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Understanding future threats to western rangelands: Modeling the performance of grazing strategies in the face of environmental change

Gregory L. Torell[1], Katherine D. Lee[2] and Caitriana Steele[3]

Rangeland ecosystems comprise 30% of the land area in the United States (Havstad et al. 2009), the health and resilience of which produce a variety of economic and social benefits. Rangelands are a dynamic resource; decisions made today affect range conditions over subsequent seasons, and conditions realized today are the product of past management decisions. Therefore, rangelands really must be managed over time. Historically, the economics literature on rangelands has focused predominantly on selecting livestock grazing strategies (namely stocking rates) to maximize economic net benefits. More recently, economic studies have incorporated insights from ecological research into models, adding ecological feedbacks to models as well as the effects of, for example, stochastic weather and invasive species.

As changing climates alter the risks to rangeland ecology, through establishment and spread of invasive species and transition of rangelands away from native perennial grasses, the economic performance of existing livestock grazing strategies may need to be re-evaluated. While economists seek out grazing strategies that maximize profit, livestock producers and land management agencies often rely on rules of thumb, such as "take half, leave half" or "50% utilization" rule. The dynamic, economic, and ecological impacts that arise from rangeland managers using this rule of thumb are still poorly understood, especially under changing environmental conditions. So, the question arises: will continued use of the traditional 50% utilization rule of thumb benefit or harm the health of rangeland ecosystems and producers in the face of a changing climate and invasive plant species?

[1] Texas A&M University, Dept. of Agricultural Economics, and Texas A&M AgriLife Research Center at El Paso
[2] University of Idaho, Dept. of Agricultural Economics and Rural Sociology
[3] USDA-ARS Jornada Experimental Range and Department of Plant and Environmental Sciences, New Mexico State University

Understanding and modeling how climate change and stocking rate decisions will affect primary production of beneficial species is critical to maintaining rangeland health and sustaining future ranching on western rangelands. Managers must focus not only on maximizing economic returns from livestock grazing, but also how stocking decisions will impact inter-species competition between edible forage species, undesirable native species and non-native invader species. This piece discusses how climate change, species ecology, and human decision making simultaneously impact rangeland health and economic returns.

An overview of contemporary rangeland modeling

For the latter part of the 20th Century, the standard ecological "range model" was the accepted approach for assessing range condition and trend on western rangelands. This model was based on Clementsian theories of succession and considered the species composition of rangeland vegetation communities to be a function of grazing intensity. However, the range model had several shortcomings in that it assumed vegetation change occurred linearly along a single axis of succession, and that grazing was the sole driver of that change (Briske et al., 2005). In response to these shortcomings and to developments in the paradigm of non-equilibrium vegetation dynamics, Westoby, et al. (1989) developed the state-and-transition framework to better represent vegetation dynamics on rangelands and to recognize multiple drivers of change. Since Westoby's paper was published, conceptual state-and-transition models (STMs) have become widely used by public and state agencies for assessing rangeland health.

The general concept of STM modeling is that any given ecologically distinct site can support multiple alternative stable ecological states, and that transitions between healthy and less healthy states are often non-linear and can occur abruptly once a threshold is crossed. Most STMs include a suite of interacting drivers, such as natural disturbances (e.g., drought, fire, extreme weather events) or management actions (e.g., changes in grazing pressure, herbicide application, reseeding) that can cause a transition from a site's current ecological state to an alternative state. Each transition from one state to another is not purely mechanistic (i.e., if this action is taken then this state is achieved). Rather, transitions are understood within the STM framework to be probabilistic in nature, where the probability of each possible transition depends on the current state of the range, as well as management and natural inputs.

Incorporation of STMs into economic modeling began in the mid-1990s, with Perrings and Walker (1997), who analyzed the sensitivity of Australian rangelands to fire impacts. As they note, the benefit of incorporating an STM framework is that the method captures common features of semi-arid rangelands that have been observed as cyclical in nature, and not successional. These include the sensitivity of system dynamics to rare and extreme events (e.g. fire, flood and drought), the interactions between grazing pressure and these extreme events, and the possibility of multiple locally stable states of the range. A further benefit of incorporating STMs into economic analyses is that it creates an ecologically sound determination of whether a combination of management practices is likely to induce a change in the state of the system.

One implication that has become clear from STMs is that management should be "opportunistic" where possible - management actions should be chosen that are most likely to increase rangeland health. However, in practice, range managers often use rules of thumb to determine the livestock-stocking rate, such as the 50% utilization rule. This approach is somewhat economically arbitrary, and is focused more on long-term steady state conditions, while ignoring shorter-term ecological flux. As climate changes, and short-term ecological fluxes occur, a lack in adjustments to stocking decisions may inadvertently trigger an ecological transition if the underlying drivers of ecological change and thresholds are not understood or ignored.

Bioeconomic impacts of stocking rate rules of thumb under changing climate and presence of invasive species

As an example of the type of analysis that will increasingly be required to understand the complex impacts of climate and invasive species, we modeled the impacts of current rangeland and grazing management practices in the desert Southwest under future climate scenarios (Torell and Lee, 2018). Specifically, we analyzed whether a common stocking rate rule of thumb, the 50% utilization rule, will continue to produce economic outcomes similar to a profit-maximizing stocking rule.

To address this question, we developed a bioeconomic model that was parameterized with long-term ecological and environmental datasets (Torell and Lee, 2018). We created a new framework by coupling an STM and economic model in which climate projections inform producer decision making and the economic impacts that arise from those decisions. The STM simulates plant biomass production as well as competition between native forage species and an undesirable invasive species, broom snakeweed. The STM is parameterized using a 35-year dataset of temperature, precipitation, and plant species biomass from Northeast New Mexico (see McDaniel, 1987, for a description of the ecological field sites and data). A detailed description of the framework can be found in Torell et al. (2018).

To model the impact of climate change on plant biomass, the STM simulations use distributions of projected climate variables from two global climate models: HadGEM2-CC365 and CCSM4 (Gent et al., 2011). The critical drivers of primary productivity assumed in this framework are: i) April-June precipitation, ii) July-September precipitation, iii) April temperature, and iv) June temperature. We simulate plant biomass and species composition outcomes of two stocking rules (50% utilization versus profit-maximization) under two climate scenarios: a case where atmospheric greenhouse gas concentrations are assumed not to change from current (1950 - 2015) levels, and the Representative Concentration Pathway 8.5 (RCP 8.5) scenario, which assumes greenhouse gas concentrations continue to rise through 2100. While climate warming and changes to precipitation regimes occur under both scenarios, RCP 8.5 projects the greatest increase in future temperatures.

Plant biomass production—specifically for desirable forage species—is simulated by the STM and then input as a constraint to an economic model of a representative stocker operation in which the decision maker chooses an annual stocking rate. When using the 50% utilization rule, the stocking rate is determined by how many animals can graze a unit area of land for a given period and still leave 50% of available forage at the end of the grazing season. We compare the 50% utilization outcomes with those of a stocking rate that maximizes the discounted net present value of the stream of annual profits over the 20-year time horizon. The stocking rate (and therefore grazing pressure) chosen in a given year influences the forage remaining after the grazing season and growth in the following season.

Under the 'no change' climate scenario and both grazing rules, 'highly invaded by broom snakeweed' is the most frequent ecological outcome. We define 'highly invaded' as broom snakeweed comprising more than 75% of the total plant biomass. By contrast, under the RCP 8.5 scenario, the prevalence of broom snakeweed trends towards 'none'. This may sound encouraging, but under RCP 8.5, years where there is little to no grazeable forage production occur more often, average forage production is lower, and the maximum forage production is less than in the 'no change' climate scenario.

Under the RCP 8.5 climate scenario, the 50% utilization and profit-maximization stocking rates rules on average choose a lower stocking rate than under the 'no change' climate scenario. This is due to an increase in the frequency of low forage production years and therefore the number of years in which the land cannot support cattle. These results indicate that rangeland profitability is likely to fall under RCP 8.5 climate scenario and that managers will find it increasingly difficult to remain in business without major changes in management and adaptation strategies (e.g., supplemental forage, mechanical removal of broom snakeweed, etc.).

Comparing the economic outcomes of the two stocking rules, the profit-maximizing stocking rule significantly outperforms the 50% utilization rule under both climate scenarios. This outcome occurs because use of the profit-maximizing stocking rates allows the decision maker to take advantage of periods of high forage production by opting for stocking rates above the 50% utilization rule. Comparing the outcome of the same grazing rule across the two climate scenarios, the mean of the distribution of economic returns is reduced under RCP 8.5. This shift indicates that years of low to moderate returns would become more likely, the lowest observed net present values would fall to zero, and the high returns that were possible under the 'no change' climate scenario become unattainable. In addition, the RCP 8.5 scenario reduces the standard deviation of net present values for both grazing rules.

In summary, the simulated outcomes of grazable forage production in the desert Southwest highlight future challenges for ranchers and rangeland managers. Though under higher future temperatures, broom snakeweed invasion decreases, so does grazable forage production. These decreases, in turn, reduce the allowable stocking rate and economic returns for livestock producers. By following the 50% utilization rule, ranchers cannot take full advantage of high forage production years. Continued use of grazing rules of thumb therefore may have negative economic impacts to ranching communities, so their use should be re-evaluated. One caveat of this analysis is that we have assumed that our representative manager is risk neutral. By contrast, risk-averse managers may be unlikely to move away from their current, more conservative strategies for setting stocking rates, largely because of their historical efficacy, and fear of damaging rangeland health.

Conclusion

In rangeland management, analyses that incorporate the linkages between ecology, climate science, management decisions, and economic outcomes are essential to help producers and land managers understand the ecological and economic trade-offs of decisions. As projected changes in temperature and precipitation impose greater stresses on sensitive rangeland sites, improved understanding of these linkages will help us to reduce the impacts and develop adaptation strategies. This is particularly true in systems at risk for non-native species invasions (e.g., cheatgrass, medusahead, leafy spurge, thistles and knapweeds) or where native woody species are expanding at the expense of perennial grasses (e.g., creosotebush, honey mesquite and western juniper). Our analysis details the impacts of climate change on an invasion of broom snakeweed, and then extrapolates key insights to other species that have been identified as potential risks in the future. Many issues remain that require analysis in the area of rangeland economics. We believe that the incorporation of modern ecological methods into economic decision models is a critical framework for understanding these issues.

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