Do Livestock and Ecosystem Services Compete? A State-and-Transition Approach

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Rangeland managers are charged with managing complex social-ecological systems. While they must be concerned with economic sustainability, they are often under pressure to provide public benefits as well. As the public becomes aware of the additional services these diverse ecosystems provide, land managers are becoming pressured to provide ecosystem services in addition to livestock production. However, there are few tools that provide the type of information rangeland managers need to understand the trade-offs of managing for different ecosystem services in order to make these complex decisions.

In 2010, the USDA Natural Resources Conservation Service (NRCS), US Forest Service (FS), and Bureau of Land Management (BLM) signed an MOU agreeing to adopt state and transition models (STMs) as a standard basis for rangeland inventory and monitoring. STMs are used to assess current conditions in relation to known ecosystem dynamics, identify management objectives and appropriate monitoring indicators, and assess whether objectives are being met (Bestelmeyer et al. 2003, Bestelmeyer et al. 2004). STMs represent a key tool in the process of adaptive management because they provide a clear representation of the best current knowledge about how a given ecosystem responds to different management and environmental factors. Currently, most STMs are diagrams accompanied by narrative descriptions (see figure 1), and may not be useful in determining ‘optimal’ management strategies. Therefore, our team created a linked ecological-economic simulation model with the goal of using a STM to determine optimal rangeland management given a range of management objectives.

We use the STM approach to model decision-making on a typical ranch in the Elkhead Watershed in northern Colorado. The ranch is a collection of ecological sites, or types of land with similar climate, soils and potential vegetation, that can transition between several states based on management and climatic events. We use field data and local knowledge to build the STM of ecological dynamics for each ecological site and determine how likely transitions are given past management and weather. Using an economic model based on the ecological STM and economic data from typical ranches in the region, we examine the decisions that contribute to, and economic outcomes that result from, changes in ecological states. In our framework, past ranch decisions affect existing ecological states, and current decisions play an important role in determining transition potentials. We also examine how current ecological conditions and management decisions influence the provision of ecosystem services other than livestock production.

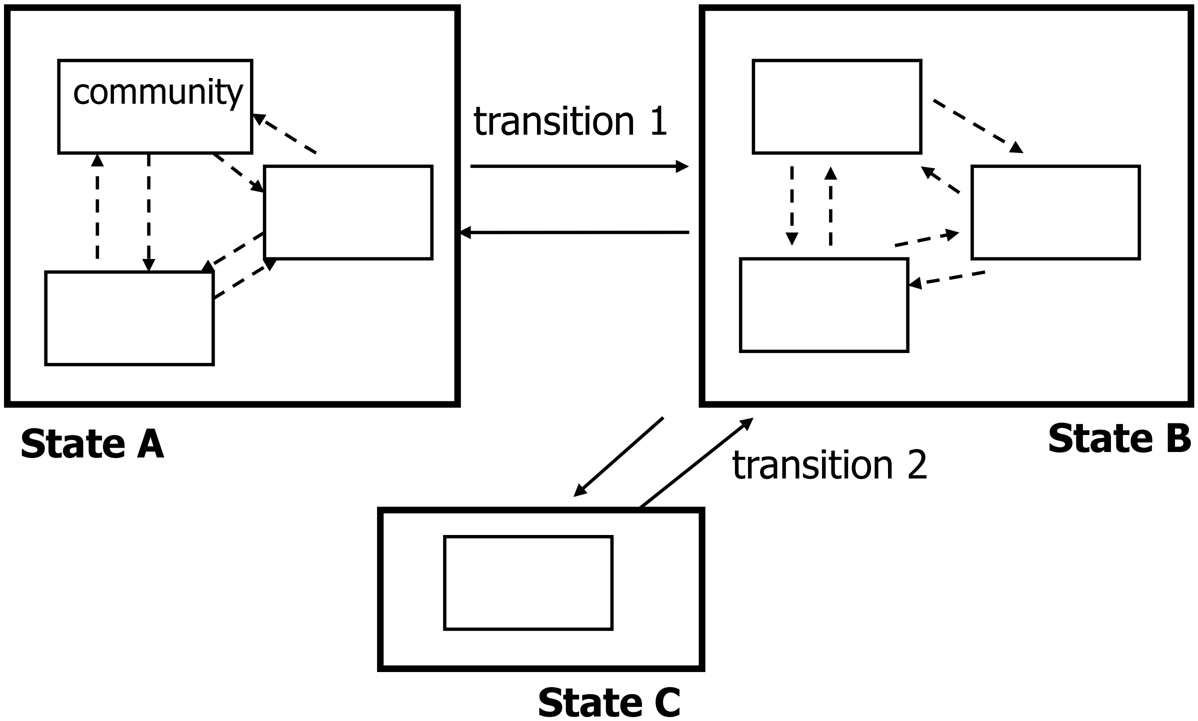

Figure 1. Example State and Transition Model (from Bestelmeyer et al. 2003)

Study Area

We have chosen to focus our model development on the northwest Colorado counties of Moffat and Routt, which cover some 7,105 square miles of diverse rangelands and forested mountains. The resource management concerns and socio-economic forces at play in these counties typify much of the broader Intermountain West. Ranching remains the dominant land use in Moffat County, and ranches account for 59% of the private land in Routt County. The study area covers a wide variety of rangeland vegetation types from high-elevation parklands, sagebrush grasslands and oak shrublands, and lower elevation semi-desert shrublands. The focal area for this linked ecological and economic model is the 150,000-acre Elkhead Watershed. The ecological sites in this area resemble those in Wyoming and Utah, as well as the broader Intermountain West region, making information gathered here regionally applicable. The coupled ecological-economic STM consists of three distinct ecological sites (Claypan, Mountain Loam, and Aspen), in addition to riparian areas, hay production and pastures.

Data and Methods

The STM was developed based on ecological data and local knowledge (see Knapp et al. 2011 for more detail). The area of land in each of the ecological sites for our representative ranch is based on the proportional make-up of the Elkhead watershed land base. Basic ranch characteristics including herd performance such as weaning percentage and bull/cow ratios are based on results of Rowe and Bartlett (2001) as well as FLIPSIM models (see Smith et al. 1997 and Agriculture and Food Policy Center 2006 for more detail regarding FLIPSIM). The ranch is comprised of 2,392 acres in the Claypan site, 386 acres in the Aspen site, and 1,057 acres in the Mountain Loam site. The forage production potential of the Claypan, Aspen, and Mountain Loam sites is dependent on the ecological state and weather events. The ranch utilizes a fixed amount of public AUMs and has access to 200 acres of riparian area, which provides a total of 2 AUMs per acre, with livestock able to utilize 35% of total production. The ranch includes 800 acres of land devoted to hay production.

Decision Variables

Decision variables under the producer's control include stocking decisions and spraying decisions. The stocking rate decision can be *Low*, *Moderate*, or *High*. The *Moderate* stocking rate is based on local recommendations (225 cows) for a ranch with our land base, with the *High* and *Low* stocking rates being 20% above (270 cows) and below (180 cows) that rate respectively. The model allows producers to spray either or both the Claypan and Mountain Loam sites to eliminate shrubs. The model does not allow the option to spray the Aspen sites as no local producers have sprayed, or would recommend spraying, these areas. Spraying is carried out with aerial application, at a cost of $20 per acre. However, local EQIP payments are available (depending on available funding) to cover 75% of these costs.

Timing of Events

As ecological changes are usually not observed in an annual time step, our model uses a three-year decision period. This three-year decision period is the same recommended amount of time for range monitoring, making alterations to herd numbers likely over this time interval. Producers make stocking and spraying decisions after observing ecological conditions, but prior to knowledge of precipitation and fire events. At the end of the three-year period, the stochastic fire events occur and new ecological states are determined based on stochastic events and management decisions, as a result of the transition probabilities associated with our STM.

Stochastic Events

Productivity in terms of usable AUMs for each of the potential ecological states is in part dependent on stochastic precipitation. The frequency of weather outcomes is based on historical precipitation data for the study area. Given the three-year time-step for the model, the weather data was analyzed over a three-year moving average, with *Dry*, and *Wet* weather events defined as three-year precipitation averages 20-percent below, and above, the historical average, respectively. Hay production occurs on irrigated, fertilized lands, and is therefore not dependent on weather events. Our model also includes stochastic fire events, which occur separately on each of the ecological sites.

Ranch Revenues

The ranch is a cow/calf operation, with the majority of revenues coming from calf sales. Annual profitability is comprised of net revenues from the livestock operations and hay operations, less fixed costs. The ranch practices spring calving and markets all calves (less replacement heifers) in the fall. While most revenues come from calf marketings, the ranch also receives revenues from the sale of cull cows and bulls. Variable costs associated with cattle include veterinary costs, salt and mineral costs and marketing costs (including transportation to market). If herd numbers are decreased, the ranch receives revenues from culling activities. If, however, herd numbers increase, the ranch is expected to purchase replacement heifers. Hay produced on the ranch is raised primarily as a feed source for the cattle operation, as most producers in the study area feed hay through the severe winter month when grazing access is limited. Actual hay requirements of the herd are dependent upon herd size and forage production, which is in turn dependent on weather events. If additional hay is needed to fulfill animal requirements, hay is purchased at market price. Therefore revenues from hay sales are dependent upon ecological states, weather impacts, and herd size, and may be negative if hay is purchased rather than sold.

Ecosystem Services

Livestock production is rarely the sole management objective of a ranch; therefore values for various ecosystem services were also collected during fieldwork. Ecosystem services measured include wildlife habitat (elk, mule deer, and sage grouse), as well as overall plant biodiversity, resistance to soil erosion and resistance to weed invasion. To compare optimal management for livestock production against management for ecosystem services, the model was initially run with the sole objective of maximizing long-term profitability strictly from cattle operations. To determine the impact of managing for ecosystem services, the model was also run with the objective of maximizing ranch profitability subject to the requirement of maintaining a minimum (or maximum) level of one of the ecosystem services. As the ranch was not able to provide an adequate level of all services simultaneously, the model was run multiple times, each time being required to maintain a given level of only one of the ecosystem services.

Solution Method

The model is designed to determine the optimal decisions for all periods resulting in the maximum present value of expected returns over the planning horizon. Optimal solutions, including the combination of stocking rate and spraying decisions, are specified for all possible ecological state combinations, and are solved using dynamic programming.

Results

Results from the model when livestock profitably is the only objective show very little incentive for producers to stock above NRCS recommendations. In fact, it is in producers' interest to 'understock' rangelands more often than it is to 'overstock.' It was never profitable to spray Claypan sites, and only profitable to spray Mountain Loam sites 33% of the time. The model ranch is unable to provide adequate levels of all ecosystem services simultaneously, yet changes to 'optimal' management decisions varied as the ranch was forced to meet critical levels of the alternative ecosystem services. The model was run with two separate penalties for not meeting the ecosystem service objectives. The first, "moderate penalty," requires a landowner to lease alternative forage when ecosystem service levels fall below (above) critical thresholds. The second, "extreme penalty," results in a shutdown of the ranch if ecosystem service objectives are not met. While this extreme result is unlikely to occur, it may be applicable in the case of sage grouse being listed as endangered. The level of penalty has a large impact on optimal decisions. For the "moderate penalty" scenario, four of the ecosystem services resulted in optimally stocking at the *High* level more often than for livestock alone, while only one ecosystem service optimally resulted in an increase in the occurrence of the *Low* stocking rate. For the "extreme penalty" all but three of the ecosystem services required an increase in the likelihood of *Low* stocking, while four ecosystem services required an increase in stocking *High* as compared to 'optimal' livestock production. In terms of spraying, the "moderate penalty" does not find it optimal to spray the Claypan site for any ecosystem service, yet finds it optimal to increase the occurrence of spraying the Mountain Loam sites for three of the ecosystem services and less likely to spray Mountain Loam sites for two of the services. For the "extreme penalty" producers are generally more likely to spray Claypan sites yet less likely to spray Mountain Loam sites.

Implications

The STM utilized for this model suggests that ranchers have very little incentive to stock higher than recommended rates, especially when considering the potential long-term determination of range condition that may be associated with higher stocking rates. Our model also suggests that producers have very little incentive to engage in brush control on rangelands, unless there is a severe penalty for not maintaining certain ecosystem services. However, if a producer is interested in providing ecosystem services other than livestock production, he/she must choose which services to provide. Our model ranch was unable to adequately provide all of the services we measured simultaneously. However, depending on objectives and penalties, there are some ecosystem services which are well aligned with livestock production, implying that livestock production can coexist with the procurement of other ecosystem services. For example, under the "moderate penalty," optimal decisions for both mule deer and sage grouse are well aligned with optimal livestock production, while optimal decisions for minimizing soil erosion or weed invasion are quite different than optimal livestock decisions. However, under the "extreme penalty" scenario, producers must choose between livestock production and other ecosystem services. However, producers are not able to provide all of the other services in conjunction with each other, and must decide which service to provide.

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