Savory

Holistic Management: Portfolio of Scientific Findings

Holistic Management Scientific Portfolio

Holistic Management Grounded in Evidence

For many years, large areas of grasslands around the world have been turning into barren deserts. This process, called desertification, is happening at an alarming rate and plays a critical role in many of the world's most pressing problems, including climate change, drought, famine, poverty and social violence. One major cause of desertification is agriculture—or the production of food and fiber from the world's land by human beings for human beings. In the past, large wild herds of grass-eating herbivores migrated and were pushed along by predators over the grasslands. These herds grazed, defecated, stomped and salivated as they moved around, building soil and deepening plant roots. Over time, the wild herds were largely replaced by small numbers of domestic, sedentary livestock and populations of predators were mostly destroyed. Without the constant activity of large numbers of cattle, the cycle of biological decay on the grasslands was interrupted and the once-rich soils turned into dry, exposed desert land.

Forty years ago, Allan Savory developed Holistic Management, an approach that helps land managers, farmers, ranchers, environmentalists, policymakers and others understand the relationship between large herds of wild herbivores and the grasslands and develop strategies for managing herds of domestic livestock to mimic those wild herds to heal the grasslands. Holistic Management is successful because it is a cost-effective, highly scalable, and nature-based solution. It is sustainable because it increases land productivity, livestock stocking rates, and profits.

Today, there are successful Holistic Management practitioners spread across the globe, from Canada to Patagonia and from Zimbabwe to Australia to Montana. More than 10,000 people have been trained in Holistic Management and its associated land and grazing planning procedures and over 40 million acres are managed holistically worldwide.

Evidence Supporting Holistic Management

The Savory Institute empowers people to properly manage livestock by teaching them how to use Holistic Management, connecting them in ways that have benefits for everyone, and removing barriers along the path to success. Many of our key audiences such as policymakers, landowners and investors want evidence that shows Holistic Management works to achieve large-scale environmental, economic, and social benefits.

To meet this need, the Savory Institute is working to measure impact by monitoring the health of ecosystem processes, sequestration of atmospheric carbon into soil carbon, well-being of our communities, as well as our financial vitality. The following portfolio that proves the principles behind Holistic Management includes peer-reviewed journal articles, theses and dissertations, and reports.

This portfolio will be ever evolving. The gaps in research, documentation, and monitoring will guide us in strategically identifying collaborations and projects in which to engage.

For more information about Holistic Management or this research portfolio, please visit http://savory.global or contact Bobby Gill, Director of Corporate Development, at bgill@savory.global.

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EVALUATION OF HOLISTIC MANAGEMENT

Teague, R., Apfelbaum, S., Lal, R., Kreuter, U.P., Rowntree, J., Davies, C.A., Conser, R., Rasmussen, M., Hatfield, J,, Wang, T., Wang, F., & Byck, P. (2016). The role of ruminants in reducing agriculture's carbon footprint in North America. Journal of Soil and Water Conservation, 71(2). 156-164.

Owing to the methane (CH_4) produced by rumen fermentation, ruminants are a source of greenhouse gas (GHG) and are perceived as a problem. We propose that with appropriate regenerative crop and grazing management, ruminants not only reduce overall GHG emissions, but also facilitate provision of essential ecosystem services, increase soil carbon (C) sequestration, and reduce environmental damage. We tested our hypothesis by examining biophysical impacts and the magnitude of all GHG emissions from key agricultural production activities, including comparisons of arable- and pastoral-based agroecosystems. Our assessment shows that globally, GHG emissions from domestic ruminants represent 11.6% (1.58 Gt C y^{-1}) of total anthropogenic emissions, while cropping and soil-associated emissions contribute 13.7% (1.86 Gt C y^{-1}). The primary source is soil erosion (1 Gt C y^{-1}), which in the United States alone is estimated at 1.72 Gt of soil y^{-1}. Permanent cover of forage plants is highly effective in reducing soil erosion, and ruminants consuming only grazed forages under appropriate management result in more C sequestration than emissions. Incorporating forages and ruminants into regeneratively managed agroecosystems can elevate soil organic C, improve soil ecological function by minimizing the damage of tillage and inorganic fertilizers and biocides, and enhance biodiversity and wildlife habitat. We conclude that to ensure long-term sustainability and ecological resilience of agroecosystems, agricultural production should be guided by policies and regenerative management protocols that include ruminant grazing. Collectively, conservation agriculture supports ecologically healthy, resilient agroecosystems and simultaneously mitigates large quantities of anthropogenic GHG emissions.

Rowntree, J., Ryals, R., DeLonge, M., Teague, R., Chiavegato, M., Byck, P., Wang, T., & Xu, S. (2016). Potential mitigation of midwest grass-finished beef production emissions with soil carbon sequestration in the United States of America. Future of Food: Journal of Food, Agriculture, and Society, 4(3).

Beef production can be environmentally detrimental due in large part to associated enteric methane (CH4) production, which contributes to climate change. However, beef production in well-managed grazing systems can aid in soil carbon sequestration (SCS), which is often ignored when assessing beef production impacts on climate change. To estimate the carbon footprint and climate change mitigation potential of upper Midwest grass-finished beef production systems, we conducted a partial life cycle assessment (LCA) comparing two grazing management strategies: 1) a non-irrigated, lightly-stocked (1.0 AU/ha), high-density (100,000 kg LW/ha) system (MOB) and 2) an irrigated, heavily-stocked (2.5 AU/ha), low-density (30,000 kg LW/ha) system (IRG). In each system, April-born steers were weaned in November, winter-backgrounded for 6 months and grazed until their endpoint the following November, with average slaughter age of 19 months and a 295 kg hot carcass weight. As the basis for the LCA, we used two years of data from Lake City Research Center, Lake City, MI. We included greenhouse gas (GHG) emissions associated with enteric CH4, soil N2O and CH4 fluxes, alfalfa and mineral supplementation, and farm energy use. We also generated results from the LCA using the enteric emissions equations of the Intergovernmental Panel on Climate Change (IPCC). We evaluated a range of potential rates of soil carbon (C) loss or gain of up to 3 Mg C ha-1 yr-1. Enteric CH4 had the largest impact on total emissions, but this varied by grazing system. Enteric CH4 composed 62 and 66% of emissions for IRG and MOB, respectively, on a land basis. Both MOB and IRG were net GHG sources when SCS was not considered. Our partial LCA indicated that when SCS potential was included, each grazing strategy could be an overall sink. Sensitivity analyses indicated that soil in the MOB and IRG systems would need to sequester 1 and 2 Mg C ha-1 yr-1 for a net zero GHG footprint, respectively. IPCC model estimates for enteric CH4 were similar to field estimates for the MOB system, but were higher for the IRG system, suggesting that 0.62 Mg C ha-1 yr-1 greater SCS would be needed to offset the animal emissions in this case.

Teague, R., Provenza, F., Kreuter, U., Steffens, T., & Barnes, M. (2013). Multi-paddock grazing on rangelands: Why the perceptual dichotomy between research results and rancher experience?. Journal of environmental management, 128. 699-717.

Maintaining or enhancing the productive capacity and resilience of rangeland ecosystems is critical for the continued support of people who depend on them for their livelihoods, especially in the face of climatic change. This is also necessary for the continued delivery of ecosystem services derived from rangelands for the broader benefit of societies around the world. Multi-paddock grazing management has been recommended since the mid-20th century as an important tool to adaptively manage range-lands ecosystems to sustain productivity and improve animal management. Moreover, there is much anecdotal evidence from producers that, if applied appropriately, multi-paddock grazing can improve forage and livestock production. By contrast, recent reviews of published rangeland-based grazing systems studies have concluded that, in general, field trials show no superiority of vegetation or animal production in multi-paddock grazing relative to continuous yearlong stocking of single-paddock live-stock production systems. Our goal is to provide a framework for rangeland management decisions that support the productivity and resiliency of rangelands and then to identify why different percep-tions exist among rangeland managers who have effectively used multi-paddock grazing systems and research scientists who have studied them. First, we discuss the ecology of grazed ecosystems under free-ranging herbivores and under single-paddock fenced conditions. Second, we identify five prin-ciples underpinning the adaptive management actions used by successful grazing managers and the ecological, physiological, and behavioral framework they use to achieve desired conservation, produc-tion, and financial goals. Third, we examine adaptive management principles needed to successfully manage rangelands subjected to varying environmental conditions. Fourth, we describe the differenc-es between the interpretation of results of grazing systems research reported in the scientific literature and the results reported by successful grazing managers; we highlight the shortcomings of most of the previously conducted grazing systems research for providing information relevant for rangeland man-agers who aim to achieve desired environmental and economic goals. Finally, we outline knowledge gaps and present testable hypotheses to broaden our understanding of how planned multi-paddock grazing management can be used at the ranching enterprise scale to facilitate the adaptive manage-ment of rangelands under dynamic environmental conditions.

Ferguson, B. G., Diemont, S. A., Alfaro-Arguello, R., Martin, J. F., Nahed-Toral, J., Álvarez-Solís, D., & Pinto-Ruíz, R. (2013). Sustainability of holistic and conventional cattle ranching in the seasonally dry tropics of Chiapas, Mexico. Agricultural Systems, 120. 38-48.

Conventional cattle ranching in the lowlands of Chiapas, Mexico typically employs extensive grazing, annual pasture burns and frequent applications of agrochemicals, threatening biodiversity and long-term productivity. A small group of innovative ranchers in the Central Valleys are converting to holistic management through careful land-use planning, rotational grazing, diversified forage, and dimin-ished use of purchased inputs. We compared the sustainability of 18 conventional and seven holistic, dual-purpose ranches, using three sets of sustainability metrics. First, we combined semistructured interviews and field observations to better describe the two productions systems and to calculate an ‘‘Organic Conversion Index’’ (OCI), combining economic, social, technological and environmental indi-cators. Holistic ranchers have more pasture divisions, higher grazing pressure, greater lengths of time between pasture burns, greater milk productivity, larger forest reserves, lower cow and calf mortality, purchase less hay and feed, and use less herbicides and pesticides than their conventional neighbors (T-tests and Fisher’s Exact Tests; all $p < 0.05$). OCI was greater (T-test, $p < 0.0005$) for holistic ranches ($81.8 \pm 4.6\%$ compliance with organic standards), than for conventional ranches ($32.1 \pm 9.0\%$ compli-ance), with holistic ranches demonstrating superiority for nine of ten OCI indicators. Second, drawing on data from the same interviews, we conducted ‘‘emergy’’ analysis to quantify the embodied energy of inputs, outputs and sustainability of the ranching systems. The Emergy Yield Ratio, an index of a systems emergy throughput relative to the emergy in purchased inputs, was marginally higher in holistic ranches (T-test; $p = 0.07$), but became significant when only ranches P40 ha were analyzed ($p = 0.04$) and when government assistance (mostly in the form of machinery) was removed from the calculations ($p = 0.008$). Holistic ranches exhibited marginally higher Emergy Sustainability Indices, a measure of system yield relative to environmental impact, for all ranches combined ($p = 0.07$) and for ranches P40 ha ($p = 0.06$). Third, we sampled vegetation and soils on seven holistic and seven conventional ranches. We found higher soil respiration, deeper topsoil, increased earthworm presence, more tightly closed herbaceous canopies (all $p < 0.05$), and marginally greater forage availability ($p = 0.053$) in holistic ranches. Other variables, including soil compaction, soil chemistry and pasture tree cover, did not differ significantly between groups. These data are a snapshot of long, complex processes. Nonetheless, these complementary metrics combine to suggest that holistic management strategies are leading to greater ecological and economic sustainability. This production model merits further study for potential broader application as well as greater attention from decision makers concerned with ranching and the environment.

Sherren, K., Fischer, J., & Fazey, I. (2012). Managing the grazing landscape: Insights for agricultural adaptation from a mid-drought photo-elicitation study in the Australian sheep-wheat belt. Agricul- tural Systems, 106(1). 72-83.

Globally, and under uncertain climate conditions, the agricultural sector will need to feed more people without degrading the ecosystem services on which production depends. Eastern Australia, coming out of a decade of drought, is at the leading edge of this challenge. Measures to adapt agriculture to increasing climate variability are urgently sought. One particularly promising measure is an adaptive grazing decision-making practice called holistic management (HM), typically involving high-intensity, short-duration rotational grazing and the encouragement of pastures with low chemical input needs. Here, we use photo-elicitation to compare the landscape perceptions of HM graziers with those of more conventional graziers, based on their choice of photo targets and the stories those photographs elicited. During that process, HM graziers described their use of adaptive farm management techniques to gain outcomes for production and ecosystems alike, demonstrating a system-based understanding of their farms conducive to farming under increased climate variability. We conclude that HM grazing should be encouraged so as to adapt the industry to climate change. More widespread uptake of HM practices – for public benefit as well as personal – depends on incentives to reduce start-up costs and expand the instruction of HM principles, first targeting those with high adaptive capacity, and removing policies that delay adaptation.

Alfaro-Arguello, R., S.A.W. Diemont, B.G., Ferguson, J.F. Martin, J. Nahed-Toral, J.D. Álvarez-Solís, R. Pinto Ruíz. (2010) Steps Toward Sustainable Ranching: An Emergy Evaluation of Conventional and Holistic Management in Chiapas, Mexico. Agricultural Systems. 103. 639-646.

Abstract: Conventional ranching in Chiapas, Mexico typically includes annual pasture burns and agrochemical use that decrease the biodiversity and forest cover of ranch lands. Members of a holistic ranching ‘‘club” in the Frailesca region of Chiapas, Mexico have moved away from this conventional management by eliminating burns and agrochemicals from their systems after decades of use because they believed that the land and their production process were growing unhealthy; they were further motivated by extension courses on holistic ranching. They have also implemented sophisticated systems of rotational grazing and diversified the use of trees. For this study all seven holistic ranchers and 18 neighboring conventional ranchers were interviewed about their cattle ranches and produc- tion strategies. An emergy analysis was conducted to compare the resource use, productivity and sustainability of the conventional and holistic ranches. Holistic ranches were found to have double the emergy sustainability index (ESI) values of conventional ranches, and the emergy yield ratio was 25% higher in holistic systems. Government assistance programs were found to have a negative impact on the ESI and were variably administered among holistic ranchers during the year of emergy evaluation. Overall improved emergy sustainability did not decrease milk nor cattle productivity. Transformities and specific emergies, the emergy of one type required to make a unit of energy (transformity) or mass (specific emergy) of another type, did not differ between conventional and holistic systems. Transformities for milk production ranged between 3.4E5 and 1.2E7 solar emjoules/joule (sej/J). Specific emergy for cattle production ranged from 3.5E10 to 1.5E11 sej/g. To improve the ESI assistance programs could be re-targeted toward incentive programs for increased forest cover in ranching systems and startup costs for holistic ranching. The results from this study show that productivity can be maintained as the sustainability of rural dairy ranches is increased. These results also show that local knowledge and understanding of the surrounding ecosystem can drive positive environmental change in production systems.

Fischer, J., K. Sherren, H. Clayton. (2009) Working in Tandem with Natural: Variability and New Paradigms for Livestock Grazing in Australia. Report submitted by researchers from Australian National University to the Federal Government House of Representatives Standing Committee on Primary Industries and Resources. 1-8.

Summary: An adaptive management paradigm already exists that addresses the concerns of this inquiry with respect to livestock grazing systems. Holistic management (HM) empowers graziers with decision frameworks to help them adapt to climate variability, and is based on observations of natural herd behaviour of large herbivores in southern Africa. HM grazing is rapidly gaining popularity on farm enterprises in Australia's temperate grazing zone. It (1) provides flexible management options in the face of climatic uncertainty, and (2) enhances the resilience of the natural environment, thus leaving it better prepared for climatic variability. Unlike many other adaptive strategies to climate change, HM grazing is a proactive, low-tech solution that has at its core a different way of thinking about grazing systems, combined with the smarter application of known management techniques. Adoption of HM grazing signals a change in farming mentality from trying to gain control over the land to working with natural variability and embracing an ethic of land stewardship. Farmers using HM grazing have reported a wide range of benefits, including reduced soil erosion, increased water efficiency, improved pasture species cover and composition, improved quality of life, and more stable financial returns. Public good benefits include increased carbon sequestration, more biodiversity, and reduced nutri- ent loads off-farm. We summarise key aspects of HM grazing. To give a flavour of first-hand accounts of the benefits outlined above, we provide anonymous quotes by HM farmers involved in our current, federally-funded research in the temperate agricultural zone. We conclude by suggesting ways in which government can support the significant shift in grazing practices that is already underway.

McLachlan, S.M., M. Yestrau. (2009) From the Ground Up: Holistic Management and Grassroots Rural Adaptation to Bovine Spongiform Encephalopathy Across Western Canada. Mitigating Strategies Global Change. 14:299-316.

Abstract: Bovine spongiform encephalopathy (BSE) has been documented in 28 countries and adversely affected farmers and rural communities around the world. Our study examines the impacts of and adaptive responses of producers to BSE in western Canada. Moreover, it explores the role that holistic management (HM), and its combined focus on environmental, social, and economic sustainability, might play in mitigating the effects of BSE. One survey was sent to 835 HM producers and another to 9,740 producers across Manitoba, Saskatchewan, and Alberta. The disease, and concomitant climate change and low commodity prices, had devastating impacts on both groups. Yet, HM producers were much more optimistic about their ability to adapt to BSE and the future of agriculture than their non-HM counterparts. Social networks, namely HM clubs and the larger HM community, enabled these producers to mitigate the impacts of BSE. Agronomic responses, especially those associated with ro-

tational grazing and increases in on-farm biodiversity were also important. That HM has been such an effective adaptive response to BSE indicates the importance of this and other grassroots responses to rural crises, whether they be associated with zoonotic diseases or indeed environmental change as a whole.

Muñoz-Erickson, T.A., B. Aguilar-González, T.D. Sisk. (2007) Linking Ecosystem Health Indicators and Collaborative Management: a Systematic Framework to Evaluate Ecological and Social Outcomes. Ecology and Society 12(2):6

Abstract: Collaborative management has gained popularity across the United States as a means of addressing the sustainability of mixed-ownership landscapes and resolving persistent conflicts in public lands management. At the same time, it has generated skepticism because its ecological and social outcomes are seldom measured. Evaluating the success of collaborative efforts is difficult because frameworks to assess on-the-ground outcomes are poorly developed or altogether lacking. Ecosystem health indicators are valuable tools for evaluating site-specific outcomes of collaboration based on the effects of collaboration on ecological and socioeconomic conditions. We present the holistic ecosystem health indicator, a promising framework for evaluating the outcomes of collaborative processes, which uses ecological, social, and interactive indicators to monitor conditions through time. Finally, we draw upon our experience working with the Diablo Trust, a community-based collaborative group in northern Arizona, USA, to illustrate the development of an indicator selection model generated through a stakeholder-driven process.

McCosker, T. (2000) Cell Grazing – The First 10 Years in Australia. Tropical Grasslands. Volume 34. 207-218.

Abstract: This paper tracks the progress of Cell Grazing in Australia from 1990 when it was first taught, to 1999, from 2 perspectives. The first is a model of an industry paradigm shift. The introduction of Cell Grazing to Australia has all the hallmarks of a paradigm shift at the industry level. It is following the classic pattern outlined by Kuhn (1970) and is well progressed to the point where its principles will be considered 'normal science' within another 10 years. The second perspective is industry-oriented, where results obtained from properties throughout eastern Australia are presented. These results illustrate the impact that Cell Grazing can have on business profitability (up to 2-3 times higher profit), soil improvement (it has doubled the available soil P on some properties with a history of phosphate application), rainfall use efficiency (generally 50-100% up on previous levels), biodiversity (usually increases) and animal performance (variable).

Cell Grazing is described as a high-level, time-control grazing method and is thus different from continuous grazing, rotational resting, rotational grazing and multi-camp rotational grazing systems. Comprehensive definitions of the different systems are used to illustrate why the scientific literature differs from industry results. Terminology used in the literature is also categorized to assist in this understanding.

Stinner, DH, B.R. Stinner, E. Marsolf (1997) Biodiversity as an Organizing Principle in Agroecosys- tem Management: Case Studies of Holistic Resource Management Practitioners in the USA. Agriculture, Ecosystems and Environment. 62, 199-213.

Abstract: Holistic Resource Management (HRM) is a process of goal setting, decision making and monitoring which integrates social, ecological and economic factors. Biodiversity enhancement is a fundamental principle in HRM and students are taught that biodiversity is the foundation of sustainable profit. In the HRM process, practitioners develop a holistic goal which includes: (1) quality of life values, (2) forms of production to support those values, and (3) landscape planning, which should protect and enhance biodiversity and support ecosystem processes of succession, energy flow, hydrological and nutrient cycling. We present an overview of the HRM model and results of interviews with 25 HRM farmers and ranchers from across the USA in which perceptions and experiences with respect to the role of biodiversity in the sustainability of their operations were explored. An ethnographic approach and qualitative research methods were used in the interviews. While only 9% of the interviewees reported thinking about biodiversity in the context of their operations before being exposed to HRM, now all of them think biodiversity is important to the sustainability of their farms and ranches. Of the people interviewed, 95% perceived increases in biodiversity (particularly with respect to plants) and 80% perceived increase in profits from their land since HRM began influencing their decisions, In addition to perceiving increases in biodiversity, all of the interviewees reported observing indications of positive changes in some of the ecosystem processes on their farms or ranches. In addition, 91% of the interviewees reported improvements in their quality of life because of changes in their time budgets. Three of the interviewees who had quantitative data on changes in numbers of plant species and economic indicators are discussed in detail. We conclude that holistic management approaches like HRM are worthy of further study.

POTENTIAL OF PROPERLY MANAGED LIVESTOCK

Neely C., Fynn, A. (2013). Critical Choices for Crop and Livestock Production Systems that Enhance Productivity and Build Ecosystem Resilience. SOLAW Background Thematic Report - TR11. United Nations FAO 1-38.

Executive Summary: The natural resource base on which agriculture depends has declined faster in the past 50 years than at any other time in human history, owing to increased global demand and degradation of land, water and biodiversity. In the same period, 75 percent of the crop genetic base has been lost. By conservative estimates, a quarter of the world's population now depends directly on land that is being degraded. While there are more hungry people in Asia than other regions, sub-Saharan Africa suffers from long-term food insecurity, with two-thirds of the productive land area in the region affected by land degradation. If current trends go unchanged, by 2025 the African continent will only be able to feed one-quarter of its population.

Degradation is caused by unsustainable agricultural production methods, especially intensive tillage (which promotes erosion of some 25 000 million tonnes of topsoil per year), nutrient mining, poor soil cover, and pollution from conventional intensive farming, deforestation and poor grazing management. Mechanical soil tillage and removal of vegetation destroy soil structure and accelerate soil erosion by exposing the soil to the impacts of rain and wind. Salinization of unsustainably irrigated land is also a major factor for soil degradation.

Six million children die of starvation every year, or 17 000 a day. A further 8 000 children die each day of preventable malnutrition and malnutrition-related diseases. Some 1.1 billion people do not have access to clean water. Agriculture accounts for 70 percent of water use, and some 24 percent of irrigated land is affected by salinity (FAO, 2007b). According to current trajectories, water use through evapotranspiration during crop production will almost double by 2050, yet water is essential for both drinking (2-5 litres per person per day) and for production.

Different food products make different demands on water: 1 litre of wheat requires 1500 litres of water, and 1 kg of meat requires 15000 litres. It takes approximately 3 000 litres to meet one person's daily food needs; 1000 times more water is needed to feed the human population as to satisfy its thirst.

There is enough water for the world's food needs to be met over the next 50 years, but allocation, provision, and efficiencies must be radically improved to avoid further water conflicts, which are already occurring. Agricultural water loss can be reduced by different crop choices and crop and livestock management practices; eliminating delivery inefficiencies and unproductive water losses; improving system design; and keeping soils covered with crop residues, other organic materials, permanent crops, cover crops and 'green manures.' More efficient water management is implicit in sustainable land management (SLM) systems, and can be achieved in the context of the kind of sustainable production intensification (SPI) needed to meet upcoming food demands on the same global agricultural area footprint.

Agriculture contributes directly as much as 14 percent of anthropogenic greenhouse gases (GHG) globally; this figure more than doubles when related land-use change is included. Livestock has come under scrutiny for the associated environmental consequences regarding water use and GHG emissions (particularly CH4 and N2O). Recent growth in the sector has lead to the industrialization of livestock production which is, in many cases, shifting from smallholder farms to large-scale commercial operations, often near urban centres. Meat production is projected to more than double over the next 50 years, a trend associated with improvements in living standards and expectations, especially in Asia.

While climate change exacerbates issues associated with the dwindling land and water resource base, it may prove to be a catalyst for accelerating uptake of sustainable agricultural practices that lead to enhanced ecosystem processes and long-term resilience.

This report provides an overview of systems of production that reduce negative agricultural impacts on use of soil, water and biological resources; many highlighted approaches regenerate ecosystem resilience and ecosystem services. This report also identifies critical practical issues for effective transition to such systems. Because of the evolution of different practices and production systems, an overlap

of the approaches featured is unavoidable, particularly concerning the elements within them (e.g. maximizing crop residue, enhancing nutrient and water cycles, etc.). As a specific example, the use of leguminous 'fertilizer trees' are integrated into conservation agriculture, agroforestry and permaculture. Users and developers of different production systems are continually seeking greater efficiencies and increased yield-to-cost/input ratios. Emerging innovations tend to borrow and synthesise the best elements from elsewhere. While it is beyond the scope of this report to provide a detailed cross-reference of SLM production systems a comprehensive analysis would prove valuable.

Janzen, H.H., 2011. What Place for Livestock on a Re-greening Earth. Animal Feed Science and Technology. 166-167, 783-796.

Abstract: Humanity is quickly encroaching upon the finite limits of the biosphere. As our numbers and appetites grow, food supplies become less secure, reserves of clean energy dwindle, pools of freshwater evaporate, the atmosphere's capacity to absorb our emissions diminishes and space for human and biotic habitat grows scarce. In response, some are now asking whether the biosphere can support our growing herds of domesticated livestock, notably ruminants. My aim in this review is to contemplate the place of these animals in a world in need of re-greening, in more ways than one. In addressing this objective, I advance the premise that the place of livestock is examined best from the vantage of 'land', broadly defined. Livestock have been implicated in many injurious processes: land use change, excess water use, nutrient excretion, fossil energy use, competition for food and emission of greenhouse gases. At the same time, they offer numerous benefits: producing food from human inedible sources, preserving ecosystem services, promoting perennials on croplands, recycling plant nutrients and providing social benefits. Thus livestock can be both stressors and benefactors to land and the aim of researchers should be to shift the net effect from stress to beneficence. To advance this goal, I offer seven questions, seen through the lenses of 'systems', 'place', 'time' and 'community', mostly to foster discourse. How do we better study whole systems? How do we better tune the systems to local land? How can we know long term consequences? How do we measure progress? How do we choose among trade-offs? How do we engage society? What will (or should) our successors' livestock systems look like? Humans and their livestock are intertwined to such an extent that their symbiosis will not likely soon be severed. Livestock offer many benefits to human society and often their place in ecosys- tems can be ecologically justified. But that does not mean that all ways of raising them are beneficial, nor that they necessarily fit everywhere. In coming decades, researchers, in concert with practitioners, consumers and policymakers, will need to show creativity, foresight and courage to envision new ways of melding animals into our ecosystems, not only to minimize harm, but to advance their re-greening.

Djihan Skinner, D., 2010. Rangeland Management for Improved Pastoralist Livelihoods: The Borana of Southern Ethiopia. Thesis submitted in partial fulfillment of the requirements for the Degree of Master of Arts in Development and Emergency Practice, Oxford Brookes University. 1-87.

Pastoralism, a livelihood system based on animal herding, has endured for centuries as a rational adaptation to often harsh and erratic grassland environments. Founded on mobility and flexibility, the pastoral system optimises the use of natural resources to maintain the livestock on which pastoralists depend for their well-being. As seen in the case of the Borana pastoralists of southern Ethiopia, however, various pressures, including poor policies, agricultural encroachment, population pressure and land degradation are now undermining the resilience of the system and of the natural resource base. Various strategies are being employed by NGOs to support the livelihoods of pastoral- ists in Borana. Since livestock is the mainstay of Borana livelihoods, a vital component of any interven- tion activity is to improve the condition of, and with it access to, the grasslands so that livestock can be maintained.

This dissertation begins by examining the pressures causing vulnerability amongst the Borana pastoralists of southern Ethiopia with specific emphasis on factors affecting the integrity of the rangeland management system. The livelihoods approach used in the paper helps to assess the importance of healthy rangelands for building assets and sustainable pastoralist livelihoods. This analysis begs the question of what can be done to revitalise the degraded rangelands of Borana. The author therefore analyses the key rangeland management techniques being employed by NGOs to rejuvenate this natural resource base and assesses their strengths and weaknesses in order to recommend a way forward. The paper suggests that indigenous knowledge and skills can serve as a useful guide for managing the rangelands while at the same time enabling the Borana pastoralist community to engage with and take ownership of this development assistance and support.

RESTORING LAND WITH LIVESTOCK

Estrada, O.J., Grogan, S., Gadzia, K.L., 1997. Livestock Impacts for Management of Reclaimed Land at Navajo Mine: The Decision-Making Process. American Society for Surface Mining and Reclama- tion. 239-244.

Abstract: Livestock grazing is the post-mining use for reclaimed land at Navajo Mine, a large surface coal mine on the Navajo Nation in northwest New Mexico. The Navajo Mine Grazing Management Program (GMP) uses holistic management on approximately 2,083 ha of reclaimed land to plan for final liability release and return of the land to the Navajo Nation, and to minimize the potential for post-release liability. The GMP began in 1991 to establish that livestock grazing on the reclaimed land is sustainable. Assuming that sustainability requires alternatives to conventional land management practices, the GMP created a Management Team consisting of company staff, local, Navajo Nation, and Federal government officials, and technical advisors. Community members contributed to the formation of a holistic goal for the GMP that articulates their values and their desire for sustainable grazing. Major decisions (e.g., ficial insemination, water supply, supplemental feed) are tested against the goal. Biological changes in the land and the grazing animals are monitored daily to provide early feedback to managers, and annually to document the results of grazing. To date, the land has shown resilience to grazing and the animals have generally prospered. Community participation in the GMP and public statements of support by local officials indicate that the GMF”Sstrategy is likely to succeed.

HOLISTIC MANAGEMENT AND WATER RESOURCES

K.T. Weber, B.S. Gokhale, 2011. Effect of grazing on soil-water content in semiarid rangelands of southeast Idaho. Journal of Arid Environments. 75, 464-470.

Abstract: Although numerous factors influence soil-water content, it is considered a key indicator of rangeland health. This paper investigates the effect of grazing on soil-water content using three treatments within the same soil association. The treatments, simulated holistic planned grazing (SHPG), rest-rotation (RESTROT), and total rest (TREST) applied stocking rates of 36, 6, and 0 animal days/hectare respectively. Soil-water content was measured continuously from 2006 to 2008 using 36 capacitance sensors. Statistical analyses revealed differences in percent volumetric-water content (%VWC) and in all treatments, the SHPG pasture had the highest %VWC. Mixed procedures models indicate strong environmental and treatment effects as explanatory variables for the observed difference in %VWC. Although results of vegetation cover analyses indicated no difference in percent shrub cover in the two production pastures (SHPG and RESTROT), percent litter cover differed in the latter years of this study. It was concluded that in addition to a variety of other factors, management decisions (grazing and rest) can have substantial influence upon soil-water content and that soil-water content can vary substantially as a result of animal impact and the duration of grazing.

Saunders, W.C., Fausch, K.D., 2006. Improved Grazing Management Increases Terrestrial Invertebrate Inputs that Feed Trout in Wyoming Rangeland Streams. Department of Fish, Wildlife, and Conservation Biology, Colorado State University. 1-6.

Abstract: Conservation of trout in western rangeland streams may benefit from providing adequate invertebrate prey resources in addition to improving instream habitat. Conventional efforts to sustain trout populations in rangeland streams of the West have focused on improving instream habitat for fish and invertebrates that has been damaged by poorly managed grazing. However, recent research suggests that terrestrial invertebrate prey that come directly from riparian vegetation and fall, crawl, or blow into streams may also play a key role in supporting trout. Studies in Virginia, Alaska, and New Zealand showed that about half the biomass of trout diets during summer afternoon periods consisted of these terrestrial prey, and research in Japan revealed that consumption of terrestrial invertebrates can exceed 80% of the summer diet and provide 50% of the energy budget required to sustain trout throughout the year. The Japanese researchers also showed that when stream reaches were covered with mesh greenhouses that reduced input of terrestrial invertebrates by 70%, the larger trout emigrated, resulting in a 50% decrease in trout biomass. These results imply that poorly managed livestock grazing in riparian areas may have substantial effects on trout populations not only by degrading instream habitat, but also by reducing or changing riparian vegetation that supplies terrestrial invertebrates on which trout rely. The aboveground biomass and structural complexity of riparian vegetation that resulted from high-density short-duration grazing appears to support greater invertebrate production and increases the transport of these invertebrates to streams where they are an important prey resource for trout. This direct input of terrestrial invertebrate prey to streams under HDSD grazing, along with increases in aquatic prey resources resulting from litter inputs and retention of adult aquatic insects after they emerge, means that these streams have the potential to support greater trout biomass.

PREDATOR/PREY RELATIONSHIP

Beschta, R.L., Ripple, W.J. 2011. Are wolves saving Yellowstone's aspen? A landscape-level test of a behaviorally mediated trophic cascade. Ecology. [doi:10.1890/11-0063.1] in press.

Abstract: By the early 1900s, Euro-Americans had extirpated gray wolves (Canis lupus) from most of the contiguous United States. Yellowstone National Park was not immune to wolf persecution and by the mid-1920s they were gone. After seven decades of absence in the park, gray wolves were reintroduced in 1995-96, again completing the large predator guild (Smith et al. 2003). Yellowstone's "experiment in time" thus provides a rare opportunity for studying potential cascading effects associated with the extirpation and subsequent reintroduction of an apex predator. Wolves represent a particularly important predator of large mammalian prey in northern hemisphere ecosystems by virtue of their group hunting and year-round activity (Peterson et al. 2003) and can have broad top-down effects upon the structure and functioning of these systems (Miller et al. 2001, Soulé et al. 2003, Ray et al. 2005). If a tri-trophic cascade involving wolves-elk (Cervus elaphus)-plants is again underway in north- ern Yellowstone, theory would suggest two primary mechanisms: (1) density mediation through prey mortality, and (2) trait mediation involving changes in prey vigilance, habitat use, and other behaviors (Brown et al. 1999, Berger 2010). Both predator-caused reductions in prey numbers and fear responses they elicit in prey can lead to cascading trophic-level effects across a wide range of biomes (Beschta and Ripple 2009, Laundré et al. 2010, Terborgh and Estes 2010). Thus, the occurrence of a trophic cascade could have important implications not only to the future structure and functioning of northern Yellowstone's ecosystems but also for other portions of the western United States where wolves have been reintroduced, are expanding their range, or remain absent. However, attempting to identify the occurrence of a trophic cascade in systems with large mammalian predators, as well as the relative importance of density and behavioral mediation, represents a continuing scientific challenge. In Yellowstone today there is an ongoing effort by various researchers to evaluate ecosystem processes in the park's two northern ungulate winter ranges: (1) the "northern range" along the northern edge of the park (NRC 2002) and (2) the "upper Gallatin winter range" along the northwestern corner of the park (Ripple and Beschta 2004b). Previous studies in northern Yellowstone have generally found that elk, in the absence of wolves, caused a decrease in aspen (Populus tremuloides) recruitment (i.e., the growth of seedlings or root sprouts above the browse level of elk). Within this context, Kauffman et al. (2010) initiated a study to provide additional understanding of factors such as elk density, elk behavior, and climate upon historical and contemporary patterns of aspen recruitment in the park's northern range.
Like previous studies, Kauffman et al. (2010) concluded that, irrespective of historical climatic conditions, elk have had a major impact on long-term aspen communities after the extirpation of wolves. But, unlike other studies that have seen improvement in the growth or recruitment of young aspen and other browse species in recent years, Kauffman et al. (2010) concluded in their Abstract: "…our estimates of relative survivorship of young browsable aspen indicate that aspen are not currently recovering in Yellowstone, even in the presence of a large wolf population." In the interest of clarifying the potential role of wolves on woody plant community dynamics in Yellowstone's northern winter ranges, we offer several counterpoints to the conclusions of Kauffman et al. (2010). We do so by readdressing the four tasks identified in their Introduction (p. 2744): (1) the history of aspen recruitment failure; (2) contemporary aspen recruitment; (3) and (4) aspen recruitment and predation risk. Task (1) covers the period when wolves were absent from Yellowstone and tasks (2) through (4) focus on the period when wolves were again present. We also include some closing comments regarding trophic cascades and ecosystem recovery.

CARBON SEQUESTRATION IN GRASSLANDS

Machmuller, M., Kramer, M., Cyle, T., Hill, N., Hancock, D., & Thompson, A. (2015). Emerging land use practices rapidly increase soil organic matter. Nature Communications, 6.

The loss of organic matter from agricultural lands constrains our ability to sustainably feed a growing population and mitigate the impacts of climate change. Addressing these challenges requires land use activities that accumulate soil carbon (C) while contributing to food production. In a region of extensive soil degradation in the southeastern United States, we evaluated soil C accumulation for 3 years across a 7-year chronosequence of three farms converted to management-intensive grazing. Here we show that these farms accumulated C at 8.0 Mg ha−1 yr−1, increasing cation exchange and water holding capacity by 95% and 34%, respectively. Thus, within a decade of management-intensive grazing practices soil C levels returned to those of native forest soils, and likely decreased fertilizer and irrigation demands. Emerging land uses, such as management-intensive grazing, may offer a rare win–win strategy combining profitable food production with rapid improvement of soil quality and short-term climate mitigation through soil C-accumulation.

Franzluebbers, A.J., Endale, D.M., Buyer, J.S., & Stuedemann, J.A. (2011). Tall Fescue Management in the Piedmont: Sequestration of Soil Organic Carbon and Total Nitrogen. Soil Science Society of America Journal. 6(3). 1016-1026.

High-quality surface-soil characteristics are important for developing environmentally sustainable agroecosystems. We evaluated the factorial combination of fertilization regime (inorganic and broiler litter) and tall fescue [Lolium arundinaceum (Schreb.) Darbysh.]–endophyte association (free, novel, and wild) with cattle grazing (plus a control treatment of inorganic fertilizer + novel endophyte with haying) on surface soil compaction and soil organic C and total N sequestration during 8 yr of management on a previously degraded Typic Kanhapludult in Georgia. Soil organic C and total N were sequestered with time at all depth intervals to 20 cm (0–3, 3–6, 6–12, and 12–20 cm). At a depth of 0 to 6 cm (surface zone most responsive to management), soil organic C sequestration was (i) greater with grazed than with hayed management (1.36 vs. 0.69 Mg C ha^{-1} yr^{-1}, respectively), (ii) similar between broiler litter and inorganic fertilization, (iii) similar among endophyte associations, and (iv) similar among zones within a grazed pasture. At a depth of 0 to 20 cm, soil organic C and total N sequestration were not significantly affected by treatment variables, but high mean sequestration rates of 1.51 Mg C ha^{-1} yr^{-1} and 0.126 Mg N ha^{-1} yr^{-1} during managed grazing of tall fescue in addition to the previous decade of unmanaged herbaceous fallow (implied sequestration rates of 0.76 Mg C ha^{-1} yr^{-1} and 0.062 Mg N ha^{-1} yr^{-1}) suggests that improved grazing management systems can have an enormous benefit to surface soil fertility restoration of degraded soils in the southeastern United States.

Itzkan, S. (2014). Upside (Drawdown): The Potential of Restorative Grazing to Mitigate Global Warming by Increasing Carbon Capture on Grasslands. Planet TECH Associates.

The global warming crisis is forcing consideration of innovative and alternative approaches to climate mitigation and reversal. Simply going to a zero fossil fuel economy will not stop catastrophic consequences, even if such an about-face in energy use were achievable. At our current level of 400 ppm atmospheric CO2, we are already well beyond what has been deemed the maximum safe level for human habitation, 350 ppm (Hansen, 2008). Indeed, recent anomalous weather and warming related events, including the unexpectedly rapid loss of arctic sea ice (Maslowski, 2012), may indicate that “amplifying feedbacks” are already underway (Glikson, 2013; Torn & Harte, 2006). This situation, unfortunately, is not likely to be remedied with a simple return to 350 ppm. Doing so may only slow warming to the rate it was at in 1988, when it was last at 350 ppm, and evidence of impact was already alarming (Hansen, 1988; Shabecoff, 1988). In fact, warming will likely be worse in a future 350 ppm scenario, because the cumulative impacts will have weakened the planet's potential to absorb excess heat. There is probably no actual reversal of warming until CO2 concentrations are brought back to preindustrial levels, well under 300 ppm.

To accomplish this essential and herculean task requires not only cessation of fossil fuel emissions, but also a drawdown of approximately 200 gigatons carbon (200 Gt C) from the atmosphere. It is clear that the only conceivable safe and long-term solution for this is through global ecosystem restoration. This will include forests and wetlands, but particularly, also, grasslands, including prairies and savannas, where carbon is sequestered through the roots of perennial plants and bound in organic soil compounds for decades to millennia (Rabbi, 2013). In total, grasslands comprise the largest ecosystem on Earth and are major stores of terrestrial carbon. By various estimates, they cover between 26% and 40% of the world's land while containing 20% to 35% of soil carbon (FAO, 2010; Ramankutty, Evan, Monfreda, & Foley, 2008; R. White, Murray, & Rohweder, 2000). Even small percentage increases in soil carbon worldwide can dramatically reduce atmospheric CO2 concentrations. Entering this conversation is the practice of Holistic Planned Grazing (HPG), in which livestock are herded in a fashion that replicates the beneficial grazing, trampling, dunging, and nutrient recycling dynamics with which wild herding ruminants coevolved with perennial grassland plants and carbon-rich soils (Savory & Butterfield, 1999). Decades of anecdotal evidence and recent studies suggest this practice has great promise, both for ecological functioning, including plant growth and hydrology, and for increasing soil organic carbon (SOC) (Dagget, 2005; Earl & Jones, 1996; Gill, 2009; Howell, 2009; Norton, 1998; Stinner, Stinner, & Martsolf, 1997; Teague et al., 2011; K. T. Weber & Gokhale, 2011). For example, Teague (2011) showed that land managed under a restorative grazing regimen (multi-paddock with ecological goals) had a far higher SOC value than land on a similar site managed with traditional (heavy continuous) grazing. When factoring across all soil profile depths measured, this added carbon equated to a 52 t C/ha. Additionally, Weber (2011) showed that land under a restorative grazing regimen (simulated Holis- tic Planned Grazing, SHGP), had significantly improved water holding capacity, measured as percent volumetric-water content, %VWC, when compared with traditionally grazed lands. Hydrological functioning is correlated with soil carbon (Feger & Hawtree, 2013; Franzluebbers, 2002).

In the absence to date, however, of robust HPG carbon data, this paper infers soil-carbon sequestration potential, based on known SOC values for representative biomes (DOE, 1999; FAO, 2009; Hiederer & Kochy, 2011; Lal, 2004b; UNEP, 2009; R. White et al., 2000; W. White, Wills, & Loecke, 2013), and, in light of this innovative approach to grasslands restoration, reevaluates current estimates on soil C losses and sinks (Lal, 1999, 2004b, 2011). The investigation shows that grassland carbon capture may be far greater, and more rapid, than what has previously been considered possible, where restoration via enhanced ruminant impact had not been factored. Managing livestock in this entirely new way, not just as consumers of grass, but also as essential elements in ecosystem balance, and with restorative goals as an intention, enables significant upward estimation of soil-carbon sequestration potential. Although there are many uncertainties, and future research is needed, these considerations broaden the narrative on climate change mitigation.

Follett, R.F., and Debbie A. Reed, 2010. Soil Carbon Sequestration in Grazing Lands: Societal Benefits and Policy Implications. Rangeland Ecology Management. 63. 4–15.

Abstract: This forum manuscript examines the importance of grazing lands for sequestering soil organic carbon (SOC), providing societal benefits, and potential influences on them of emerging policies and legislation. Global estimates are that grazing lands occupy, 3.6 billion ha and account for about one-fourth of potential carbon (C) sequestration in world soils. They remove the equivalent of 20% of the carbon dioxide (CO2) released annually into the earth's atmosphere from global deforestation and land-use changes. Atmospheric CO2 enters grazing lands soils through photosynthetic assimilation by green plants, subsequent cycling, an sequestration of some of that C as SOC to in turn contribute to the ability of grazing lands to provide societal (environmental and economic) benefits in every country where they exist. Environmental benefits provided include maintenance and well-being of immediate and surrounding soil and water resources, air quality, human and wildlife habitat, and esthetics. Grazing lands contribute to the economic well-being of those living on the land, to trade, and to exchange of goods and services derived from them at local, regional, or national levels. Rates of SOC sequestration vary with climate, soil, and management; examples and conditions selected from US literature illustrate the SOC sequestration that might be achieved. Public efforts, policy considerations, and research in the United States illustrate possible alternatives that impact grazing lands. Discussion of US policy issues related to SOC sequestration and global climate change reflect the importance attached to these topics and of pending legislative initiatives in the United States. Addressing primarily US policy does not lessen the importance of such issues in other countries, but allows an in-depth analysis of legislation, US Department of Agriculture program efforts, soil C credits in greenhouse gas markets, and research needs.

Follett, R.F., Kimble, J.M., Lal, R., 2001. The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. CRC Press LLC. 1-457.

Abstract: The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect, edited by R.F. Follett, J.M. Kimble, and R. Lal, describes grazing lands, the areas they occupy, and their important role in sequestering C to help mitigate the greenhouse effect. The editors and 36 other authors prepared the 17 chapters in this volume which each includes extensive references. Chapter 16 provides a summary and overview of C sequestration in grazing land soils and estimates the overall potential of U.S. grazing land to sequester C, while Chapter 17 considers research needs and priorities. Grazing lands represent the largest and most diverse single land resource in the U.S. and in the world. In the U.S., rangelands and pastures together make up about 55% of the total land surface, and more than half of the earth's land surface is grazed. Grazing lands occupy an even larger area than cropland in the U.S. — 212 Mha (524 million acres) of privately owned and over 124 Mha (300 million acres) of publicly owned land, or more than twice the area of cropland. The large area grazing land occupies, its diversity of climates and soils, and the potential to improve its use and productivity all contribute to its great importance for sequestering C and mitigating the greenhouse effect and other aspects of climate change.

Neely, C., Bunning, S., Wilkes, A., eds., 2009. Review of Evidence on Drylands Pastoral Systems and Climate Change: Implications and Opportunities for Mitigation and Adaptation. Food and Agriculture Organization of the United Nations. 1-50.

In light of global concerns over the impacts of climate change and climate variability, this document provides an overview of opportunities for adaptation and mitigation in dryland pastoral and agropastoral systems. It makes a case for a concerted global effort to promote mitigation practices that also have benefits for adaptation and livelihoods of pastoralists and agropastoralists in drylands. This review first highlights the importance of drylands, grazing lands and livestock based livelihoods and illustrates the interrelations between climate change, land and livestock. It then provides estimates of the potential carbon storage and sequestration in pasture and rangelands in drylands and outlines the main land management measures for improving carbon cycling and grassland management. The socio-economic dimensions of rangeland management and the climate change adaptation and associated co-benefits are then highlighted. In conclusion, it presents some key messages on the importance of grasslands and rangelands in terms of their contribution to carbon sequestration and to the livelihoods of the poor. It highlights the fact that management strategies and practices that contribute to mitigating climate change will also play a major role in climate change adaptation and reducing vulnerability to natural disasters for the millions of people – including the poor – who depend on these land-use systems. Finally, it provides some suggestions on ways forward in light of the current policy framework and climate change negotiations. The review also highlights the vast untapped potential for climate change mitigation and adaptation associated with improved carbon sequestration in pastoral systems and rangelands. Much of this potential lies in soil carbon sequestration. Its neglect during the Kyoto process1 stemmed from concerns regarding perceived difficulties of measurement and monitoring due to soil spatial variability, and of ensuring permanence (IPCC, 2008). Recent negotiations have highlighted the potential for Reducing Emissions from Deforestation and Forest Degradation (REDD) and for carbon sequestration in soils and above-ground biomass in other lands besides forests. Evidence regarding the potential for carbon sequestration in rangelands and grasslands is continually accumulating. The review demonstrates that there is a strong justification for a concerted international process to explore and support efforts for achieving carbon sequestration and promoting sustainable (agro)-pastoral livelihoods in dryland systems through the ongoing post-Kyoto deliberations and negotiations.

Conant, R.T., 2010. Challenges and Opportunities for Carbon Sequestration in Grassland Systems: A Technical Report on Grassland Management and Climate Change Mitigation. Food and Agricul- ture Organization of the United Nations. Vol. 9. 1-67.

Implementing grassland management practices that increase carbon uptake by increasing productivity or reducing carbon losses (e.g. through high rates of offtake) can lead to net accumulation of carbon in grassland soils – sequestering atmospheric carbon dioxide (CO_2). Globally, the potential to sequester carbon by improving grassland practices or rehabilitating degraded grasslands is substantial – of the same order as that of agricultural and forestry sequestration. Because practices that sequester carbon in grasslands often enhance productivity, policies designed to encourage carbon sequestering grassland management practices could lead to near-term dividends in greater forage production and enhanced producer income. Practices that sequester carbon in grasslands also tend to enhance resilience in the face of climate variability, and are thus likely to enhance longer-term adaptation to changing climates. Developing policies to encourage the adoption of practices that sequester carbon has several significant challenges, such as demonstrating additionality, addressing the potential for losses of sequestered carbon, and engaging smallholders and pastoralists with uncertain land tenure. In addition, the paucity of data in developing countries hampers the measurement, monitoring and verifying of carbon sequestration in response to those practices. This report reviews the current status of opportunities and challenges for grassland carbon sequestration. Based on these observations, the report then identifies components that could foster the inclusion of grasslands in a post-2012 climate agreement, and the development of policies to improve grassland management.

Fynn, A.J., P. Alvarez, J.R. Brown, M.R. George, C. Kustin, E.A. Laca, J.T. Oldfield, T. Schohr, C.L. Neely, and C.P. Wong. (2009). Soil Carbon Sequestration in U.S. Rangelands Issues Paper for Protocol Development. Environmental Defense Fund, New York, NY, USA. 1-47

Executive Summary: Rangelands are uncultivated lands that include grasslands, savannas, steppes, shrublands, deserts and tundra. The native vegetation on rangelands is predominantly grasses, forbs and shrubs (Kothmann 1974). Rangelands cover 31% of the land surface area of the United States (Havstad et al. 2009), and up to half of the land surface area worldwide (Svejcar et al. 2008, Lund 2007). Most land areas that are not developed, not cultivated, not forested, and not solid rock or ice can be classified as rangelands. Because of their extent, a small change in soil carbon stocks across rangeland ecosystems would have a large impact on greenhouse gas accounts. There are 761 million acres of rangelands in the U.S. (Havstad et al. 2009), half of which is public lands in the West (Follett et al. 2001). The primary activity focus on rangelands is grazing. Rangelands and grazing lands and are two broadly overlapping categories. U.S. grazing lands, including managed pasturelands, have the potential to remove an additional 198 million tons of carbon dioxide (CO2) from the atmosphere per year for 30 years (Follett et al. 2001), when saturation is reached. This would offset 3.3 % of U.S. CO2 emissions from fossil fuels (EIA 2008), and help protect rangeland soil quality for the future. The past twenty years have seen a tremendous enhancement of the understanding of soil carbon, both its role in the global carbon cycle and the factors that influence its dynamics. Although soil organic carbon (SOC) has long been of interest to scientists, technical advisors and land managers as an indicator of soil health, the link between the carbon cycle and global climate change has provided increased impetus for quantification and ultimately, management. Even if atmospheric concentrations of greenhouse gases were quickly stabilized, anthropogenic warming and sea levels would continue to rise for centuries (IPCC 2007a). Even the most drastic reductions in emissions of anthropogenic greenhouse gases may not do enough, on their own, to preserve current environmental integrity for future generations. If the effects of global warming are to be kept to a minimum, carbon already emitted to the atmosphere as a result of human activities must be sequestered into stable forms. Various strategies have been proposed, including the use of untested technologies requiring huge expenditures of energy and resources. For example, while geologic and deep ocean sequestration schemes have been proven physically possible, the economic, environmental and social costs associated with these technologies remain uncertain. For the immediate future, sequestration in terrestrial ecosystems via natural processes remains the most viable and ready to implement option, and one of the most cost-effective (Department of Energy 2009). Soils hold over three times as much carbon as the atmosphere (Lehmann and Joseph 2009), more than the Earth's vegetation and atmosphere combined, and have the capacity to hold much more (Lal 2004). Carbon stocks in terrestrial ecosystems have been greatly depleted since the beginning of the Industrial Revolution, with changes in land use and deforestation responsible for the emission of over 498 gigatons of CO2 to the atmosphere (IPCC 2000), approximately half of which has been lost from soils (IPCC 2000, Lal 1999). Each ton of carbon stored in soils removes or retains 3.67 tons of CO2 from the atmosphere. Soil carbon comprises SOC and soil inorganic carbon (SIC). SOC is a complex and dynamic group of compounds formed from carbon originally harvested from the atmosphere by plants. During photosynthesis, plants transform atmospheric carbon into the forms useful for energy and growth (Schlesinger 1997). Organic carbon then cycles from the plant to the soil, where it becomes an important source of energy for the soil ecosystem, driving many other nutrient cycles. SIC is the result of mineral weathering and forms a small proportion of many productive soils. The focus of this paper is on SOC sequestration. SOC makes up approximately 50% of all soil organic matter (SOM) (Wilke 2005, Nelson and Sommers 1982). SOM content is correlated with productivity and defines soil fertility and stability (Herrick and Wander 1998). SOC and SOM buffer soil temperature, water quality, pH and hydrology (Pattanayak et al. 2005, Evrendilek et al. 2004). Increases in SOC and SOM lead to greater pore spaces and surface area within the soil, which subsequently retains more water and nutrients (Tisdale et al. 1985, Greenhalgh and Sauer 2003). This factor is of critical importance in U.S. rangelands, most of which experience less than 600 mm precipitation per year. Higher soil carbon levels can reduce the impacts of drought and flood.

U.S. rangelands cover a vast area, comprise many different ecosystems, and experience a wide range of environmental conditions. A protocol will reward landowners for changes in management practices or changes in carbon stocks. There are pros and cons associated with each approach. Where landowners and land managers have the ability to select which project actions to apply, these choices will be made with the goal of maximizing productivity and carbon sequestration according to local conditions. The ecological state of the landscape (Asner et al. 2003), its vegetation (Derner and Schuman 2007) and land use history all influence the effectiveness of different project actions. Project actions for soil carbon sequestration, some of which require further research, include:

- Changes in land use:
  - Conversion of abandoned and degraded cropland to grassland (Franzluebbers and Stuedemann 2009);
  - Avoided conversion of rangeland to cropland or urban development (Causarano et al. 2008)

- Changes in land management:
  - Extensive management (i.e. does not require infrastructure development).
  - Adjustments in stocking rates (Schuman et al. 1999, Conant and Paustian 2002).
  - Integrated nutrient management (FAO 2008, Franzluebbers and Stuedemann 2005, 2008).
  - Introduction or reintroduction of grasses, legumes and shrubs on degraded lands (Schuman et al. 2001, Conant et al. 2001).
  - Managing invasive species.
  - Intensive management (i.e. requires infrastructure development).
  - Reseeding grassland species.
  - Addition of trees and shrubs for silvopastoralism (Sharrow 1997, Nair et al. 2009).
  - Managing invasive shrubs and trees (Franzluebbers et al. 2002).
  - Riparian zone restoration.
  - Introduction of black carbon (biochar) into soils (Lehmann and Joseph 2009).

Rangeland ecosystems are complex systems involving different greenhouse gas (GHG) fluxes. Changes in management that lead to increases in soil carbon stocks can in some cases lead to increased emissions of other GHGs, notably methane and nitrous oxide. Management practices should be assessed to ensure that gains in soil carbon are not negated by increases in non-CO2 GHGs. There are two motivating factors likely to encourage landowners to adopt carbon sequestration practices. The first is the range of biophysical benefits; soil carbon is positively correlated with productivity such that as soil carbon increases, long-term soil productivity can be expected to increase under proper management. The second factor is increased financial benefit; landowners could benefit from revenues from the sale of emissions reductions credits resulting from increased soil carbon sequestration. The existence of a comprehensive rangeland soil carbon protocol will allow increases in soil carbon storage to be converted to verified emissions reductions for use within an offset market, Cap and Trade system, or other regulatory framework or program. Environmental and financial benefit will result from carbon sequestration above that which would have occurred in the absence of the project. This additional sequestration will be achieved by the transition from one set of management practices to another, not by any set of management practices per se. The many co-benefits associated with increasing levels of soil carbon suggest the prospect of win-win scenarios for landowners, climate change mitigation, and ecosystem services. Optimizing uptake of sequestration activity depends on the design and implementation of the protocol, since it is here that incentives to implement changes in management practices will be generated. When it comes to quantifying changes in soil carbon stocks, it is generally true that accuracy costs more, and that less expensive methods are less accurate. Extremes are not desirable: extreme data coarseness leads to low confidence in sequestration values and low market interest in credits generated; on the other hand, overly expensive quantification costs also lead to low uptake. Between these two extremes a balanced methodology will optimize adoption rates and environmental benefit. There are many methods available for assessing changes in rangeland soil carbon stocks. Rather than tie a protocol to the limitations of one particular method, it is logical to combine the strengths of different methods into a single methodology, which may be updated as economics and technical advances allow. Potential elements of a final protocol include use of a performance standard, site specific measurement, ecosystem modeling and remote sensing by satellite. It is important to achieve a balanced solution at a viable cost, and provide the economic and social incentives for adoption of enhanced management.

GRAZING

Wang, T., Teague, W.R., Park, S.C., Bevers, S., 2015. GHG Mitigation Potential of Different Grazing Strategies in the United States Southern Great Plains. Sustainability. 7. 13500-13521.

Abstract: The possibility of reducing greenhouse gas (GHG) emissions by ruminants using improved grazing is investigated by estimating GHG emissions for cow-calf farms under light continuous (LC), heavy continuous (HC) and rotational grazing, also known as multi-paddock (MP), management strategies in Southern Great Plain (SGP) using life cycle assessment (LCA). Our results indicated a GHG emission with these grazing treatments of 8034.90 kg·CO2e·calf−1·year−1 for cow-calf farms in SGP region, which is higher, compared to that for other regions, due to the high percentage (79.6%) of enteric CH4 emissions caused by relatively lower feed quality on the unfertilized rangeland. Sensitivity analyses on MP grazing strategy showed that an increase in grass quality and digestibility could potentially reduce GHG emission by 30%. Despite higher GHG emissions on a per calf basis, net GHG emissions in SGP region are potentially negative when carbon (C) sequestration is taken into account. With net C emission rates of −2002.8, −1731.6 and −89.5 Kg C ha−1·year−1 after converting from HC to MP, HC to LC and from LC to MP, our analysis indicated cow-calf farms converting from continuous to MP grazing in SGP region are likely net carbon sinks for decades.

Teague, W.R., Dowhower, S.L., Baker, S.A., Haile, N., DeLaune, P.B., Conover, D.M., 2011. Grazing Management Impacts on Vegetation, Soil Biota and Soil Chemical, Physical and Hydrological Properties in Tall Grass Prairie. Agriculture, Ecosystems and Environment. 141. 310– 322.

Abstract: To assess whether adaptive management using multi-paddock grazing is superior to continuous grazing regarding conservation and restoration of resources we evaluated the impact of multi-paddock (MP) grazing at a high stocking rate compared to light continuous (LC) and heavy continuous (HC) grazing on neighboring commercial ranches in each of three proximate counties in north Texas tall grass prairie. The same management had been conducted on all ranches for at least the previous 9 years. Impact on soils and vegetation was compared to ungrazed areas (EX) in two of the counties. MP grazing was managed using light to moderate defoliation during the growing season followed by adequate recovery before regrazing after approximately 40 days and 80 days during fast and slow growing conditions, respectively. The vegetation was dominated by high seral grasses with MP grazing and EX, and dominated by short grasses and forbs with HC grazing. LC grazing had a lower proportion of high seral grasses than MP grazing or EX. Bare ground was higher on HC than LC, MP and EX, while soil aggregate stability was higher with MP than HC grazing but not LC grazing and EX. Soil penetration resistance was lowest with MP grazing and EX and highest with HC grazing. Bulk density did not differ among grazing management categories. Infiltration rate did not differ among grazing management categories but sediment loss was higher with HC than the other grazing management categories. Soil organic matter and cation exchange capacity were higher with MP grazing and EX than both LC and HC grazing. The fungal/bacterial ratio was highest with MP grazing indicating superior water-holding capacity and nutrient availability and retention for MP grazing. This study documents the positive results for long-term maintenance of resources and economic viability by ranchers who use adaptive management and MP grazing relative to those who practice continuous season-long stocking.

Briske, D.D., Sayre, N.F., Huntsinger, L., Fernandez-Gimenez, M., Budd, B., Derner, J.D. (2011). Ori- gin, Persistence, and Resolution of the Rotational Grazing Debate: Integrating Human Dimensions Into Rangeland Research. Rangeland Ecology & Management, 64(4):325-334.

Abstract: The debate regarding the benefits of rotational grazing has eluded resolution within the US rangeland profession for more than 60 yr. This forum examines the origin of the debate and the major reasons for its persistence in an attempt to identify common ground for resolution, and to search for meaningful lessons from this central chapter in the history of the US rangeland profession. Rotational grazing was a component of the institutional and scientific response to severe rangeland degradation at the turn of the 20th century, and it has since become the professional norm for grazing management. Managers have found that rotational grazing systems can work for diverse management purposes, but scientific experiments have demonstrated that they do not necessarily work for specific ecological purposes. These interpretations appear contradictory, but we contend that they can be reconciled by evaluation within the context of complex adaptive systems in which human variables such as goal setting, experiential knowledge, and decision making are given equal importance to biophysical variables. The scientific evidence refuting the ecological benefits of rotational grazing is robust, but also narrowly focused, because it derives from experiments that intentionally excluded these human variables. Consequently, the profession has attempted to answer a broad, complex question—whether or not managers should adopt rotational grazing—with necessarily narrow experimental research focused exclusively on ecological processes. The rotational grazing debate persists because the rangeland profession has not yet developed a management and research framework capable of incorporating both the social and biophysical components of complex adaptive systems. We recommend moving beyond the debate over whether or not rotational grazing works by focusing on adaptive management and the integration of experiential and experimental, as well as social and biophysical, knowledge to provide a more comprehensive framework for the management of rangeland systems.

Teague, W.R., Provenza, F.D., Norton, B.E., Steffens, T., Barnes, M.K., Kothmann, M.M., Roath, R.L. (2009). Benefits of Multi-Paddock Grazing Management on Rangelands: Limitations of Experimental Grazing Research and Knowledge Gaps. In: Schroder, H.G. (Ed.), Grasslands: Ecology, Management and Restoration. Nova Science Publishers, New York, pp. 41–80.

Abstract: The benefits of multi-paddock rotational grazing on commercial livestock enterprises have been evident for many years in many countries. Despite these observations and the results of numerous studies of planned grazing deferment before the mid-1980s that show benefit to species composition, most recent rangelands grazing studies suggest that rotational grazing benefits neither vegetation nor animal production relative to continuous grazing. Detailed comparisons of research methods and practical experiences of successful practitioners of multi-paddock grazing systems identify a number of areas that explain why such different perceptions have arisen. Consistent with producer experience, published data from small paddock trials on both temporal and spatial aspects of grazing management indicates the potential for significantly higher production under multi-paddock rotational grazing relative to continuous grazing and conservative stocking. While research findings often suggest multi-paddock grazing management is not superior to continuous grazing, researchers have not managed trials to answer practical questions such as: how good is this management option, where is it successful, and what does it take to make it work as well as possible? In contrast, successful ranchers manage strategically to achieve the best possible profitability and ecosystem health. They use basic knowledge of plant physiology and ecology generated by research within an adaptive, goal-oriented management approach to successfully implement planned grazing management. Published research and experience from ranchers have indicated that the following management factors are the keys to achieving desired goals: (1) Planned grazing and financial planning to reduce costs, improve work efficiency and enhance profitability and environmental goals; (2) Adjusting animal numbers or having a buffer area available so that animal numbers match forage availability in wet and dry years; (3) Grazing grasses and forbs moderately and for short periods during the growing season to allow adequate recovery; (4) Timing grazing to mitigate detrimental effects of defoliation at critical points in the life cycle of preferred species inter- and intra-annually; (5) Where significant regrowth is likely, grazing the area again before the forage has matured too much; (6) Using fire to smudge patch-grazing imprints and manage livestock distribution; and (7) Using multiple livestock species. In all these areas, management is the key to success. Many researchers have failed to sufficiently account for these management factors, either in their treatment applications or in the evaluation of their results. To define the potential impact, researchers must quantify the management strategies for best achieving whole-ranch business and ecosystem results under different grazing management. Conducting research on ranches that have been successfully managed with planned multi-paddock grazing for many years, together with systems-level simulation modeling, offer complementary approaches to traditional small-paddock field research. These methods are particularly applicable where logistics preclude field experimentation, or when assessing impact over decadal time frames. This chapter discusses these points, suggests areas of research that may explain differences in perception among land managers and researchers, and provides information to achieve the full potential of planned multi-paddock grazing management.

Richards, C., Lawrence, G., 2009. Adaptation and Change in Queensland's Rangelands: Cell Grazing as an Emerging Ideology of Pastoral-Ecology. Land Use Policy 26. 630–639.

Abstract: Does the current global political economic framework, or more specifically, the cost–price squeeze associated with primary production, restrict the choices of Australian cattle graziers in moving to more sustainable practices? It has often been argued by primary producers and academics, alike, that current terms of trade have resulted in reduced profitability at the property level, and as such, have made it difficult for landholders to shift to practices which are environmentally sustainable. Whilst there is mounting evidence that this is case, there is also evidence that some graziers have been able to adapt to the prevailing market conditions through an ideological as well as "practice" shift. Findings from qualitative research in Central Queensland, Australia, has highlighted how "cell grazing" departs from the traditional or conventional aspects of grazing which can be described as productivist, to an approach closely approximating Lang and Heasman's (2004) "ecologically integrated paradigm" [Lang, T., Heasman, M., 2004. Food Wars: The Global Battle for Mouths Minds and Markets. Earthscan, London]. It is argued that cell grazing is, at present, a marginal activity that requires an ideological and cultural shift, as well as an investment in new infrastructure, however, current cell grazing activities may also demonstrate that beef grazing has the potential to be both economically and environmentally sustainable.

Earl, J.M., Jones, C.E.. (1996). The Need for a New Approach to Grazing Management – Is Cell Grazing the Answer? Rangeland Journal. 18(2). 327-350.

Abstract: With any grazing method, the grazing pressure applied to an individual plant is a site, stock density and time dependent variable and the diet selection hierarchy of grazing animals is to the disadvantage of the most palatable and actively growing pasture components. The greater the differences in palatability and abundance among the components of a sward, and the lower the stock density, the greater the variation in the grazing pressure exerted. These effects are heightened when animals are set-stocked under adverse environmental conditions. This paper reports the comparative effects of cell grazing and continuous grazing on pasture composition on three properties on the Northern Tablelands of New South Wales. The basal diameters, relative frequency and contribution to dry weight of the most desirable, palatable species at each site were found to remain constant or to increase under cell grazing, while declining significantly under continuous stocking. The converse was true for the least palatable components of the pasture, which declined significantly under cell grazing but changed little under continuous grazing. Percentage ground cover was significantly higher after two years of cell grazing than under continuous grazing. These changes in pasture composition may have long-term benefits with respect to erosion control, nutrient cycling, hydrological function and the stability of animal production at the cell grazed sites.

DESERTIFICATION

Weber, K.T., Horst, S., 2011. Desertification and Livestock Grazing: The roles of Sedentarization, Mobility and Rest. Research, Policy and Practice. 1:19.

Abstract: Pastoralism is an ancient form of self-provisioning that is still in wide use today throughout the world. While many pastoral regions are the focus of current desertification studies, the long history of sustainability evidenced by these cultures is of great interest. Numerous studies suggesting a general trend of desertification intimate degradation is a recent phenomenon principally attributable to changes in land tenure, management, and treatment. This paper explores the suggested causes of land degradation and identifies the land management and grazing treatments shared by many pastoral cultures. The singular commonality found in nearly all studies of degradation is the prevalence of partial or total rest. While historical observations rightly suggest that desertification is the result of both climatic and anthropic factors, recent focus has been placed upon the effect of sedentarisation. This paper attempts to coalesce these two streams of thinking with particular focus upon inclusive planning processes which may improve arid and semiarid rangeland ecosystems using livestock as a solution to the problem of land degradation.

HOLISTIC MANAGEMENT REBUTTAL

Itzkan, S.J, 2011. Regarding Holechek and Briske, and Rebuttals by Teague, Gill & Savory. 1-19.

Overview: This paper investigates the grazing management assessment reports authored by Briske (2008), and Holechek (2000) in light of their claims regarding methodologies for grassland restoration advocated by Allan Savory. Rebuttals to the Briske and Holechek conclusions are provided by Teague (2008), Gill (2008, 2009a, 2009b, 2009c), and Savory (2000). The Briske and Holechek papers both claim that methodologies for grazing management attributed to Allan Savory are not supported by the reviewed literature, and therefore should not be given further support by extension services and other land management stakeholders. This is becoming an increasingly germane topic within the environmental community, not only for land preservation, but because of the growing awareness of the impact that grassland restoration can have on climate change mitigation. Although the Briske and Holechek papers are often cited, they are not without their critics. Strong refutation is provided by Teague, Gill, and Savory who present point-by-point counter arguments. Their principal claim is that the methodologies cited by Briske and Holechek are not those advocated by Savory, even if the wording has been borrowed, and that continued association of Savory with the practices followed in the studies is inexcusable. Most notably, the studies cited by Briske and Holechek are using stocking rates and grazing timings that are predetermined. Thus, by design, they cannot be adaptive to conditions on the ground, and cannot support a goal for land recovery. Such grazing systems, claim Teague, Gill, and Savory, are the antithesis of what Savory advocates, which is management for maximum ecosystem health by simulating the herd behavior in which ungulates and grasslands co-evolved. Typically, this will entail higher stocking densities, shorter grazing periods, and longer recovery times than are traditionally recommended, but, as nature dictates, they are different in each environment. There is no prescribed recipe. Finding the proper impact for the particular ecosystem is the goal of the “Holistic Rancher”, and the whole point of this approach is to reverse the desertification that is exacerbated by traditional or “continuous” grazing. As the refuting authors claim, without vigilant adaptation to conditions on the ground, deterioration from grazing is almost certain, and the actual herd densities are immaterial. Either we replicate natural animal impact, or the land dies. Thus, contrary to proving Savory wrong, the studies of the type cited by Briske and Holechek, it is argued by their refuters, only prove what Savory is the first to predict, that grazing systems which don’t provide the animal impact grasslands evolved with, will degrade the land and contribute to biodiversity loss. Such studies, argue the refuters, offer no insight into how grasslands evolved nor how we can restore them to their natural conditions, which, not long ago, supported millions of mammals on soils meters deep in arid regions. Additionally, says Teague, the papers cited by Briske and Holechek are referring to small paddock studies that are not indicative of what happens on a ranch. Teague cites numerous papers not mentioned by Briske which show an entirely different picture of ecosystem impact where cattle are allowed to interact with their environment in a natural fashion. Teague makes the claim, echoed by the other refuters, that instead of extrapolating from unrepresentative paddock studies, we should direct our attention to the ranches around the world that are successfully managing for ecosystem restoration.

Gill, C. (2009) Doing What Works: Sloppy Science is Damaging Rangelands and Wildlife. What's Missing is a Complex Functioning Whole. Range Magazine. Fall. 49-51.

The author's 25,000 acre property in West Texas, USA has seen livestock numbers increase by 400% and the amount of forage taken has tripled resulting in a substantial increase in profitability.

WHITE PAPERS AND REPORTS RELATED TO HOLISTIC MANAGEMENT

Savory Institute. 2015. Restoring the Climate through Capture and Storage of Soil Carbon Through Holistic Planned Grazing.

The quantity of carbon contained in soils is directly related to the diversity and health of soil life. All organic carbon sequestered in soils is extracted from the atmosphere by photosynthesis and converted to complex molecules by bacteria and fungi in synergy with insects and animals. An effective, profitable, and culturally relevant method for increasing soil organic carbon is to restore grasslands worldwide to their optimal health. To accomplish this at the scale and pace that we need, Holistic Management a one of its associated processes, Holistic Planned Grazing offers us a tangible way to restore the climate by properly managing livestock to build soil life. Since the 1970s Holistic Management's effectiveness has been well documented on millions of hectares on four continents. By restoring grasslands through Holistic Planned Grazing we have the potential to remove the excess atmospheric carbon that has been the result of both anthropogenic soil loss over the past 10,000 years and industrial-era greenhouse gas emissions. This sequestration potential, when applied to up to 5 billion hectares of degraded grassland soils, could return 10 or more gigatons of excess atmospheric carbon to the terrestrial sink annually thereby lowering greenhouse gas concentrations to pre-industrial levels in a matter of decades. This while restoring agriculture productivity, providing jobs for thousands of people in rural communities, supplying high quality protein for millions, and enhancing wildlife habitat and water resources.

Savory Institute. 2015. An Exploration of Methane and Properly Managed Livestock through Holistic Management.

Questions about livestock and methane are frequently posed in discussions of Holistic Management and the use of domestic livestock for eco-restoration and as food sources. This paper offers an overview of methane as a greenhouse gas and examines the dynamic of methane in the carbon cycle and the role of livestock.

Pinjuv, G. (2011). Gigaton Analysis of the Livestock Industry: The Case for Adoption of a Moderate Intensification Model. The Carbon War Room. 1-17.

Gurian-Sherman D. (2011). Raising the Steaks: Global Warming and Pasture-Raised Beef Production in the United States. Union of Concerned Scientists. 1-56.

Cox, C., Hug, A., Bruzelius, N., 2011. Losing Ground. Environmental Working Group. 1-36.

Van Steenbergen, F., Tuinhof, A., and Knoop, L., 2011. Controlled Intensive Grazing: Savahhah Grasslands, Africa. Transforming Landscapes, Transforming Lives The Business of Sustainable Water Buffer Management. 40-42.