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Subcommittee on Public Lands and Environmental Regulation
Increasing Carbon Soil Sequestration on Public Lands
Expert Testimony by
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Good afternoon. Thank you Chairman Bishop, Ranking Member Grijalva, and all of the members of this subcommittee for the chance to speak with you today. I am Richard Teague, Associate Resident Director of Texas A&M AgriLife Research in Vernon, Texas. I am also a Professor in the Department of Ecosystem Science and Management at Texas A&M University and Senior Scientist of the Texas A&M Norman Borlaug Institute for International Agriculture. I am honored to speak with you today about the important issue of increasing carbon sequestration on public lands.

Background and experience

I was raised in a farm community and schooled in Zimbabwe before obtaining a BSc (Agriculture) in grassland science (1972) at Natal University in Pietermaritzburg, South Africa, and a PhD in botany and microbiology (1987) at the University of the Witwatersrand in Johannesburg, South Africa. As a research scientist working on the management of rangelands since 1972, I have visited most grazing areas of the world, attending conferences and presenting the results of my research. I actively seek out leading conservation ranchers in the ecoregions I visit, including Zimbabwe, South Africa, Namibia, Australia, New Zealand, Argentina, Chile, Canada and most of the western rangeland states in USA. I am intimately aware of the research that has been done on grazing management in most parts of the world. As part of my research activities, I worked with a number of leading ecological and grassland management academics as well as the leading conservation ranchers in those countries, especially Zimbabwe and South Africa. Since arriving in Texas in 1991 I have concentrated on researching the best management strategies to sustain and improve resources and livelihoods on rangelands.

The need to manage for improved ecosystem function

For humans to live sustainably, natural resources need to be used and managed in ways that prevent their depletion and that ensure their resilience for self-replenishment. To ensure the long-term sustainability of these resources, agricultural production should be guided by policies and management protocols that support ecologically healthy and resilient ecosystems and that mitigate anthropogenic greenhouse gas (GHG) emissions. Healthy agro-ecosystems are considerably more productive, stable and resilient than those in poor condition. Maintaining or enhancing the productive capacity and resilience of rangeland ecosystems is critical for the people who depend on them for their livelihoods and for the continued delivery of rangeland ecosystem services for the broader benefit of societies around the world. Such services include the maintenance of stable and productive soils, the delivery of clean water, the sustenance of plants, animals and other organisms that support human livelihoods, and other characteristics that support aesthetic and cultural values (Daily 1997; Grice and Hodgkinson 2002). While ranch livelihoods depend on healthy ecosystems, the value of ecosystem services to society is worth more than mere agricultural earnings. High soil carbon is the foundation of a healthy ecosystem. Rangelands are a huge sink for carbon dioxide (CO_2) but most rangeland is degraded to some degree, and regenerative grazing will be needed in most situations to improve ecosystem function. To remain economically viable, managers must maintain or improve the biophysical functions and processes necessary for sustaining ecosystem health and resilience, including soil organic matter accumulation, solar energy capture, water infiltration, and nutrient cycling while also maintaining ecosystem biodiversity. In the long term, this strategy provides the greatest cumulative production potential and economic profits without decreasing delivery of ecosystem services for society.

The ability of food production systems to meet the demands of burgeoning human populations with higher per capita consumption depends on the alignment of increased production with the maintenance of healthy ecosystems and GHG mitigation. Solutions to produce such alignments must maintain the terrestrial and atmospheric natural resource base. At the same time they must address environmental, social, cultural and economic complexity, tradeoffs among different choices and they must also address unintended consequences. In contrast to the deficiencies of many traditional agricultural production systems, ecologically sensitive management of ruminant livestock in native perennial rangelands can positively contribute to critical ecosystem services, including carbon sequestration, maintenance of stable and productive soil structure, maintenance of functional water catchments and delivery of clean water, production of healthy food, protection of critical wildlife habitat, and enhancement of biodiversity (Liebig et al. 2010; Delgado et al. 2011).

In this paper I indicate how livestock management can facilitate the provisioning of essential ecosystem services, increase soil carbon sequestration, reduce GHG emissions and reduce environmental damage caused by current agricultural practices. I outline the value of using conservation-based grazing management and the potential for improvements in grazing management to enhance carbon sequestration through the sustainable, regenerative use of natural resources.

Restoring soil carbon on rangelands

The loss of soil carbon is extremely damaging in a number of ways. Loss of soil carbon negatively impacts ecosystem function and the provision of vital ecosystem services. The most limiting factor to ecosystem function and productivity on rangelands is the amount of water entering the soil. Water entering the soil and water retention in the soil are both directly influenced by soil carbon content. Thus loss of soil carbon causes degradation that affects all ecosystem processes (Thurow 1991). The amount of carbon in soils is directly related to the diversity and health of soil biota and as these microbes are dependent on plants, the manner in which we treat plants is critical to restoring soil carbon levels (Bardgett and McAlister 1999; Sacks et al. 2014). Nearly all organic carbon sequestered in soils is derived from the atmosphere by photosynthesis in plants and other organisms and converted to complex organic molecules in the soil by bacteria and fungi operating synergistically with insects and animals. In rangelands the influence of livestock can result in losses or gains in soil carbon depending on how the plants are managed. Poor grazing management that maintains grazing pressure without respite for plants to recover causes degradation, while grazing that defoliates plants moderately and provides for recovery before the plants are grazed again reverses degradation and increases the amount of carbon sequestered in the soil.

The impact of continuous grazing

Prior to man herding grazers in sedentary circumstances, large herds of wild grazers lived under free-ranging conditions over the world's grazing ecosystems. The co-evolution of plants and herbivores under changing environmental conditions has resulted in highly resilient grazed ecosystems that support more animal biomass and sustain considerably higher levels of herbivory than other terrestrial habitats (Frank et al. 1998). Grazing, fire and fluctuating climatic regimes create the dynamic resilience of organisms that respond constantly to biophysical events. As a consequence, most ecosystems never reach a steady state or climax seral stage (Pielou 1991). Rather, periodic disturbances rejuvenate and transform landscapes with respect to soil nutrients and structure, plant species composition, structure and biodiversity (Hulbert 1988). Although grazing pressure can be intense at some sites in free-ranging conditions of grazed ecosystems, concentrated grazing seldom lasts long when the movement of herbivores is not restricted; instead grazed plants are typically afforded time for inter-defoliation recovery when herds move to new feeding grounds (Frank et al. 1998).

Unfortunately, the replacement of free-ranging wild herbivores with livestock managed by humans has frequently led to severe degradation of rangelands. Domesticated livestock have become sedentary as humans restricted their movements across landscapes, suppressed periodic fire, and eliminated large predators (Milchunas and Lauenroth 1993). This has led to the removal of periodic animal use and positive impacts of animals on plants followed by the key revitalizing element of periodic recovery from defoliation for plants and to decreased nutritional quality and health for herbivores (Provenza 2008). In many instances, pressure on grazed plants has been further elevated through the use of supplementary feed to retain high animal numbers during less productive periods (Oesterheld et al. 1992).

Animals do not graze uniformly over the landscape but repeatedly consume preferred plants and patches of vegetation. This selectivity is affected most by vegetative heterogeneity at the landscape level and to a lesser degree by plant heterogeneity at the feeding-station scale and by distance of forage resources from water (Stuth 1991). Overgrazing occurs when individual plants are subjected to multiple, severe defoliations without sufficient physiological recovery time. In turn, excessive herbivory removes threshold amounts of biomass and litter, causing soil exposure and degradation in heavily used areas (Thurow 1991; Teague 2011). The spatial arrangement and scale of vegetative patchiness are major determinants of patterns of grazing and site selection when livestock are stocked continuously in a given area. These factors combine to increase vegetative heterogeneity as the size of the grazing paddock increases, which typically causes heavy, repeated impacts on preferred areas while other parts of the paddock receive light or no utilization (Coughenour 1991; Fuls 1992; Kellner and Bosch 1992; Teague et al. 2004). Figure 1 illustrates the impact of grazing on a rangeland landscape. Note the uneven impacts that result in greater than expected impact on the favored areas and underutilization over the rest of the landscape.

These impacts over the heavily grazed portions of the landscape set in motion a degradation spiral. Droughts, which are common in many rangeland ecosystems, exacerbate the effects of chronic defoliation (McIvor 2007), causing preferred plants to be less productive and eventually perish unless afforded a recovery period. This increases the amount of bare ground and favors less desirable plants, which are more highly physically and chemically defended species of grass, forbs and shrubs (Briske 1991; Provenza 2008). Reducing stocking rates to low levels to reduce degradation often exacerbates uneven grazing impact because the most desirable areas and plants within them continue to be more frequently and intensively grazed while less desired areas and plants are visited less often (Teague et al. 2004). Therefore, while stocking according to forage supply is a crucial first step in sustainable rangeland management for livestock production, it must be applied in conjunction with other practices that increase animal distribution and movement, and that include periodic growing season recovery and short grazing periods to mitigate the damaging effects of repeated selective grazing (Morris and Tainton 1991; O'Connor 1992; Provenza 2008). This process of degradation causes loss of soil carbon as the amount of bare ground increases and as the most productive grasses that contribute most to sequestering soil carbon are replaced by less productive grasses. Thus the impact of overgrazing directly causes greater loss of soil carbon and a decrease in the amount of carbon sequestered.

Managing to improve ecosystem function

The key to sustaining and regenerating ecosystem function in rangelands is actively managing for reduction of bare ground, promoting the most beneficial and productive plants by grazing moderately over the whole landscape, and providing adequate recovery to grazed plants. These changes result in decreased soil carbon loss and increase carbon sequestration. Ecosystem function is enhanced when the amount of water entering and being retained in the soil, increases. While many grassland ecosystems have been degraded through unsustainable livestock production practices, ranchers throughout the world have shown it is possible to use planned multi-paddock grazing to reverse degradation in areas with as little rain as 250 mm per year to areas receiving over 1,500 mm per year. This reversal is also possible on public rangelands, as demonstrated by numerous ranchers on privately owned ranchland in the Great Plains and western rangelands.

Restoring the ecological functionality of these degraded ecosystems necessitates the use of regenerative grazing management practices. Such grazing management has resulted in increasing forage productivity, restoration of preferred herbaceous species that were harmed by previous grazing practices, and increased soil organic carbon and soil fertility, water holding capacity and economic profitability for ranchers (Teague et al., 2011; Teague et al. 2013). In "across the fence" comparisons in semi-arid rangelands of Texas, planned multi-paddock grazing applied to areas previously degraded through prolonged continuous grazing resulted in carbon sequestration and soil organic carbon increases that lead to an estimated average difference of 30 metric tons of carbon per hectare over a decade compared to commonly practiced heavy continuous grazing (Teague et al. 2011). When domestic ruminants are managed in a way that restores and enhances grassland ecosystem function and where the only feedstock is grass produced via solar energy, increased carbon stocks in the soil will lead to larger and more diverse populations of soil microbes, which in turn increase carbon sequestration, including methane oxidation (Bardgett and McAlister 1999; Teague et al. 2013). Therefore, as long as management results in building soil health, and does not have other carbon inputs, grazing animals can lead to carbon "negative" budgets, i.e. more carbon enters the ground than is emitted, either directly via carbon loss from the soil or indirectly via ruminant greenhouse gas emissions (DeRamus et al. 2003; Liebig et al. 2010; Janzen 2010; Delgado et al. 2011).

Ranching in rangeland ecosystems is characterized by ever-changing and unpredictable environmental conditions and circumstances due to low, variable and spatially and temporally heterogeneous precipitation and plant productivity, and to fluctuating economic conditions driven by market price fluctuations and shifting social values. By using soil, water and plant resources efficiently and sustainably, successful rangeland managers enhance the health of the ecosystems upon which they depend, their profitability and their life quality, while also providing ecosystems services desired by society (Walker et al. 2002). They combine scientific principles and local knowledge to proactively manage animals to influence four ecosystem processes: efficient conversion of solar energy by plants; interception and retention of precipitation in the soil; optimal cycling of nutrients; and promotion of high ecosystem biodiversity with more complex mixtures and combinations of desirable plant species (Stinner et al. 1997; Reed et al. 1999; Savory and Butterfield 1999; Gerrish 2004; Barnes et al. 2008; Diaz-Solis et al. 2009; Teague et al. 2013). To accomplish this, successful managers apply the following five principles:

1. Provide sufficient forage for animals to select a diet of adequate quantity and quality;
2. Manage grazing so animals eat a wide variety of plants and decrease impacts on desirable plants;
3. Leave enough leaf biomass on defoliated plants to facilitate interception and infiltration of precipitation and to maintain sufficient photosynthetic capacity for rapid plant recovery;

4. Allow adequate post-grazing recovery to maintain plant vigor and desired plant composition; and
5. Plan and create the means to control grazing pressure in time and space to facilitate the previous 4 principles.

This has been achieved most successfully by using multiple paddocks per herd, or moving animals around by herding, or using fire to achieve light to moderate defoliation for short periods of time during the growing season followed by adequate recovery time before grazing again. Multi-paddock grazing thus facilitates grazing of the whole landscape by grazing one paddock at a time, as illustrated in Figure 2. Using many paddocks spreads the impact of livestock over the whole landscape, and by managing each subdivision to ensure moderate use in the growing season and adequate recovery, the negative impacts of grazing under continuous grazing (even at low stocking rates) are mitigated, resulting in much better ecological condition and soil health. This also facilitates selecting a wider variety of plant species, regulating how much of a paddock is grazed before it is vacated to recover and the length of time necessary to allow full recovery. The USDA-Natural Resources Conservation Service promotes regenerative multi-paddock grazing as the best means to improve soil health.

Superior results in terms of range ecosystem improvement, productivity, soil carbon and fertility, water holding capacity and profitability have been regularly obtained by ranchers using multiple paddocks per herd with short periods of grazing, long recovery periods and proactively changing recovery periods and other management elements as conditions change (Teague et al. 2011; 2013). One of the most important benefits of using planned multi-paddock grazing is that it facilitates making essential adjustments to all facets of management to avoid incurring negative impacts and taking advantage of positive events that occur. The main items that have been found to achieve best results include:

- Matching animal numbers to available forage at all times;
- Spreading grazing over the whole ranch;
- Defoliating moderately in growing season;
- Using short grazing periods;
- Allowing adequate recovery before regrazing;
- Grazing again before forage becomes too mature for good animal performance; and
- Proactively changing these elements according to changing conditions.

Many ranchers around the world have used these proactive, multi-paddock grazing management principles to restore ecosystem services and productivity on degraded rangelands. Many ranches in drier ecosystems were initially so bare of vegetation that they would have been classified as desertified. The overwhelming majority of conservation awards to ranchers operating on native rangelands have gone to ranchers using multi-paddock grazing of one form or another. These ranchers operate in extensive, heterogeneous landscapes, where they are confronted with the adverse effects of uneven grazing distribution, and their collective ecological and management knowledge of multi paddock grazing indicates the necessity of using proactive, multi-paddock grazing management to achieve superior outcomes. This form of grazing management has been shown to be effective in restoring plant cover of the soil, plant species composition and productivity on millions of hectares on four continents, primarily in semi-arid and arid areas, since the 1970s. Sacks et al. (2014) have postulated that it has the potential to remove excess atmospheric carbon resulting from anthropogenic soil loss and degradation over the past 10,000 years, as well as industrial-era greenhouse gas emissions. This sequestration potential, when applied to the approximately 5 billion hectares of degraded range and agricultural soils, could theoretically return 10 or more gigatons of excess atmospheric carbon to the soil annually and lower greenhouse gas concentrations to pre-industrial levels in a matter of decades. As a low-tech approach it is inexpensive and entails little of the risk inherent to large-scale, industrial environmental solutions. On public lands where permanent structures are not favored, the common practices of herding, or forming paddocks with moveable, solar-powered electric fences offer eminently practical and low cost solutions.

An analysis of ranching failures (Teague et al. 2013) reveals many common problems that need to be avoided. They include:

- Too many animals before soil and plants had improved
- Not developing suitable stock water system
- Inadequate planning
- Not adapting as conditions change
- Defoliating too heavily in growing season
- Long grazing periods
- Inadequate recovery before regrazing
- Expecting improvements where conditions are very limiting

Contradictory results from research and ranch based experience

Most research related to grazing management (reviewed by Briske et al. 2008; 2011), and thus carbon sequestration potential on rangelands, has been short-term and has examined the issue from a reductionist viewpoint that ignores the critical influences of scale (Figure 3), and does not use proactive multi-paddock grazing to achieve sound animal production, resource improvement, and socio-economic goals under constantly varying conditions on rangelands (Teague et al. 2013). Figure 3 superimposes hypothetical research plots on this landscape at the scale of most grazing management research. Note that no matter which plot or group of plots is chosen NONE of them shows the impact that occurs over the whole landscape. This illustrates how poorly most research on this topic has misrepresented what actually happens on commercial ranch landscapes.

In a recent review of the literature to determine why many research projects have arrived at conclusions that are contradictory to results obtained worldwide on ranches managed for conservation goals, Teague et al. (2013) report a number of key reasons. First, the application of experimental treatments in controlled grazing experiments has, in general, not taken into account commonly recognized principles to maintain health and vigor of plants and nutrient intake of animals. In addition, the spatial limitations, short-term nature, and inflexible grazing treatments imposed in most experiments have prevented researchers from adequately accounting for the spatial heterogeneity of vegetation, temporal shifts in weather, plant composition, time lags in learning necessary for animals to perform to their potential with changes in management, and stocking rate adjustments that characterize most rangeland production systems. Such experimental limitations have frequently led to results that imply multi-paddock grazing treatments are no better than, or inferior to, lightly or moderately stocked continuous grazing treatments, when in each case the reaction of organisms of interest are at the mercy of these factors without management to adjust to these factors.

By contrast, many ranchers have achieved excellent animal production and soil and vegetation improvements using multi-paddock grazing and find that the flexibility and timeliness of feedback inherent in multi-paddock grazing facilitate improved management compared to continuous grazing. They have responded to changing environmental circumstances through the use of proactive management practices that include regular resource monitoring and timely adjustments in livestock placement and numbers. In complex ever-evolving ecosystems, components emerge, change, and then disappear and managers cope and then capitalize on changes they help to initiate (Teague et al. 2013). We typically long for a standard recipe to ensure that we sustain the status quo, despite knowing that we are awash with variability in social and biophysical environments with changes largely out of our control. Instead, good management of complex systems requires flexibility, and less attempt to *control* than to *understand* and *respond appropriately and continuously* to changes as they arise. In the context of productive landscapes, successes should be judged at the system level and based on whether the system can support those who depend on it.

A second and related reason most grazing trials have not corroborated successful ranch-scale multi-paddock grazing experiences is that they have not adequately addressed animal-plant interactions at appropriate scales. Without management intervention, plant- and area-selective grazing increases with increasing paddock size and time. In general, small-scale and short-term grazing trials have not accounted for the uneven distribution of livestock in large continuously grazed paddocks, which leads to localised pasture degradation over time (see Figure 3). Neither has it accounted for the more even distribution of livestock in small continuously grazed research paddocks that leads to more even utilization. In addition, ranchers achieving positive results with planned multi-paddock grazing generally proactively manage recovery time to provide consistently adequate physiological recovery for defoliated plants. Either way, the conclusions are affected by the design and implementation of the study.

By ignoring successful restoration examples of conservation award winning ranchers who use planned multi-paddock grazing to proactively achieve desired goals and avoid negative consequences, research scientists have grossly underestimated the potential of management to facilitate carbon sequestration on the rangelands of the world. Consequently, they do not represent the subject adequately because conclusions have been selectively chosen so as to exclude published data showing superior results from proactively managed multi-paddock grazing at commercial ranch scales. The studies referenced underestimate positive benefits to soil and ecosystem function, so they almost certainly underestimate the potential of rangelands to sequester carbon and benefit ecosystem function overall.

Research that concentrates only on differences in productivity without meaningfully taking into account negative impacts on the environment can lead to misleading extrapolations. Such conclusions cloud rather than enhance knowledge about sustainable grazing management and have no relevance for practical grazing management applications. Further, published multi-paddock grazing research from Australia, Southern Africa, Argentina and USA have arrived at the opposite view to those expressed by Briske et al. (2008; 2011) when: i) conducted at the scale of ranching operations, ii) proactively managed as conditions changed to achieve desired ecosystem and production goals, and iii) measured parameters indicating change in ecosystem function (see Teague et al. 2011; 2013).

Conclusions

For soils to be a net sink for GHGs rather than a major source of GHGs as at present, grazing management on rangelands must build rather than compromise soil carbon and soil microbial functions, and reduce creation of bare soil and resulting erosion more effectively. With appropriate management in grazing situations, ruminant livestock have an important role to play in achieving these goals. They facilitate carbon sequestration in the soil to more than offset their GHG emissions, while providing essential ecosystem services that enhance both human and ecosystem well-being, such as improving water catchment function, stabilization of soil and soil fertility, carbon sequestration, enhancing wildlife habitat and biodiversity, and promoting the ability of local populations to sustain livelihoods.

Achieving these positive results on rangeland requires a change in land management practice. Emerging research suggests that non-conventional grazing management on cultivated pastures and rangeland might at least reduce GHG footprint, and at best, turn livestock management practices into a tool to improve the global environment, local ecosystems, economies, and even human health. Based on this research and observations on ranches around the world, planned multi-paddock grazing management can increase soil plant cover, plant productivity and soil organic carbon and thereby provide carbon sinks that far exceed the production of GHGs from the grazing ruminants. Planned multi-paddock grazing management also results in less erosion and improved hydrological processes that reduce non-livestock related GHG emissions. Where planned multi-paddock grazing has been applied in semi-arid and arid lands for some time, ephemeral streams have re-perennialized and biodiversity has recovered to varying degrees. Soil building grasses, nitrogen fixing native leguminous plant species, and even pollinators have come back. In short, planned multi-paddock grazing management appears to be an effective and low-cost way to reverse the deleterious effects to ecosystems of long-term continuous grazing.

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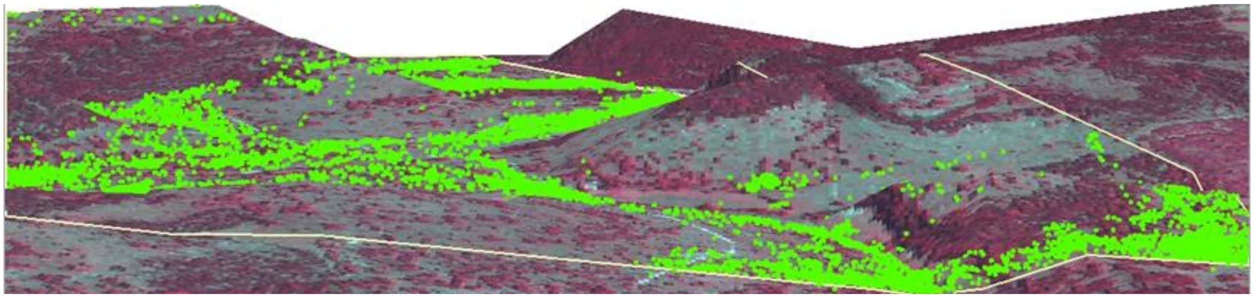

Figure 1. The heterogeneous impact of continuous grazing over a ranch landscape. The green dots are GPS locations of collared cows over a year of grazing. Plants in the heavily frequented areas are overgrazed, causing increased bare ground, poor plant productivity and replacement of desirable plants with less desirable plants degrading ecosystem function.

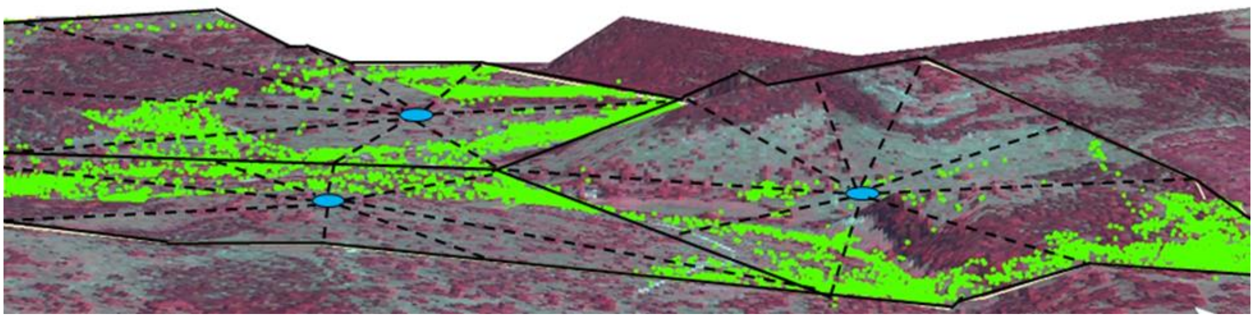

Figure 2. How multi-paddock grazing can facilitate better ecological condition and soil health. All animals graze in a single paddock for a short period before grazing the following paddocks in turn. Each paddock is afforded sufficient time of recovery before being grazed again. This results in spreading the grazing over the whole landscape and facilitates the animals selecting a wider variety of plants. This allows the manager to regulate how heavily each paddock is grazed and ensure each paddock has recovered before being regrazed. Done correctly this reverses degradation.

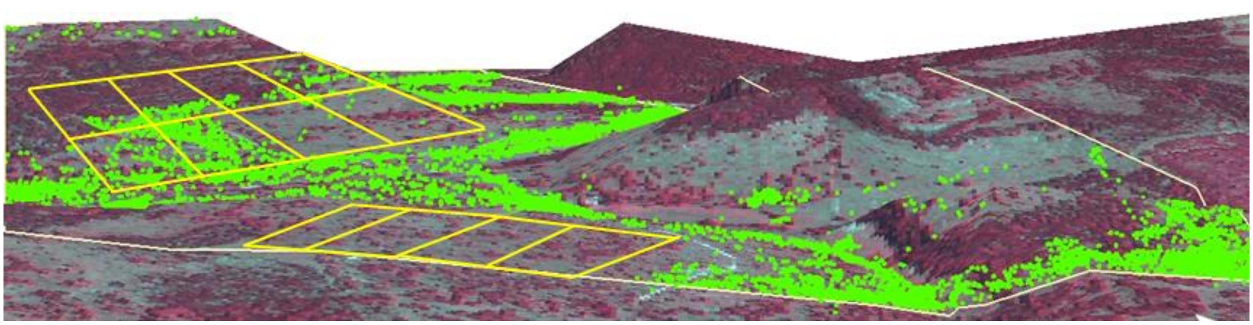

Figure 3. How previous small-scale plots misrepresent continuous grazing impacts on ranch landscapes. The small areas superimposed on the landscape represent small plot research areas commonly used to determine what impacts the grazing animals are making. Clearly none of them represents the impact being made in the ranch scale paddock. This has resulted in research projects underestimating the impacts of continuous grazing in large commercial scale ranches.