removal of actively growing meristematic tissue has the potential for greatly effecting carbohydrates reserves and all those functions noted by Valentine (1990) above. Trlica (1999) showed a significant drop in carbohydrate reserves with a single clipping and indicated that repeated defoliations would further reduce reserve levels and forage production would decline further. A plant that is harvested often, has more photosynthetic tissue removed and little opportunity for regrowth. As a result, timing of grazing is an important consideration when monitoring use.

When developing utilization standards, proper use considers the physiological requirements for maintaining plant health and vigor as well as management considerations such as streambank stability, ground cover, soil compaction, wildlife habitat, fish habitat, etc. Rassmussen (1994) noted that, in

general, proper use of key grass species is 50-60 percent on sites considered to be in satisfactory condition. He added that the "take half, leave half" rule of thumb insures that there is sufficient meristematic tissue remaining for maintenance of the existing plants. Translated, this means that plant communities will be able to maintain their existing status with 50 percent use. Padget (1995) noted that communities that are in less than satisfactory condition, however, will not see any improvement in their ecological status. Even though heavier grazing after plants are no longer producing actively growing meristematic tissue may not negatively impact the long-term productivity of those plants, he felt that other resource impacts (including those to soils, streambanks and stream channels) require that utilization be maintained at these levels.

Utilization vs. Residue

There is a very rich literature on the subject of utilization and residue (stubble height) in managing grazing on rangelands. Many recent papers criticize the use of utilization data in management. Despite these criticisms there is no denying that estimating levels of utilization in order to achieve proper stocking rates has a long history in range management.

Standards for use in riparian areas have been studied by many authors. Clary and Webster (1989) compiled information from numerous sources and recommended that "utilization of streamside herbaceous forage should be limited to about 65 percent of the current growth, and livestock should be removed by July 15 to allow sufficient time for plant re-growth". Utilization based on current growth, however, does not translate directly to utilization based on total annual production. The authors went on to note that recommendations of 40-50 percent utilization (approximately 3 to 4 inches of residual stubble height) will maintain plant vigor. They noted, however, that additional stubble height (e.g. 6 inches or more) might be necessary to protect riparian ecosystem function. The authors noted that "Vigorous woody plant growth and at least 6 inches of residual herbaceous plant height at the end of the growing/grazing season typified the riparian areas in excellent, good, or rapidly improving condition." This stubble height was shown to equate to average use levels of 24 to 32 percent.

Standards for stubble height, rather than percent utilization, are noted for riparian communities occurring along the "greenline" only. The "greenline" is defined as the first plant communities dominated by perennial vegetation as you proceed outward from the center of the channel. The amount of forage left along the stream's edge has been found to be important in catching sediments during runoff periods, both from the stream channel as well as from overland flow (Clary and Webster 1989). The trapping of sediment is critical in the rebuilding of streambanks as well as the maintenance of water quality. Greenline standards, however, cannot be applied to many subalpine and alpine riparian ecosystems. Here plants rarely reach heights at full maturity equal to those of the standards. At these elevations utilization standards for greenline are determined by using nongreenline riparian standards with emphasis on streambank trampling standards.

Conclusion

Because scientists are constantly trying to make new discoveries or to develop new concepts and theories, the body of knowledge produced by science undergoes constant change. Such change is progress toward a better understanding of nature. It is achieved by constantly questioning whether our current ideas are correct. The result is that theories come and go, or at least are modified through time, as old ideas are questioned and new evidence is discovered.

We have observed this process in our discussion of the "take half-leave half" rule. Originally based on an anecdotal theory, it was first supported by evidence that root growth stops if use occurs beyond the 50-60% use level. Then, research found that the amount of root growth may have less effect than first thought. More recently, researchers (Richards and Caldwell, 1985 and Richards et al.,1987) showed that it is the removal of meristematic tissue that has a greater impact on a plant's ability to maintain vigor and reproductive capability over time. As a result, timing of grazing is an important consideration when monitoring use. But, it was also observed (Valentine, 1990) that prolonged depletion of Total Available Carbohydrates (TAC) by overgrazing or in combination with severe restriction of environmental resources required for growth can result in reduced root growth, tiller bud development, rhizome development, forage yield, and even death. Then we were reminded by Rasmussen (1994) that the "take half, leave half" rule of thumb insures that there is sufficient meristematic tissue remaining for maintenance of the existing plants. Translated, this means that plant communities will be able to maintain their existing status with 50 percent use. Clary and Webster (1989) went on to note that recommendations of 40-50 percent utilization (approximately 3 to 4 inches of residual stubble height) will maintain plant vigor. Hall and Bryant (1995) and McKenney (1997) observed the foraging behavior of cattle, and documented how this affects utilization patterns and levels. Many, many other studies have been documented relative to types of grazing systems, the effect of rest, variations in timing and frequency, plant physiology, ungulate grazing behavior, etc.

The body of research on rangeland management is housed largely in the research halls of the United States Forest Service, where rangeland regulatory management was born. For the first 50 years, the Forest Service had almost sole proprietorship on range research. Then, gradually universities began first teaching, then research, on range and/or livestock grazing management. For the most part, however, theories are tested at one of the hundreds of field labs or research stations administered by the Forest Service. It is appropriate that the field application (applied science) of research results (research science) can be "tested" by practicing range scientists trained by universities and employed by land managing agencies working cooperatively to find the "best science".

There have been some refinements to the old "take half-leave half" rule of thumb, but "the baby has not been thrown out with the bath water". Each new discovery prompts a change. Modifications are made to account for the new data, which is exactly what should happen through time to any scientific data. New research and new theories continue to rely a great deal upon the veracity of the "take half-leave half rule".

LITERATURE CITED

Archer, Steve and Fred E. Smeins. 1991. Ecosystem Level Processes. In Grazing Management—An Ecological Perspective. Eds. Rodney K. Heitschmitt and Jerry W. Stuth. Texas A&M University. Timber Press, Portland, OR. http://cnrit.tamu.edu/rlem/textbook/Chapter5.htm

Briske, D.D. 1991. Developmental Morphology and Physiology of Grasses. In Grazing Management—An Ecological Perspective. Eds. Rodney K. Heitschmitt and Jerry W. Stuth. Texas A&M University. Timber Press, Portland, OR. http://cnrit.tamu.edu/rlem/textbook/Chapter4.htm

Brotherson, Jack D. and W. Todd Brotherson. 1981. Grazing Impacts on the Sagebrush Communities of Central Utah. Great Basin Naturalist. Department of Botany and Range Science, Brigham Young University. Provo, UT

Buckhouse, John C. et.al. 1994. New Methods to Classify, Inventory, and Monitor Rangeland, National Academy Press, Washington, D.C. 1994. http://www.nap.edu/books/0309048796/html/R9.html)

Burkhardt, J. Wayne. 1996. Herbivory in the Intermountain West - An Overview of Evolutionary History, Historic Cultural Impacts and Lessons From the Past. Idaho Forest, Wildlife and Range Experiment Station College of Natural Resources, University of Idaho. http://www.idrange.org/research/burkhardt.pdf

Buwai and M.J. Trlica. 1977. Multiple Defoliation Effects on Herbage Yield, Vigor, and Total Nonstructural Carbohydrates of Five Range Species. Colorado State University, Ft. Collins, CO. http://jrm.library.arizona.edu/data/1977/303/1buwa.pdf

Clary, Warren P. and Bert F. Webster. 1989. Managing Grazing of Riparian Areas in the Intermountain Region, GTR INT-263. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 13 p.

Frazier, Joseph. 1979. Grazing systems for western rangelands. USDA, Forest Service, Intermountain Region, Humboldt National Forest.

Hall, Frederick C. and Larry Bryant. 1995. Herbaceous Stubble Height as a Warning of Impending Cattle Grazing Damage to Riparian Areas. General Technical Report PNW-GTR-362. USDA, Forest Service, Pacific Northwest Research Station. La Grande, OR. http://www.fs.fed.us/pnw/pubs/gtr362.pdf

Hall, Marcus.2001. Repairing Mountains. Restoration, Ecology, and Wilderness in Twentieth-Century Utah. http://www.wsl.ch/staff/marcus.hall/Hall_Repairing_Mtns_2001.pdf

Holechek, Jerry and Dee Galt. 2000. Grazing Intensity Guidelines. Rangelands. The Society for Range Management, Lakewood, CO.

Holechek, Jerry and Dee Galt. 2004. More on Stubble Height Guidelines. Rangelands. The Society for Range Management, Lakewood, CO.

Holechek, Jerry L., Rex D. Peiper, and Carlton H. Herbel. 1989. Range management principles and practices. Prentice Hall, Englewood Cliffs, New Jersey, 501 p.

Jones, Brian. 1996. Cattle Grazing On Public Lands. GeoSystemsAnalysis, Inc. Tucson, AZ. **http://www.thebeckoning.com/environment/cattle/grazing.html#2**

Kosco Barbara H. and James W. Bartolome. 1981. Forest Grazing: Past and Future.Journal of Range Management 34(3), May 1981. Fort Collins, CO. http://jrm.library.arizona.edu/data/1981/343/24kosc.pdf

Krueger, William C, et. al. 2002. Issue Paper—Environmental Impacts of Livestock on U.S. Grazing Lands. Council for Agricultural Science and Technology, 4420 West Lincoln Way, Ames, IA http://www.cast-science.org/cast/pub/grazinglands_ip.pdf).

Manske Llewellyn L. 1999. Bilogical Effects of Defoliation on Grass Plants. North Dakota State University, Dickinson Research Extension Center, Dickinson, ND. http://www.ag.ndsu.nodak.edu/dickinso/research/1998/range98b.htm

Manske Llewellyn L. 2000. Defoliation Applied at Some Phenological Growth Stages Negatively Affects Grass Plants. North Dakota State University, Dickinson Research Extension Center, Dickinson, ND. http://www.ag.ndsu.nodak.edu/dickinso/research/1999/range99a.htm

Manske Llewellyn L. 2004. Biologically Effective Grazing Management. North Dakota State University, Dickinson Research Extension Center, Dickinson, ND. http://www.ag.ndsu.nodak.edu/dickinso/research/2003/range03a.htm

McGinnies, W.G., K.W. Parker, and G.E. Glendening. 1941. Southwestern Range Ecology. United States Department of Agriculture, Forest Service, Southwestern Region, Albuquerque, NM.

McKinney, Earl. 1997. It May Be Utilization, But Is It Management? Rangelands. The Society for Range Management, Lakewood, CO.

Mitchell, John E. 2000. Rangeland resource trends in the United States: A technical document supporting the 2000 USDA Forest Service RPA Assessment. Gen. Tech. Rep. RMRS-GTR-68. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 84 p. http://www.fs.fed.us/rm/pubs/rmrs_gtr68a.pdf

Padgett, Wayne G. 1995. Wasatch-Cache Proposed Action, Alternative 2: Amend the Forest Plan. 22 p. Wasatch-Cache National Forest, Salt Lake City, UT.

Provenza, Frederick D. 1991. Viewpoint: Range science and range management are complementary but distinct endeavors. Journal of Range Mangement 44(2). March 1991. http://jrm.library.arizona.edu/data/1991/442/16prov.pdf

Rasmussen, G. Allen. 1994. Application of New Theories on Plant Responses to Grazing, Rangeland Extension, Utah State University. Logan, UT.

Rowley, William D. 1985. U.S. Forest Service Grazing and Rangelands—A History. Texas A&M University Press. College Station, TX. pp. 270.

Sampson, Arthur W. 1923. Range and Pasture Management. Stanhope Press. Boston. pp. 421.

Schmutz, Ervin M. 1971. Bulletin A-73, Estimations of Range Use with Grazed-Class Photo Guides. Cooperative Extension Service and Agricultural Experiment Station, The Univrsity of Arizona, Tucson, AZ..

Stoddart, Laurence A. and Arthur D. Smith. 1943. Range Management. McGraw-Hill Book Company, Inc. New York and London. pp. 547.

Trilica, M. J. 1999. Grass Growth and Response to Grazing—No. 6.108. Colorado State University Cooperative Extension. Fort Collins, CO. http://www.ext.colostate.edu/pubs/natres/06108.html

USDA Forest Service. 1964. Range Environmental Analysis Handbook (FSH 2209.21). Intermountain Region. Ogden, UT.

Vallentine, John F. 1990. Grazing Management. Academic Press, Inc. San Diego, CA. 533 p.