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Assessing optimal configurations of multi-paddock grazing strategies in tallgrass prairie using a simulation model

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ABSTRACT

Maintaining or enhancing the productive capacity and resilience of rangeland ecosystems is critical for the continued support of livelihoods and the ecosystem services that benefit society at large. While the benefits of multi-paddock grazing management have been evident for many years in many countries, it is extremely difficult if not impossible to adequately assess the consequences of the different combinations of management options possible when using multi-paddock management under constantly varying conditions on rangelands. To investigate grazing scenarios that would be impractical to conduct in the field we developed a simulation model to focus on addressing the impacts of different cattle grazing management options with multi-paddock management on ecological condition (EC) and profitability. Cattle ranching options are simulated over 25 years periods under varying levels of multi-paddock grazing management complexity at low to moderate stocking levels and fixed or variable stocking rates. We examine the likely ecological and economic effects of shortening grazing periods, lengthening recovery periods, using fixed versus adaptive operational decisions and increasing the number of paddocks in the grazing configuration. At initial stocking levels of up to at 70% of forage standing crop, both EC and profitability are increased with increasing number of paddocks. Shorter periods of grazing increase both EC and profitability while increasing recovery periods increases both EC and profitability initially but profitability decreases if recovery periods are too long. Both EC and profitability are positively related to number of paddocks used.

1. Introduction

Semi-arid rangelands occupy approximately one third of the earth's land area and are degrading primarily due to inappropriate land use practices (Millennium Ecosystem Assessment, 2005). At least one billion rural and urban people depend on them for their livelihoods, often through livestock production, or for ecosystem services that affect human well-being (Ragab and Prudhomme, 2002). Such ecosystem services include maintaining stable and productive soils, minimizing soil erosion, delivering clean water, and sustaining plants, animals and other organisms that support livelihoods and human esthetic and cultural values (Daily, 1997; Grice and Hodgkinson, 2002). Therefore, there are huge economic and social costs associated with this degradation. Improving or sustaining the long-term productivity and resilience of semi-arid rangelands requires management strategies based on an understanding of the feedback-mechanisms between vegetation and livestock in a fluctuating environment (Walker et al., 2002; Müller et al., 2007) and a decision framework that is adaptable and enables decisions to be made under constantly changing circumstances to take advantage of positive events and mitigate the damage of negative events (Savory and Butterfield, 1999; Teague et al., 2013).

From the late Mesozoic era grazing ecosystems coevolved and coexisted with free-ranging herbivores that generally moved constantly in response to changes in the quantity and quality of available vegetation, resulting in grazing for short periods and usually allowing plants to recover between defoliation events (Frank et al., 1998). However, in most of the world's semi-arid rangelands, the replacement of free-ranging wild herbivores with fenced-in livestock has removed the key ecosystem regulatory process of periodic vegetation defoliation and regrowth (Frank et al., 1998). This, coupled with the use of supplemental feed to maintain artificially high numbers of domestic grazers during

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periods of low vegetation production, has led to widespread overgrazing (Oesterheld et al., 1992; Milchunas and Lauenroth, 1993), degradation of vegetation and soils (Milchunas and Lauenroth, 1993; Teague et al., 2011), declines in productivity and biodiversity (Archer and Smeins, 1991; West, 1993; Knopf, 1994; Frank et al., 1998), and a reduction in ecosystem resilience (Peterson et al., 1998).

Although the key regulatory role played by the periodicity of grazing and recovery is becoming increasingly clear (Earl and Jones, 1996; Savory and Butterfield, 1999; Tainton et al., 1999; Jacobo et al., 2006; Müller et al., 2007; Provenza, 2008; Teague et al., 2011), controversy remains (Briske et al., 2008). One view is that rangeland ecosystems reach a steady–state equilibrium primarily in response to a fixed grazing pressure, which logically leads to the conclusion that rangeland degradation (loss of productivity) is attributable to excessive stocking rates *per se* (Lamprey, 1983; Dean and Macdonald, 1994). An alternative view is that rangelands are non-equilibrium systems responding primarily to variable and unpredictable rainfall, with biotic factors such as grazing exerting only marginal influence (Behnke and Scoones, 1993; Sandford, 1994; Scoones, 1994), which logically leads to the conclusion that fixed stocking rates are unsuitable and "opportunistic" grazing strategies should be employed (Westoby et al., 1989). These strategies typically involve de-stocking at the first indication of a pending drought and rapid restocking after the drought, with no provision for periodic de-stocking of pastures to allow for the recovery of defoliated vegetation, believed by many to be essential to maintain rangeland productivity, ecological function and resilience (Müller et al., 2007; Teague et al., 2004, 2011).

Adjusting stock numbers to match forage biomass and multiple paddocks per herd to regulate grazing intensity, provision of periods of recovery and spreading grazing pressure over more of the management landscape have been used successfully by ranchers around the world since the mid-20th century (Earl and Jones, 1996; Beukes and Cowling, 2003; Jacobo et al., 2006; Teague et al., 2004, 2011).

A major problem associated with empirically evaluating the ecological performance of multi-paddock grazing strategies stems from the difficulty of obtaining field data at appropriately large spatial and temporal scales. For this reason, simulation models have frequently been used to investigate grazing scenarios that would be impractical to conduct in the field (Wiegand et al., 1995; Pickup, 1996; Jeltsch et al., 1997; Illius and O'Connor, 2000; Weber et al., 2000; Beukes et al., 2002).

This study addresses questions on the consequences of using a wide range of applications of multi-paddock grazing management over decadal time frames in commercial scale ranch settings. Changes in ecological condition and profitability of cattle ranching are simulated over 25-year periods under varying levels of management complexity at low to moderate stocking levels and fixed stocking rates. An overview of the study area is provided, and then the general structure of the model and model equations are described. The model is then used to evaluate what combinations of periods of grazing, length of recovery and adaptive changes in management in response to prevailing conditions provide the best ecological condition and ranch profitability with multi-paddock grazing.

2. Methods

2.1. Study ecosystem

The model was parameterized to represent typical commercial cattle ranches of the southern tallgrass prairie in Texas, U.S.A. Mean annual rainfall ranges from 800 to 900 mm with a bi-modal distribution peaking in May–June and September (U.S. Department of Commerce, 1956–2000). Elevation ranges from 15 m in coastal prairies to 330 m in north Texas and the climate is continental with an average 320 and 220 frost-free growing days on the coast and in north Texas, respectively.

Native tallgrass prairie in Texas now occurs principally in the Gulf Coastal Prairies and Marshes region in the south and the Cross Timbers and Prairies in the north (Hatch et al., 1990). Soils are predominantly moderately fertile to fertile and range from loamy sands to clay-loams derived from limestone. Land that has not been used for agriculture is dominated by the original vegetation and is used primarily for cattle grazing. The vegetation is dominated by the C_4 tall grasses *Schizachyrium scoparius*, *Andropogon gerardii*, and *Sorghastrum nutans*, C_4 mid grasses *Bouteloua curtipendula*, and *Sporobolus compositus*, and *Bothriochloa laguroides*, C_3 midgrass *Nassella leucotricha*, and forbs *Ambrosia psilostachya*, *Aster ericoides* and *Gutierrezia texana* (Hatch et al., 1990; Diggs et al., 1999).

Cattle production includes both cow-calf and stocker programs. Stockers are generally purchased as recently weaned animals in fall and grown out to be sold when prices are high in late summer. Warm season grasses provide most of the herbaceous production while cool season grasses and some forbs provide forage during the cooler time of the year (Teague et al., 2001). Cattle production systems in the area are typical of semi-arid rangelands throughout the world in that producers usually practice continuous grazing and seldom adjust stocking rates based on environmental conditions. Most commercial ranches are slightly to moderately degraded and in fair to poor ecological condition (Teague et al., 2011). A stocker operation is simulated in which the rancher buys young steers each year in fall and markets them off the property in late summer the following year. This simplifies computation and interpretation compared to simulating a year round cow-calf operation.

2.2. Model overview

To simulate long-term changes in ecological condition and profitability of the hypothetical ranch, elements of previous models developed by Blackburn and Kothmann (1989), McFarland et al. (1992), Glasscock (2001), Glasscock et al. (2005), Díaz-Solis et al. (2003, 2006a, b), and Teague et al. (2009) were adapted. The resulting model is a compartment model based on difference equations ($\Delta t = 1$ day), which was programmed in STELLA 9.1 (High Performance Systems Inc., Hanover, New Hampshire), simulating the dynamics of standing crop forage, ecological condition, diet selection, cattle production, profit and loss under continuous and several mixed-paddock grazing management strategies (Fig. 1).

The vegetation sub-model represents the dynamics of live and dead forage resulting from the processes of net primary production, senescence, and decomposition, as well as the loss of live and dead forage via grazing. The cattle production sub-model represents the forage intake requirements of cattle, the proportions of live and dead vegetation in their diets, the associated dry matter digestibility and crude protein level of their diets, and their resulting weight gain.

Ecological condition (EC) represents the productivity, health and composition of the herbaceous vegetation to provide an index of ecological functional integrity. EC class is quantified on a relative scale to represent rangeland as: Excellent ($EC = 1.25$), Good ($EC = 1.0$), Fair ($EC = 0.75$), and Poor ($EC = 0.50$) condition. It is increased or decreased according to the proportion of ANPP consumed by the cattle, or utilization, which is the percentage of ANPP consumed by cattle each year as outlined by Díaz-Solís et al. (2003).