# BEHAVIOR - THE KEYSTONE IN OPTIMIZING FREE-RANGING UNGULATE PRODUCTION

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**Summary**

This chapter provides an overview on several topics paramount to understanding domestic free-ranging livestock foraging behavior. Animal behavior has always played a pivotal role in human management strategies involving domestic livestock, only within the last 30 years has there been a coordinated effort to try and use behavior principles in managing free-ranging livestock. Coupled with this focus has come advances in several key supporting sciences and technologies that impact today's domestic livestock management. This combined package of information and awareness has resulted in a new focus on husbandry, once considered only art it is now enmeshed within the arena of science, ethics and animal welfare. What is known and what remains to be learned will provide domestic livestock production with opportunities that will benefit ecosystem stewardship as we move through the $21^{st}$ century.

## 1. Introduction

The earliest recorded history of animal behavior is probably cave paintings from Paleolithic times depicting man hunting large mammals. The success of these hunts was intrinsically linked to "understanding" animal behavior. While the principles underlying all animal behavior are similar, this chapter focuses on domestic livestock.

Documentation of free-ranging domestic animal behaviors began early in the 20th century, but, it has only been since the 1950's that behavior has been considered an integral part of the disciplines of animal and range science. Even then, some did not believe grazing behavior studies contributed to the evaluation of management practices. However, the scientific consensus today is that the study and use of animal behavior principles is integral to the management of free-ranging herbivores.

Of the world's 13 x $10^9$ ha of land surface about 30% can be associated with livestock use. The majority of land used for livestock can be considered to dry, too steep or too sloping for crop production and has been termed rangelands. These lands include deserts, forests and all natural grasslands. Rangelands represent 2.6 $10^9$ ha or about 20% of the earth's surface, however, it has been estimated that between 20% and 73% of this rangeland is degraded. Therefore, understanding and using animal behavior as a biological tool in restoration of these landscapes in both developed as well as the developing world will be essential for mankind in the 21st century and beyond. Today's lifestyle in the developed world has separated most people from the livestock that feed and cloth them. This alienation frequently has colored conceptions and understandings concerning livestock practices and processes. The goal of this chapter is to focus on how understanding animal behavior can be used to improve native landscapes as well as optimize food and fiber production from domestic free-ranging ungulates.

## 2. Defining Animal Behavior

Animal behavior has been defined as anything an organism does that involves action and response to stimulation —- the response of an individual, group or species to a whole range of factors constituting its environment which also includes muscle contractions. The word ethology, or the study of animal behavior, is derived from the Greek language and dates from approximately 1843. *Applied ethology* has been defined to describe behavior concerned with animal species that are of direct practical interest to people. Ethology may be one of the most complex fields of scientific study because differentiating and classifying what animals are doing and why, is not easily categorized, even when using tools such as video. This challenge was apparent in the early 1900's by a scientist who stated that the real difficulty in interpreting what an animal is doing lies not in the tendency to interpret animal intelligence in the terms of human experience, for we have no other way; but in the faulty and imperfect analysis of human experience.

The World Wide Web has made instantaneous access to published material a reality through a number of sites such as http://www.nal.usda.gov/awic/pubs/Beef/web.htm. However, at present no single site exists where all journals and textbooks pertaining to foraging animal behavior can be found. Details of what is presented in this chapter can be researched further using journals such as *Applied Animal Behaviour Science, Animal Behaviour, Adaptive Behavior, Behavioral Ecology,* and *Sociobiology* and books listed in Table 1.

## 3. Concepts Fundamental to Foraging

### 3.1. Stocking rate

Stocking rate is an animal-to-area relationship. Stocking rate refers to number of animals placed on a particular area (paddock) over some time interval and is often expressed as number of animals or their equivalents per area of land. Common terms to express area are acres, sections, hectares or square kilometers. This calculation has been considered the most fundamental in the management of free-ranging animals and one of the four basic components necessary to properly manage free-ranging animals along with proper timing of use, distribution and grazing system. The actual numbers of animals to be place on the landscape depends on the kind and class of livestock and their daily forage requirements. Different kinds and classes of domestic livestock have been related to each other on the basis of animal unit (AU) equivalents (Table 2). An AU has been defined as one mature non-lactating bovine weighing 500 kg that is fed at a maintenance level or the equivalent, expressed as $(\text{weight})^{0.75}$. This information is essential when determining stocking. Furthermore, stocking rate should be determined before animals begin to forage. Too often, greed, ignorance or both have inflated this calculation and the result has frequently resulted in a long-term and devastating impact to the landscape. Stocking rates seldom remain constant over time due to variability in effective precipitation that directly affects plant growth and ultimately where animals forage on the landscape. As a general rule of thumb, the more arid the environment the more variable is the effective precipitation and hence the more conservative should be the stocking rate. Since standing crop and foraging are spatially dynamic alternative ways have been proposed on how stocking rate could be calculated including, determining the kilograms of body weight per ton of feed available. Another method would assume a set distance on either side of an animal's head is available at any point in time in which foraging could take place. If this distance (1 m might be a good estimate for a mature cow) is multiplied by the meters an animal travels, the area obtained would be more representative of where foraging may have occurred rather than using the area of the entire paddock.

Table 1. Text books devoted to free-ranging animal behavior and the landscapes on which foraging takes place.

Table 2. Commonly accepted livestock animal unit (AU) equivalents. Adapted from Bell, 1972.

### 3.2. Animal density and stocking pressure

Stocking pressure or grazing pressure is an animal-to-forage relationship that has been defined as the ratio between number of animals expressed in AU equivalents and the mass of forage dry matter available per unit area at any point in time. Superficially the concept is easy to understand, but, in reality the full significance of this relationship to range animal ecology is complex and not fully explained by the current way in which it is calculated. The definition assumes the relationship is between foraging area and animal numbers, yet free-ranging animals seldom use the entire area available in an even and uniform fashion especially during foraging on rangeland. Furthermore, the impact of current foraging can be immense to future foraging as it impacts the physical and chemical properties of plant regrowth as well as soils. To date, these interactions are overlooked in this calculation. However, with Global Positioning System (GPS) technology and geographical information system (GIS) technology, alternative approaches exist that would provide a more accurate denominator.

## 4. Foraging Behavior

### 4.1. Spatial concepts

How to ensure optimum animal distribution over a landscape remains unanswered due to an incomplete understanding of the factors and their interrelationships that underlie foraging patterns. At least 22 factors can be listed within six categories including: animals, their behaviors, physical developments, husbandry practices, abiotic factors and vegetation.

Free-ranging animals are typically drawn to green vegetation (quality) over mass (quantity) of vegetation available. This is one of the factors that can contribute to livestock poisoning, especially if the first plants to begin growth in the spring contain toxic compounds and no alternatives are available. Furthermore, certain plants may be toxic to certain animal species but not on a continuous basis making it necessary to remove livestock from certain areas periodically. Practices such as fertilization, mowing and burning have been used to lure animals away from or into certain areas on the landscape. Once forage begins to grow due to effective precipitation, animal distribution across a landscape becomes spatially and temporally dynamic.

Topography impacts animal distribution. Recently it has been shown that within cattle groups some animals tend to forage closer to streams and within riparian areas while others will climb slopes when foraging. Apparently these behavioral traits can be passed from dam to offspring. Species tend to use topography differently. Cattle prefer to forage in riparian areas while sheep will forage more on slopes. North vs. south facing slopes receive differential use and the steeper the topography, the less use either slope receives.

Abiotic factors also affect animal distribution. Sheep and cattle forage into the wind, thus prevailing wind direction should be considered in paddock geometry and the location of drinking water. Though high ambient air temperature has been shown to reduce the time cattle spend foraging and the spatial distribution of sheep, development of shade for free-ranging livestock has not been a management priority. However, in hot climates the dairy industry uses misting and shade structures to cool animals.

If herding is the oldest technique for improving animal distribution, then nutrient placement of minerals and drinking water must surely run a close second. Proper water placement can be one of the most desirable ways to improve uniformity of foraging. It has been recommended that for cattle, to foster optimum use of rangeland, drinking water should be available at least every 3.2 km. In general, this distance can be greater for sheep. Overall salt and mineral placement is not as persuasive a method to distribute livestock across landscapes as is drinking water and self-fed protein supplements such as those termed low-moisture blocks.

Once barbed wire became available in the 1870's it was not long before the first rotational stocking strategies began to appear. Fencing is probably second only to water in promoting uniform use of ranges. With the application of high density stocking strategies to rangelands a renewed interest in free-ranging animal behavior appeared. The opinion of some scientists was that high density stocking strategies may result in animal production outcomes not totally explained by nutrition; however, this remains to be thoroughly researched. However, this point requires further research to confirm or refute. The specific merits of various rotational strategies proposed to improved animal and plant performance on rangelands includes one from Rhodesia, termed short duration grazing (SDG). Though it has been rejected by many scientists for use on rangelands, grazing systems continue to be employed for other reasons. All foraging strategies involve animal behavior, thus making the study of animal behavior an essential part of all management strategies.

### 4.2. From Specialized Individuals To Unique Groups – Flocks, Herds And Mixed Species Groups

Social organization within livestock groups is not random. Social behavior among animals is influenced by the presence or absence of other individuals whose association have been dictated by management goals and husbandry practices. Studies indicate farm animals prefer being in groups, yet management of livestock groups can lead to conflicts and social stress. Information about living in groups is beginning to be assembled, yet very little information exists concerning free-ranging ungulates. Social behaviors among cattle were probably first investigated in dairy cattle. Modern animal agriculture depends on the economic, efficient and ecologically effective management of animal groups; therefore, understanding social organization is essential to the design of production systems. Group behavior is just as complex as that of individuals. The costs and benefits for living in groups, frequently associated with avoiding predators is not as important in the 21$^{st}$ century as it was with our domesticated animal's ancestors.

The first coordinated efforts by a country to preserve valuable feral animal traits began in the mid 1970s in New Zealand. The Soay sheep on the island of Hirta, Scotland , the feral cattle on Swona Island, Scotland, the Chillingham Park cattle in the UK and the "mostrenca" cattle from the Donana region of Spain all represent animal groups that have escaped man's direct husbandry and should provide useful insight into animal behaviors not altered through human selection and husbandry practices. Though the social organization of cattle has been intensely studied more remains to be understood

Animals use their senses not only to select forage but also in social learning. Social learning, social facilitation, and allelomimetic or contagious behavior, all employ visual, olfactory and auditory cues. Social learning was found to be relatively unimportant in heifers, social facilitation can cause mature cows to eat poisonous plants, including locoweed (*Astragalus* and *Oxytropis* species). Furthermore, to get inexperienced sheep to accept a new feed, it is advisable to place them with peers that have been habituated to the feed. What lambs learn from their dams may persist up to three years with even a brief exposure at six months of age. A complete understanding of how social learning affects group dynamics will require more studies.

It has been asked, "Is there an optimum group size?" Though some believe animal group size is more of a response than a tool to improve rangelands there may be an optimum animal group size that represents a "best fit" among a number of factors including animal genetics (especially as it affects disposition), standing crop quantity as well as quality and landscape topography. Neither the maximal nor optimal group size has been identified for livestock, yet one may exist. Therefore, the answer to this question is not simple because animal groups appear to be highly structured. Group sizes are determined by a number of factors including the animal's ability to recognize individuals. The upper limit of peers that cattle recognize may be around 100. Recent research suggests that predators can influence the vigilant behavior of cattle depending on group size. Possibly determining optimal size may employ a peak fitness function.

Research during the 1960's on arid rangeland found that two-year-old Hereford and Santa Gertrudis cows appeared to prefer small (4 to 8) and large (15) size groups, respectively. Feral cattle foraging on Chihuahuan Desert rangeland formed smaller (1 to 20) size groups compared to domestic cattle that formed larger (30 to 50) size groups. Hereford cows with calves on bluestem paddocks during the summer in the Osage Hills of Oklahoma typically grazed in groups of 20 to 30 cows. Research on a California foothill paddock 75 ha in size found 14 to 16 randomly chosen beef cows (mean age of 7 years) formed naturally occurring subgroups of 3 to 6 animals (mean = 4) during July and January daytime observations. Single sheep or groups of two sheep spent less time grazing than groups with three or more animals; thus, a minimum of three sheep (preferably four) should be used when studying sheep grazing behavior. When forage is abundant, cow groups are larger than when less forage is available. Furthermore, the proper number of animals required to quantify behavioral differences among a group of animals may need to be larger than the number to statistically detect differences within nutritional experiments since animal-to-animal variability regarding behavioral traits may be greater than traits associated with measuring nutritional responses.

How animals use a landscape may be influenced by the landscape on which they were raised as well as by genetics. The effect of 'place' on behavior may be illustrated by the behavior of sheep maintained on hills and moors in the UK. The natural homing instinct of these sheep allows them to remain on the pastures without fencing. This has been described as hefting. Cattle and sheep utilize a landscape differently among seasons, and tend to range more as plant maturity increases and less when vegetation is abundant. Intraspecific and interspecific animal associations are complex.

Though natural selection has occurred since time began, artificial selection directed by humans has only taken place for the last 10 to 15 thousand years. Within a species, there exists a tension in free-ranging ungulates between individual and group activities. Gregarious animals within a species tend to forage at a similar rate during temporally and spatially synchronous periods over a landscape. Furthermore, it has long been recognized that cattle with *indicus* genes tend to perform better in hot humid climates while cattle with European genetics (*taurus*) perform better in cooler and dryer climates. Besides physiological differences these two cattle species show behavioral differences in travel with *indicus* cattle traveling further than *taurus* genetics. There are also temperament differences between species. Brahmans (*indicus* genetics) tend to be more excitable compared to European breeds.

The experience an animal has on a landscape influences future utilization. Naïve cattle may harvest fewer total bites but select from a broader array of forage than experienced animals. Experiences early in the life of cattle on a particular landscape can affect their subsequent distribution and use of that landscape later in life. Therefore, the adage that says everything we subject animals to teaches them something is true.

As a general rule, it appears beneficial for animals to remain in groups in which individuals are familiar with each other. Little is known about how management decisions to cull or add animals affect the formation or stability of social subgroups. Disrupting the social order of a group of dairy cows by moving them among groups may or may not be correlated with a decline in overall milk production; yet, a decline in milk production may occur on day one following formation of new social groups. Dominance ranks are specific to a particular group adding complexity to the study of dominance. However, no studies have been reported on the effect of herd size on regrouping behavior of cows, especially among free-ranging cattle.

### 4.3. Group Cohesiveness

Domestic livestock are social animals; however, modern livestock production systems inhibit self-regulation because of man's desire to maximize economic returns, with potentially significant and far reaching negative implications to animal production systems. Individual behavior may vary depending on the size of group which in turn can alter group dynamics. In a herd of American Buffalo, removal of a single aggressive cow noticeably calmed the remainder of the herd. Group size appears to have a significant effect on intraspecific relationships. When group size in a production system differs from the group size that would form under natural conditions, behaviors can be negatively impacted. Social behavior has been defined as behavior which is influenced by the presence or absence of another individual. Animal groups are dynamic and form a continuum from loose aggregations to tight-knit associations that can change depending on time of year due to a host of biotic as well as abiotic factors. The expression of an animal's social behavior has been impacted by domestication, yet the basic social characteristics of domestic animals are similar to those of their wild conspecifics. Thus, behavior affecting an animal's ability to adapt is at least partially based on heritable genetic differences that must have conferred positive reproductive success.

Cattle and sheep normally do not form cohesive groups that consistently remain together under free-ranging conditions. However, it is possible to alter the behavior of sheep and other small ruminants so they will remain with cattle through a socialization process termed bonding. Once bonded, wethers especially prefer to tenaciously remain near cattle under free-ranging conditions. This cohesive group of large and small ruminants has been termed a flerd (contraction of flock and herd). It is also possible to manage both meat and hair goats in a flerd. Flerds can help reduced coyote predation of small ruminants because cows will instinctively intimidate approaching canines. Furthermore, because animals are found together in a paddock overall management of mixed-species groups that contain bonded small ruminants is facilitated. In addition, flerds reduce the need for constructing internal conventional fences for controlling small ruminants if the fencing is adequate to control cattle and the small ruminants have been previously bonded to cattle. Even though dietary differences among flocks, herds and flerds remain similar on arid landscapes with abundant standing crop, animal distribution does differ. While the spatial pattern of cattle with either bonded or non-bonded small ruminants are similar small ruminants in a flerd tended to disperse more uniformly across an arid landscape than those in a flock. Flerds demonstrate how behavior can be used to enhance free-ranging livestock management.

Though dominance is important it may not be the only factor necessary to explain group cohesiveness. The spacing of individuals on a landscape appears to involve the maintenance of individual distances among animals and a dynamic area that surrounds and moves with individuals comprising the group. Sheep breeds differ in nearest neighbor distances. Cattle tend to form more dense groups in open areas compared to areas with moderate tree or shrub cover. Furthermore, different behaviors dictate different spacing patterns. During periods of rest, socially dominant cows tend to be found in the center of a resting group while subordinate cows tend to occupy the periphery. Socialization definitely plays a role in the formation and maintenance of all animal groups.

## 5. The Central Role of Plant Chemistry in Foraging Behavior

Globally, rangeland degradation has resulted in vegetation conversions on all continents during the past 2 centuries. In many rangeland environments, though not all, this conversion has often been the replacement of graminoid species by woody species more resistant to foraging. For many rangelands, the conversion and expansion of these woody shrubs has occurred over the course of just a few decades. The rapid expansion of shrubs into rangelands during the past century has serious implications for fragile arid and semi-arid environments.

A few key references relative to this subject are listed in Table 3. Shrubs generally are well defended and have survived and flourished under systems receiving heavy foraging. A variety of secondary compounds from several chemical classes (e.g., alkaloids, phenolics, tannins, saponins, terpenes) occur in range plants, and both genetic as well as environmental factors drive their concentrations (e.g., species, competition, soil conditions, moisture, nutrient availability, phenology/season, climatic, atmospheric, mechanical damage, microbial profile, herbivory, light, temperature, humidity, $CO_2$, ozone, plant age, leaf age, plant part, regrowth, constitutive vs. induced). Additionally, small compounds (plant volatiles) are released into the atmosphere (amounts affected by wind, light, humidity, temperature, time of day, season, plant physiology, etc.).

Secondary compounds (PSM) play a critical role in herbivore behavior. Feeding and foraging behaviors are affected on a variety of scales, from whether or not to eat a certain plant to cyclic feeding between types of plants to whether or not to visit an area. Chemical variability within and among plant species is central to diet selection. Studies conducted at the JER revealed differential use of tarbush (*Flourensia cernua* DC) by ruminants. This Chihuahuan Desert shrub contains high levels of terpenes, and sheep and goats browsing tarbush in small paddocks exhibited differential selectivity that was related to leaf surface epicuticular wax and individual mono- and sesquiterpene concentrations.

Selective behavior is affected by taste, aroma, sight, touch, and trigeminal nerve stimulation. Many secondary compounds (e.g., sesquiterpenes, cyanogenic glycosides, alkaloids, flavonoids, and saponins) are bitter, while tannins are offensive due to their astringent properties. These characteristics are all integrated into a combined flavor to which an animal perceives and responds. Odor, texture, and taste combine to create flavors, which can be associated with a particular food and its post-ingestive consequences. Animals can learn to associate flavors and flavor intensities paired with high- or low-nutrient feeds or high toxin feeds and alter preference. For example, goats quickly learn (within a day) to eat old-growth blackbrush rather than high-tannin new growth by associating flavor with internal malaise. Because satiety and malaise are on a continuum, both nutrients and toxins can alter preference through temporary effects of end products of metabolism (e.g., $NH_3$, Volatile Fatty Acids, minerals, osmolarity, acidosis, nutrient imbalances and deficiencies) on chemoreceptors, mechanoreceptors, and osmoreceptors. By integrating positive or negative feedbacks with the sensory properties of the food just eaten, animals can learn to modify diets on a more permanent basis, and both past experience and metabolic state affect this process. Learning from dam and peers, previous experience (both early life and long term), and novelty/familiarity and generalization of flavors are important processes in learning and creating/maintaining aversions and preferences. Learning is an ongoing process because new information is continually received from sampling, trial and error, social interactions, etc.

Table 3. Twelve key references on the role of plant chemistry in foraging behavior.

For example, herbivores typically sample new plants cautiously and subsequently alter intake based on whether they receive positive or negative feedback. Flavor diversity may play a role in animal behavior and distribution as evidenced by lambs that generally preferred to feed in locations with more variety of nutrients and flavors.

Secondary compounds cause physiological effects that can ultimately alter behavior in a variety of ways. Physiological mechanisms to cope with PSM include detoxification, reduced absorption, microbial modification and degradation, etc. For example, condensed tannins are generally thought to reduce digestibility but are poorly absorbed and therefore not particularly toxic, while hydrolyzable tannins are generally absorbed and more toxic. Terpenes can decrease in vitro digestibility in ruminants, presumably through their negative microbial impacts. Volatiles such as terpenes may be lost during mastication and eructation prior to exerting negative effects. Furthermore, a great deal of difference exists among species in terms of how animals deal with PSM. Anatomical (e.g., prehensile lips and selection of specific plant parts) and physiological differences, location of fermentation, synthesis of salivary proteins, etc. all vary among species. For example, browsers often produce proline-rich salivary proteins that bind tannins and reduce their negative effects; in general browsers such as deer produce these proteins, while grazers such as cattle and sheep do not.

Both sensory and metabolic feedbacks signal the browser to alter behavior, via feeding cessation, changing diets, changing pattern of feeding, etc. Altered feeding behavior is a mechanism to deal with negative influences of PSM such as dilution of nutrients and metabolic costs of detoxification. Behavioral mechanisms to cope with PSM include avoidance (especially bitter compounds), reducing intake, temporary cessation of intake, changing diet composition, changing feeding pattern, regulating PSM intake below a critical threshold, consuming counteractive/complementary diet components, consuming soil, etc. For example, animals can change location to minimize intake of PSM, whether moving from tree to tree (or shrub to shrub), or moving to a new location/patch on the landscape. Because blood levels of PSM can negatively affect intake, some herbivores are able to alter feeding patterns and behaviors spatially and/or temporally (by forming transient aversions) to regulate intake of PSM and maintain blood metabolites at concentrations below a critical threshold. Cautious sampling behavior and diet mixing may allow detoxification enzymes to remain induced to a point that they offer protection in the event of PSM consumption. It has been suggested that tolerance and avoidance of PSM are inversely related and exist on a continuum as a strategy to integrate behavioral and physiological mechanisms for coping with PSM. The basis of this continuum hypothesis is that tradeoffs exist for costs associated with avoidance (e.g., behavioral costs from increased selectivity such as lower intake and increased travel time) and tolerance (detoxification, toxicosis).

Botanical diversity has the potential to increase intake through diet diversity both within (biodiversity) and among chemical class (complementarity). The basis of complementarity is that animals may be able to consume more toxin-containing forages with diverse chemical makeup because detoxification is spread over more metabolic pathways, thereby reducing the constraints on a given pathway for enzymes and substrates. Increasing number of species of tannin-rich Mediterranean shrubs offered to goats and sheep generally increased cumulative shrub intake. Offering a high-saponin shrub, along with these shrubs further increased intake presumably via complementarity. Furthermore it has been observed that sheep fed diets with oxalates, tannins, or terpenes consumed more total feed when offered in pairs vs. singly, and as much (combined intake) as controls receiving no PSM when all three were offered together. The sequence in which nutritious foods are offered appear to also affect intake with or without PSM (oxalates, tannins, or terpenes) with sheep that were fed PSM foods in the morning consumed more of them, and that restricting nutritious feeds during conditioning caused animals to learn to mix feeds with and without PSM (capitalizing on complementary interactions), which continued even when nutritious alternatives were available ad libitum in later periods. Greater diversity may provide opportunity for animals to learn to mix diets that will improve nutrient intake while reducing intake of a specific toxin (or class of toxins). It has been reported that sheep receiving a high quality (protein and energy) diet ate more total toxins when fed three diets containing different toxins compared to sheep with access to a low quality diet. Often studies that find a relationship of preference or intake and PSM involve animals on a low plane of nutrition, with less pronounced effects on high quality diets. However, even with a higher plane of nutrition, animals may not consume more PSM unless there are no alternatives.

Decreased intake, altered length/number of feeding bouts, switching to forage with different concentrations and classes of PSM are specific behavioral mechanisms utilized by herbivores to provide time for toxin clearance prior to resumption of intake. Pattern of intake may be as important as amount of intake in terms of the ability of an animal to cope with PSM. Lambs fed diets containing monoterpenes in concentrations representing multiples found in sagebrush decreased intake with higher terpene concentrations, besides altering their temporal pattern of feed intake; lambs receiving diets with higher concentrations of terpenes spent more time eating later in the feeding period, thereby spreading PSM intake over a longer timeframe. Altered meal patterns have been observed as a behavioral mechanism to regulate PSM intake by marsupials consuming eucalyptus. In addition to reduced total intake, a decreased rate of intake has been reported per feeding bout along with a decreased meal length in response to increased PSM intake. While meal size appeared to be reduced, meal frequency was unaffected by PSM intake.

The inverse relationship of PSM and herbivory by koalas under field conditions suggests spatial chemical distribution may influence animal distribution. The scale of heterogeneity of PSM distribution may also affect efficiency of herbivory, as intake, number of feeding bouts, rate of intake, and number of diet switches by possums decreased, while travel increased as scale of heterogeneity (i.e., distances between patches varying in chemical classes and concentrations) increased. Thus, spatial scale of heterogeneity within an environment may affect foraging decisions and optimal diet switching and therefore play a role in maximizing intake while coping with PSM. Although much less information is available regarding ruminant behavior and PSM (beyond classic intake reduction), it has been noted that tannins can alter feeding behavior by causing more and shorter feeding bouts. Workers in Utah examined the effect of spatial and temporal availability of forage on sagebrush use by lambs under field conditions, comparing high vs. low stocking density on areas the same size and moved daily and a third treatment with high stocking density on thee-fold greater area rotated every third day (temporal aspect). They reported time spent browsing sagebrush to be 25, 16, and <1% for high density/one day, high density/three days, and low density stocking, respectively. The three day treatment exhibited cyclic sagebrush feeding, with almost none on the first day and high use by the third day as understory became scarce.

Swedish researchers found that intake can be affected by the order in which patches containing PMS are encountered. While preference for low hydrolyzable tannin content appears to be the main determinant of intake by fallow deer, sequence of encounter could also affect intake because deer ate more high-tannin food when it was more common. In addition to frequency, patchiness and spatial proximity of neighboring plants may be important if distance affects perceived contrast of tastes. Fallow deer fed in groups ate more hydrolyzable tannin (less pronounced selectivity) than when tested individually. Relative quality of other plants in association with a given plant can affect it's consumption, and the degree to which a plant is defended or susceptible to herbivory when associated with other palatable/unpalatable plants appears to be affected by spatial distribution phenomenon. To some extent, herbivore foraging behavior and intake of plants containing PSM are driven by the neighboring plants with which they are associated, and in turn, use of plants with secondary compounds can alter plant communities and herbivore distribution. Spatial arrangement of plant species probably greatly influences how effectively an animal can utilize PSM complementarity.

Natural products are known to have antimicrobial and other medicinal properties in humans, although the extent to which herbivores self-medicate and take advantage of nature's pharmacy is in its infancy. However, scientists in Utah demonstrated that sheep fed diets containing grain, quebracho tannin, or oxalate treatments were able to associate specific medicines (sodium bentonite, PEG, or dicalcium phosphate) with the diets that relieved illnesses caused by the respective diets. Sheep receiving PEG free-choice can regulate PEG intake as needed based on tannin intake and alter behavior to spend more time in areas where PEG is located when consuming high-tannin diets. Tannins can alter feeding behavior by causing more and shorter feeding bouts, while administering PEG restores meal length back to normal. Proportions of high-tannin to high-terpene plants on a landscape may affect how they are used, which has implications for maintaining biodiversity. Seeding high-tannin shrubs in areas has been suggested as a potential mechanism to increase utilization of terpene-containing shrubs.

Teaching animals at a young age (socialization, etc.) to mix and consume more toxins may have positive effects on biodiversity. Animals with experience consuming toxins may have greater diet breadth and consume more PSM-containing plants even when nutritious alternatives are available; thus, training animals (e.g., short-term restriction or altered timing of familiar nutritious forages) to consume a variety of combinations of feeds may improve uniformity of rangeland use and help prevent shrub encroachment. As mentioned above, both high stocking density and increased time of exposure (both of which reduce alternatives) increased sagebrush use by sheep. Restriction of alternatives may help train animals to learn about complementarity and to use less desirable plants.

### 6. Ethics, Laws, Health, Safety and Animal Welfare

Animal behavior and animal welfare are different disciplines yet ethology has been closely associated with welfare issues. Welfare is difficult to define because what it measures is often relative rather than absolute yet we have an obligation to ensure animals do not suffer unnecessarily. When an animal cannot cope with stimuli coming from its environment, a welfare problem exists.

The first animal rights legislation aimed at preventing cruel and improper treatment of domestic livestock dates to the early 1800's in the United Kingdom; however, the modern animal welfare movement probably began in the 1960's with the book entitled *Animal Machines*. Since Harrison's book, the case for animal welfare and animal rights has largely focused on "factory farm" type production systems. The importance of welfare issues continue to grow as evidenced by chapters as well as entire textbooks devoted to the subject. Currently there are two scientific journals devoted to welfare issues entitled *Animal Welfare* and *Journal of Applied Animal Welfare*, begun in 1992 and 1998, respectively. Today, issues of animal feelings, especially as they affect mental, psychological and cognitive needs, are also considered welfare issues.

Welfare issues that focus on extensively managed livestock have been addressed though not to the extent of that involving intensively managed animal species. Though frequently overlooked, natural disasters can cause more suffering and death among free-ranging livestock than many animal husbandry practices. Though natural disasters wreak havoc and stress on the human population this does not excuse humans to become complacent during these times concerning livestock welfare.

Currently farm animal production in the United States is not regulated under the Animal Welfare Act (http://www.nal.usda.gov/awic/legislat/usdaleg1.htm); yet research in most developed countries, including the USA, follow something similar to the Institutional Animal Care and Use Committee (http://www.iacuc.org.) protocol when conducting research. Many scientific journals now require IACUC approval of the experimental design in order for the research results to get published.

The welfare and ethics of such husbandry practices as dehorning, branding and castration affect free-ranging livestock along with issues surrounding predation. While cattlemen in Australia can tolerate predation losses from the presence of some dingoes, sheep producers cannot co-exist economically with dingo infestation. These issues are complex and defy simple answers or simply more research because many of these answers will not come not from science but from the societal ethics that underpin the science. As a result a tension exists within questions such as: Is the loss of "some" livestock by predation acceptable? Should naïve animals be given ‘training’ before being placed on a ‘new’ landscape to shorten their adjustment period, especially in harsh rangeland environments? Though it is unacceptable to let animals die of starvation during a drought, how much weight loss and thirst should animals be allowed to experience before it is no longer ethically acceptable? How much am I as a consumer willing to pay for an end product that has an ethical economic cost attached to it? Data on this question suggests that words and actions of consumers often differ. How long is it ethically acceptable to allow animals to seek their diet from standing crop that contains forage that may have secondary compounds that will be toxic if consumed in excess quantities? Is there an optimum size group for free-ranging animals based on behavioral traits that is unrelated to how we currently calculate stocking rate? These are just some of the animal welfare questions that impact free-ranging animal management that currently remain unanswered. Those that require scientific research to ethically improve the art and science of free-ranging livestock production should be addressed immediately. Animal welfare issues must be addressed proactively by research and industry not only for the welfare of animals but for the health and safety of humans, currently a growing point of concern world wide. Evolving tools requiring computers and modeling may assist in answering some of these questions by reducing the number of animals required in a research programs.

### 7. Low-Stress Management Strategies

Low-stress animal handling originated in antiquity when animal husbandry was practiced by the same humans who directly benefited from the products they produced. Today’s economy has largely separated animal production from consumers who still depend on animals for food and fiber. Agricultural colleges and universities are now educating students with scientific as well as husbandry skills that blend the art and science of what is commonly referred to as low-stress management. A premier text by Smith (see bibliography) provides practical scientific-based insight into the principles of low-stress management and its practical application to handling livestock. Low-stress animal handling requires the manager to think and communicate with the animals in a way the animal understands, that is seldom the handler's native language. In general, the slower and smoother (non-jerky) humans move when attempting to bring about a change in an animal's behavior, the faster and more accurate will be the animal's response. As technological advances continue to impact free-ranging animal production, an increased focus will be required to ensure animals are produced in a safe low-stress environment.

## 8. Animal Behavior and 21st Century Range Animal Ecology

The role of behavior in free-ranging animal management surely predates recorded history. Recognizing the role behavior patterns play in diagnosing an animal's health was recorded as early as 1851. However, it was not until the mid-1950's that behavior became a legitimate part of animal science research. Furthermore, it is only much more recently that the role of behavior in management of free-ranging animals has been emphasized. Today it is generally accepted that it is at the nutrition-behavior interface that the most progress in production agriculture of free-ranging animals can being made.

Managing animal distribution remains one of the yet to be solved challenges in range animal ecology, especially as it results in the unequal use of individual plants, not just areas on the landscape or species. Though herding may be the best way to address this issue the economics and availability of individuals trained in the principles of herding remains questionable in developed countries. Wire fencing is currently the most widely used method to control free-ranging animals where economics permit. Conceptually fences are static yet fences were designed to attempt and manage two dynamic very non-static resources — plants and animals. This presents both a physiological and psychological dilemma setting the stage for using animal behavior in a new and useful manner to control animals.

Virtual fencing relies on controlling animals by altering an animal's behavior through sensory cues, most often considered irritating by the animal. The first sense stimulated with convention fencing involves sight of a physical object that prevents forward movement. However, with virtual fencing the animal is unable to see a physical barrier but must be made aware of a boundary using one or more of the other senses, most commonly hearing and tactile stimulation. Virtual fencing was initially developed in the 1970's for containing household pets, principally dogs. The perimeter of an area in which the pet was to remain was outlined with wires place either just below on directly on the soil surface. From these wires an RF signal would emanate. The pet would wear a collar around its neck that contained electronics to produce audio as well as an electrical stimulation cues. If the animal attempted to breech the perimeter wire delineating the area in which the pet was to remain a sound and or electrical stimulation would be administered to the animal through the collar as the wire was approached at a predetermined critical distance. The first research with livestock using this type of equipment was conducted in the later 1980's using goats, since then sheep, ponies and cattle have all been successfully controlled using commercial pet containment systems. It must be understood that since this method of animal control relies on altering animal behavior virtual boundaries can be "leaky" since animal behaviors are never 100% predictable. Therefore, where health or safety issues involving humans or animals are of concern virtual fencing, when commercially available, will not be the containment method of choice.

The first time that an RF signal originating from GPS satellites was used to control free-ranging beef cattle took place in April 2002, thus eliminating the challenges topography often posses when using conventional ground-based fencing. Furthermore, it was possible to administer a suite of cues in a bilateral fashion making it possible to directionally move cattle across a landscape as well as hold cattle and even flerds behind static boundaries. This particular type of virtual fencing methodology has been termed directional virtual fencing (DVF™).

By melding GPS and GIS with animal behavior, it has now been shown in a research setting that it is possible to obtain autonomous control of free-ranging animals in a spatially and temporally flexible manner. The availability of GPS has been the single most important technological advancement that will eventually allow virtual fencing to be implemented on extensive landscapes regardless of their topography or remoteness. Because of the great variability in the response of cows to sensory cues used in this method of animal control the future of this methodology must not only embrace feedback from aspects of the landscape provided through GIS data but also feedback from the animal itself in order to optimize the cuing package to realize free-ranging animal control. Though much behavioral biology remains to be understood as we approach the control of biological systems using sensory cues, there remain many legal and ethical issues to be addressed. This is especially important since animals can now be controlled similarly to robots using electronics packages connected to an animal's brain.

It may not be necessary to instrument all animals with virtual fencing devices within a gregarious group of free-ranging animals if the management objective is group control. However, determining which animals within a species group should wear virtual fencing devices in order to control the entire group has yet to be determined. A sage cattle producer in Australia has suggested that if he were forced to choose which of his cattle he would instrument he thought he would probably instrument those animals that were the first to leave the drinking water. Research with sheep has suggested that movement of a group of sheep may be initiated by individuals that are both less gregarious and more independent when observed. Furthermore, these sheep appear to keep their back to other sheep and maintain a greater distance of separation between themselves and the flock. In actuality the traits that would characterize leadership traits within a gregarious livestock group on which virtual fencing is to be used is yet to be scientifically determined.

### 8.1. Technological Advancements – Animal + Machine

The initial interface between machines and animals probably dates from the late 14$^{th}$ to early 15$^{th}$ century when bells were first used on livestock. One of the earliest records dates from 1440 and involved a bell tied to the "lead" sheep whose job it was to lead the remainder of the flock (origin of the term bell-wether). A report from 1853 suggested that a lead cow deprived of her bell demonstrated "frustrated" and "belligerent" behaviors indicating that the interface between machines and animals brings with it new management challenges.

An example of melding animal behavior with machines to foster management involved autonomously obtaining free-ranging cattle liveweights. However, two separate technologies were needed for this to come to fruition. Load cells developed after the 1940's were necessary to implement electronic weighing and when this technology was coupled with automated animal identification autonomous weighing of cattle began being discussed as early as 1972. Automatic weighing was probably first demonstrated with dairy cows during the 1970's. However, the first system designed to operate unattended in a remote location for simultaneously identifying and weighing free-ranging beef cattle involved joint research between the USDA-ARS-JER and LANL. Periodic liveweights were obtained by combining the animal's innate need for hydration (behavior) with a mechanical and electronic system through which the cattle had to pass before they were given access to drinking water. With this behaviorally based data acquisition system it was possible to detect between a 5% and 11% change in a cow's liveweight 90% of the time depending on the number of times a cow was weighed within a 7-day period. Other researchers have used similar systems to not only record liveweight but water consumption.

Often what begins as research equipment enters the commercial market, as evidenced by electronic animal identification. The number of companies offering animal-identification products and services grew from 16 to 54 between October 2002 and August 2006, respectively. Today electronic identification tags are readily available and may ultimately become a legal requirement for tracking animal commerce world wide. However, there remains the question of verification of authenticity, especially when health and safety of our food supply is in question. This concern has resulted in other identification methods that rely on attributes of the animal itself, including: DNA "fingerprinting", autoimmune antibody labels, muzzle pattern, retinal vascular pattern, iris pattern, and facial recognition.

The automated measurement of animal travel has also experienced an evolution. The first device developed for paddock studies were reported in the mid 1950's and consisted of a device attached to a harness and pulled by the animal. The device consisted of a wheel and mileage recorder to record the distance traveled by sheep and cattle. During the 1970's, digital pedometers, originally designed for humans to record activity, were attached to the metacarpus of a cow's front leg to monitor travel of free-ranging cattle. These instruments were first used in the 1920's to monitor activity of sheep. With the eventual use of two pedometers per cow, precision was improved and it was possible to compare how nutrition and an animal's physiological state influenced cattle travel without having the observer present to influence the observation. Spatial differences in food resources (patch density) on a landscape affect animal travel making movement strategies a central focus in ecology. Furthermore, travel is basic to an understanding of some of our most fundamental foraging concepts (see Sec. 4 A). Today monitoring free-ranging cattle travel has moved from mechanical devices to electronic technology that relies on GPS. However, electronic pedometers are still used for detecting estrous in dairy cattle.

One of the first reported studies in which animals were to be tracked autonomously was described by Australian researchers in 1975. In this study animals were equipped with equipment saddles that emitted signals allowing the animal to be tracked using the then current state-of- art electronics. However, following the launch of the Sputnik and Vanguard satellites in the late 1950's, wildlife biologists began considering the possibility of tracking animals from space. The first such tracking study using GPS was used to track moose during the 1970's. With GPS technology the distances animals travel can now be investigated with a resolution not previously possible.

Other examples of integrating animal behavior and machines involves robotic sheep shearing and automatic milking based on the cow's physiological cues that cause her to move to and enter a fully automated milking parlor where machines rather than human labor performs the milking. As wireless sensors recede into the background to become what has been called ubiquitous computing or calm technology, the future of the animal-machine interface appears bright. However, no matter how clever the devices the human mind develops in response to future production agriculture needs, nothing should ever replace the human's and his capacity to reason in melding appropriate technology with animal behavior.

### 8.2. Choices and Consequences

In contrast, communication, understanding, partnerships and a re-linking of producers and consumers will be essential for redesigning animal agriculture that has meaning for addressing global issues facing production agriculture today. Managing free-ranging animals will become increasingly specialized, demanding a greater knowledge and expertise on a wide variety of topics compared to only a few decades ago. Besides knowledge of nutrition, genetics, veterinary medicine and animal behavior, 21st century livestock managers must be computer and electronic literate in a way not required of their contemporaries. Furthermore, human understanding will require a paradigm shift that puts husbandry back into the livestock management equation. One of many examples as to how this should be done involves capitalizing on the animal's time schedule and not our own to accomplish management goals. By allowing the animal to optimize innate behaviors we should be in a better position to optimize abiotic as well as biotic outcomes to the ecosystem as a whole.

### Related Chapters

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### Glossary

| | |
|---|---|
| **AU** | **:** Animal Unit |
| **DVF™** | **:** Directional Virtual Fencing |

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| **FLERD** | **:** Small ruminants, sheep and goats that have had their behavior modified such that they choose to remain in the presence of cattle under free-ranging conditions. A mixed species group composed of animals usually associated with a flock and herd. |
| **GPS** | **:** Global Positioning System |
| **GIS** | **:** Geographic Information System |
| **IACUC** | **:** Institutional Animal Care and Use Committee |
| **LANL** | **:** Los Alamos National Laboratory |
| **PEG** | **:** Polyethylene Glycol |
| **PSM** | **:** Plant secondary compounds also called secondary compounds |
| **RF** | **:** Radio Frequency |
| **RIPARIAN** | **:** The land located on either side of a natural flowing or non-flowing watercourse |
| **SDG** | **:** Short Duration Grazing |
| **USDA-ARS-JER** | **:** United States Department of Agriculture – Agriculture Research Service-Jornada Experimental Range |

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