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ANALYSIS

An ecological economic simulation model for assessing fire and grazing management effects on mesquite rangelands in Texas

W.R. Teague[a,c,*], W.E. Grant[b], U.P. Kreuter[c], H. Diaz-Solis[d], S. Dube[c], M.M. Kothmann[c], W.E. Pinchak[a,c], R.J. Ansley[a,c]

[a]Texas Agricultural Experiment Station, Texas A&M University System, Box 1658, Vernon, TX 76384, USA
[b]Ecological Systems Laboratory, Department of Wildlife and Fisheries Sciences, Texas A&M University, 2258 College Station, TX 77843-2258, USA
[c]Department of Ecosystem Science and Management, Texas A&M University, 2126 TAMU, College Station, TX 77843-2126, USA
[d]Departamento de Recursos Naturales Renovables, Universidad Autónoma Agraria Antonio Narro, Saltillo, Coahuila 25315, Mexico

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ABSTRACT

In the southern Great Plains of North America, fire exclusion has contributed to many rangelands converting from native grassland to woody shrublands dominated by mesquite (*Prosopis glandulosa* Torr.) and cactus (*Opuntia* spp.), threatening ecosystem health and human livelihoods in the region. Prescribed fire is the least expensive method of treating mesquite and other undesirable plants, but its role is as a maintenance treatment to prolong the life of more expensive brush control treatments. Using a simulation model of a hypothetical 1000 ha ranch, we evaluate the biological and economic implications of management scenarios involving the regular application of summer fire to reduce mesquite and cactus over a 30-year time period. We compared the model output with experimental data to corroborate model output before evaluating various management scenarios over a range of stocking rates. Scenarios included (a) varying initial range condition, (b) different frequencies of summer burning, and (c) different initial amounts of mesquite brush. Model simulations corroborated field data sufficiently well to give confidence in the output of the model. In our simulations the option of not treating to reduce brush and cactus had a major negative impact on range condition, secondary productivity and profitability. In contrast, all simulated fire treatments improved range condition, productivity and profitability except when initial range condition was poor. Initial range condition and stocking rate were the major factors affecting both productivity and profitability. Compared to other factors over which managers have short-term control, frequency of burning and the initial amount of mesquite cover, had a relatively minor impact. Simulations indicated that the highest level of profit consistent with maintaining or improving range condition was attained when individual animal production was 92–95% that of the maximum production per animal, a situation invariably associated with relatively low stocking rates.

* *Corresponding author*. Texas Agricultural Experiment Station, P.O. Box 1658, Vernon, TX 76384, USA. Tel.: +1 9405529941; fax: +1 940 553 4657.
E-mail address: r-teague@tamu.edu (W.R. Teague).

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1. Introduction

North American prairies evolved under episodic grazing and widespread warm season wildfires that historically limited woody plants. However, the growth of forage-based livestock production and the threat of fire damage to buildings and structures in rural areas led to suppression of wildfires. Together with reduced grass competition from heavy livestock grazing, enhanced distribution by livestock, increased global CO_2 and removal of prairie dogs (*Cynomys ludovicianus*), fire reduction has contributed to many southern rangelands converting from native grasslands to woody shrublands (Schlesinger et al., 1990; Archer, 1994, 1995; Archer and Smeins, 1991; Collins et al., 1998; Polley et al., 1994; Kramp et al., 1998; Weltzin et al., 1998). This epidemic invasion of woody and succulent species has resulted in a decline in biodiversity (West, 1993; Knopf, 1994), a reduction in ecosystem resilience (Peterson et al., 1998), and a greater likelihood of irreversible changes in plant species composition (Westoby et al., 1989). Maintaining or restoring rangeland ecosystem health and resilience is a critical social imperative to ensure the future supply of the ecosystem services they supply, which are critical for the future well-being of human societies in the region. Such services include provision of stable soils, reliable and clean supplies of water, and the natural occurrence of plants, animals and other organisms to meet the aesthetic and cultural values and livelihoods of people living in rangelands (Grice and Hodgkinson, 2002).

Honey mesquite (*Prosopis glandulosa* Torr.) dominates many rangelands in the southern Great Plains of North America, reducing forage production and interfering with livestock foraging and management (Scifres, 1980). If left unchecked, mesquite encroachment progresses within grassland ecosystems until a closed canopy woodland thicket occurs (Ansley et al., 2004), which threatens the sustainability of livestock ranching as well as wildlife habitat (Rollins and Cearley, 2004) and grassland birds (Knopf, 1994). Increase in mesquite cover can significantly reduce grass productivity but it generally affects watersheds less than other woody species (Carlson et al., 1991). Cacti (*Opuntia* spp.) become increasingly abundant as range condition declines thereby reducing forage production and hampering livestock management (Hamilton and Ueckert, 2004).

Although it is economically rational to use aerially applied root-killing herbicides to reduce mesquite, fire is generally considered to be the least expensive method of treating mesquite and other undesirable fire-intolerant plants; yet its use as a rangeland management treatment has been mainly to prolong the life of more expensive brush control treatments (Scifres and Hamilton, 1993; Teague et al., 2001). While prescribed fire is an effective means of reducing woody plants and cacti, a threshold amount of flammable fine fuel (forage) is needed to carry fire that is sufficiently intensive to reduce woody plants (Ansley and Jacoby, 1998). Furthermore, to effectively control woody plants and cacti fire must be applied regularly (Hamilton and Ueckert, 2004). Many rangelands occur in semi-arid environments in which forage-based livestock production is the primary agricultural activity and intermittent droughts are inevitable (Thurow and Taylor, 1999). Accumulating sufficient fine fuel to carry fires in such environments requires the reduction in livestock numbers compared to areas where fire is not used. Therefore, sustainable utilization of semi-arid rangelands depends on complex management of animal species, stocking rates, and the vegetation composition, structure, phenology and quality.

While effective management requires sound ecological data about the land being managed, obtaining such data is not sufficient to ensure the implementation of restoration practices by landowners. Rational decisions at the ranch, regional and national levels, depend on researchers providing not only ecologically sound but also economically effective alternatives for land use. Furthermore, because natural resource depletion and recovery compound over time, it is necessary to assess the sustainability of management alternatives over decadal time frames (Teague, 1996). In addition, to determine the true advantage of restoration management, it is necessary to compare the benefits of changing management practices with the cost of *not* changing current practices, which rather than maintaining productivity, may lead to loss of production through shifts in plant species composition, accelerated soil erosion, and loss in biodiversity. In this paper we use the generic term "range condition" to denote overall ecosystem functional integrity and productivity.

Models have great potential as research tools to enhance our knowledge of ecosystem function and as decision aids for natural resource managers, including ranchers. They can achieve this by collating results from experiments in different fields or locations within the context of a more encompassing systems management framework that treats the ranch business as a complete bio-economic unit. In order to improve decision making, ranchers need answers to questions at the systems level, including the biological and economic elements of the rangeland production entities they are attempting to manage (Beukes et al., 2002). Simulation models can uniquely provide assessments of such bio-economic production elements at the systems level when logistics preclude local field experimentation or where assessments over decadal time frames are locally unavailable. However, to be useful as a decision aid for resource managers, models must provide predicted results that strongly correlate with field data (Teague and Foy, 2002).

In this paper we present the use of a simulation model to explore the range condition, production and economic consequences of implementing land management actions that include the use of prescribed fire applications, specifically summer fires that are more effective than cool season fires for controlling mesquite and cactus (Ansley and Jacoby, 1998; Ansley et al., 2002a; Ansley and Castellano, 2007). Based on current management practices, we assume that a method other than fire (e.g., herbicide), is used as the initial mesquite reduction treatment. Our objective was to be able to use a simple ecological economic simulation model to evaluate the bio-economic implications over a 30-year period of management scenarios that incorporate different fire frequencies, different initial amounts of mesquite, cactus, and herbaceous vegetation states (range condition) and different cattle stocking rates. We first describe how we modified the SESS model (Diaz-Solis et al., 2003) to include woody and cactus vegetation components and the ability to simulate the productivity and