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What can ecological science tell us about opportunities for carbon sequestration on arid rangelands in the United States?

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ABSTRACT

Scientific interest in carbon sequestration on rangelands is largely driven by their extent, while the interest of ranchers in the United States centers on opportunities to enhance revenue streams. Rangelands cover approximately 30% of the earth's ice-free land surface and hold an equivalent amount of the world's terrestrial carbon. Rangelands are grasslands, shrublands, and savannas and cover 312 million hectares in the United States. On the arid and semi-arid sites typical of rangelands annual fluxes are small and unpredictable over time and space, varying primarily with precipitation, but also with soils and vegetation. There is broad scientific consensus that non-equilibrium ecological models better explain the dynamics of such rangelands than equilibrium models, yet current and proposed carbon sequestration policies and associated grazing management recommendations in the United States often do not incorporate this developing scientific understanding of rangeland dynamics. Carbon uptake on arid and semi-arid rangelands is most often controlled by abiotic factors not easily changed by management of grazing or vegetation. Additionality may be impossible to achieve consistently through management on rangelands near the more xeric end of a rangeland climatic gradient. This point is illustrated by a preliminary examination of efforts to develop voluntary cap and trade markets for carbon credits in the United States, and options including payment for ecosystem services or avoided conversion, and carbon taxation. A preliminary analysis focusing on cap and trade and payment for avoided conversion or ecosystem services illustrates the misalignment between policies targeting vegetation management for enhanced carbon uptake and non-equilibrium carbon dynamics on arid United States rangelands. It is possible that current proposed carbon policy as exemplified by carbon credit exchange or offsets will result in a net increase in emissions, as well as investment in failed management. Rather than focusing on annual fluxes, policy and management initiatives should seek long-term protection of rangelands and rangeland soils to conserve carbon, and a broader range of environmental and social benefits.

1. Introduction

Rangelands are one of the most widely distributed landscapes in the world. Found at the more arid end of the earth's climates, approximately 30% of the ice-free global land surface can be considered rangeland (FAO, 2009), although estimates vary widely depending on the particular definition used (Lund, 2007). In turn, rangelands are thought to have as much as 30% of terrestrial carbon stocks (Schuman et al., 2002; FAO, 2009). Debates about the impacts of livestock grazing, climate change, and cultivation on rangelands now include concerns about their effects on carbon cycling. Interest in increasing carbon flux from the atmosphere into the soils and vegetation of rangelands in the United States has led to a number of national policies and market-based projects designed to encourage management that enhances this flux (McCarl and Sands, 2007). It is now commonplace to use the rationale of increasing carbon sequestration to argue for changes in grazing management. Focusing on the U.S., we argue that, given recent developments in the scientific understanding of rangeland ecological dynamics, grazing management strategies and associated management practices cannot lead to reliably increased capture of carbon on many arid rangelands. For this reason, policies for such rangelands that are based on additionality are unlikely to be effective, and may even lead to increased emissions.

Proposals for managing rangelands for climate change mitigation are gaining attention at state and federal levels in the United States. Primarily because they are so extensive, the 312 million ha of U.S. rangelands (USFS, 1989), defined here as grassland,

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shrubland, and savanna, contain significant carbon stocks. Traditional land use, largely grazing, does not involve tillage, potentially resulting in less soil carbon loss than that connected to cultivation (Uri and Bloodworth, 2000). It has been estimated that grazing lands contribute about 15% of U.S. soil carbon sequestration potential (Lal et al., 2003). U.S. rangeland livestock producers, generally operating with low and variable financial returns, continue to express considerable interest in diversifying income streams to include payments related to carbon sequestration (Diaz et al., 2009). Land management and conservation organizations also seek to promote management for increased carbon sequestration on private and public rangelands (Audubon California, 2012). As the U.S. failed to ratify the Kyoto treaty, the voluntary markets for trading carbon credits have thus far been the main thrust of initiatives for incentivizing management for carbon sequestration domestically.

While the specific applications are still contested, there is broad scientific consensus that non-equilibrium models better explain the ecological dynamics of arid rangelands, in the U.S. and throughout the world, than equilibrium models (Briske et al., 2005; Vetter, 2005). The ecological behavior of rangeland systems has been much debated and researched in the last twenty years, but it is not clear that what has been learned through investigation, experimentation, and theoretical development has been integrated into carbon sequestration initiatives and management recommendations. Further, a lack of information has led to overgeneralized applications of scientific and traditional ecological knowledge despite the fact that such knowledge is linked to locales of specific environmental characteristics within rangeland systems. Just as different definitions of the term ‘‘rangeland’’ can lead to vastly different estimates of how much rangeland there is, overgeneralization of ecological knowledge to areas of differing environmental parameters can lead to incorrect assumptions about potential management outcomes. Site specificity is important because rangelands are so widespread, temporally and spatially diverse, and diverse in structure and function.

Because synthesis of information about rangelands has suffered from poorly defined terms and variable usage, this paper begins with a definition of rangeland and a review of the development of explanatory rangeland vegetation change models and their linkage to ecological sites. Next, the interaction of rangeland ecological dynamics and management for carbon sequestration is analyzed. Finally, the implications of this science for carbon sequestration management and policy initiatives are presented and discussed, and we offer recommendations for rangeland carbon policies that accommodate recent developments in rangeland ecological science.

2. Rangelands and rangeland ecosystem dynamics

Rangelands have been defined as a type of vegetation, a land use, or what is left when other types are excluded. Definitions of rangeland that include specific uses, usually livestock grazing (NRCS, 1997; Holechek et al., 2010), are not a good basis for stable descriptions of extent or processes. Defining rangelands as ‘‘land not permanently ice and snow, urban, cropland, or forest’’ (Stoddard et al., 1975) does not identify what rangelands actually are. Defining rangelands as grasslands, shrublands, and savanna (Heady and Child, 1994) incorporates a wide range of communities from arid to semi-arid and can be distinguished from other more productive systems like woodlands, forests, wetlands, and croplands. These distinctions are essential for predicting and measuring carbon at the landscape scale. Included within this definition are what have been defined as ‘‘grazing lands’’ (NRCS, 1997; Follett and Reed, 2010) to emphasize the importance of large herbivore grazing, and intensively managed lands used for grazing that have been termed ‘‘pasturelands’’ (Holechek et al., 2010). Rangelands can be temporally transient, especially at the margins with forest, wetlands, and croplands (Heady and Child, 1994). Rangelands with sufficient rainfall, or suitable for irrigation, may be temporarily or permanently converted to cropland or forest. U.S. arid and semi-rangelands generally fall to the west of the 100th Meridian.

For nearly a century, the management of U.S. rangelands has been informed by predictive models for vegetation change linked to geographic areas known first as ‘‘range sites’’ and now as ‘‘ecological sites’’ (Brown, 2010). Early in the twentieth century, Sampson (1917) adapted the then new concepts of Clementsian plant succession into a model relating grazing pressure to vegetation change away from and towards an equilibrial ‘‘climax’’ of ideal plant species composition. This linear, deterministic model was used in developing a general framework for evaluating progress in sustainable livestock grazing and rehabilitation of deteriorated rangeland. The utility of this approach was greatly enhanced by the development of what was called the ‘‘quantitative range condition’’ model (Dyksterhuis, 1949), which measured range condition as the difference between the current species composition and productivity and the ideal climax state. What operationalized this approach was combining Sampson’s ideas about species composition with newer theories of an edaphic climax to identify what were termed *range sites*, defined as rangeland areas with a similar potential climax state (SCS, 1976). This formed the basis for evaluating the ‘‘health’’ of rangelands and for informing grazing management.

The term *ecological site* replaced range site by the early 1990s (NRCS, 1994). This was more than just an alteration in terminology, as the change reflected significant advances since the 1980s in models describing succession. It has been found that non-equilibrium models better explain ecological dynamics then do equilibrium-based models, particularly when rangeland is at the arid end of a gradient from dry to mesic conditions (Briske et al., 2005; Vetter, 2005). Non-equilibrium or disequilibrium models posit that abiotic factors such as weather, soil structure, erosion, and water table depth are the dominant drivers of rangeland productivity and species composition (Ho, 2001), and that the relationship with livestock grazing is often non-linear (Westoby et al., 1989; Ellis and Swift, 1988). On arid rangelands spatial and temporal variation in water and forage resources is high, annual production is as unpredictable as rainfall and temperature patterns, and extremes of precipitation or temperature are not uncommon. Non-equilibrium models also posit the existence of multiple stable (within a management timeframe) vegetation states maintained largely by abiotic factors, rather than a single endpoint climax or stable equilibrium state (Westoby et al., 1989; Stringham et al., 2003) created mostly by biotic interactions, including grazing pressure. As a result, an ecological site is described more by climate, topography, and soils, than reference to a climax vegetation (Brown, 2010). Assessments of range condition have been largely decoupled from the use of linear distance to climax.

Westoby et al. (1989) provided an alternative approach to describing the dynamics of managed ecological sites using state and transition models which accommodate non-linear, non-equilibrium ecology and varied management objectives. Current use of ecological site by federal agencies emphasizes concepts of stable states and thresholds and utilizes recent advances in available soil information and Geographic Information System (GIS) technology (Brown, 2010). The more traditional goals of sustainable grazing management and enhanced forage production have been joined by the need to evaluate and anticipate response of rangelands to global change and the potential for carbon sequestration.