Modelling the Long-Term Impact on Herder Incomes and Environmental Services in an Uncertain World

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Abstract

Environmental, market and political influences affect herders' livelihoods with the expectation that they maintain biologically and economically resilient systems. To balance these external influences and the trade-offs within a grassland system it involves the consideration of interactions between grassland ecology, technology use, environmental externalities, utilisation by grazing animals for food and fibre production, and the long-term profitability of the farming system. Many of these variables are slow-moving and are trade-offs are most efficiently studied with models. The *StageTHREE* Sustainable Grasslands Model, which utilizes the core functions and dynamics of more mechanistic tools, has been designed to minimize the skill and data required for parameterisation. It allows the key dynamics of the grassland systems to be incorporated along with the stochasticity of the system, in terms of both the uncertainty of the production and market environment. This enables an investigation into the sustainability and environmental impacts of alternative livestock management practices, so that these can be evaluated in relation to policy options. This paper presents an insight into the integration of herder level bioeconomic modelling for the analysis of grassland policy impacts in Mongolia and China. The research highlights that policy settings that reduce stocking rates can improve the environmental services from grasslands, and in most cases, also improve herder livelihoods and resilience.

Introduction

The management of grasslands is of critical importance to the livelihoods of over 5m low income herding households and ruminant livestock production derived from 520m hectares across the northern steppes of China and Mongolia (Kemp et al. 2020). Under ongoing grassland degradation with concurrent increases in livestock numbers and stocking rates, existing and new grassland policies are being considered to better meet the objectives of concurrently improving herders' livelihoods while maintaining biologically and economically resilient systems (Brown et al. 2021). However, herders as the agents of change in the management of grasslands are influenced by a variety of interacting social, economic and environmental pressures (Addison et al. 2020). For both herders and policy designers to consider and balance the trade-offs of these influences within a grassland system involves the consideration of complex interactions between grassland ecology, technology use, environmental externalities, utilisation of the grassland resource by grazing animals for food and fibre production, and the profitability of the herder systems over the longer term (Behrendt et al. 2020b).

The aim of this paper is to introduce the use of bioeconomic modelling of herder level grassland systems in both Mongolia and China to inform the analysis of different grassland policy options. The bioeconomic modelling enables the identification of the expected relationships between the productivity and profitability of herders in response to changes in stocking rate (as the herder's behavioural response to different policy settings and a key driver for improving grassland condition and meeting societal objectives) as well as the expected environmental changes within the grassland system and its externalities. This information is an integral part to undertaking *ex-ante* analysis of alternative policies that influence herders' management of grassland systems, and to determine their environmental and net social impacts (Brown et al. 2021).

Methods and study site

The two case study regions within Mongolia are the Khashaat soum (Arkhangai aimag) and Altanbulag soum (Tuv aimag) both located within steppe grasslands to the south and west of Ulaanbaatar. In the Inner Mongolia Autonomous Region of China, the case studies cover three biomes, namely the desert, typical and sandy steppes. The grasslands and their management within these regions vary with details provided by Han et al. (2021) and Kemp et al. (2020). This study uses a typical farm approach to define and model the herder systems within each grassland case study region.

The *StageTHREE* Sustainable Grasslands Model (SGM), which utilizes the core functions and dynamics of more mechanistic tools, such as the GrazPlan suite (Donnelly et al. 1997) and SGS Grassland Model (Johnson et al. 2003) has been designed to minimize the skill and data required for parameterisation. It considers both output price (sheep/goat meat and wool/cashmere) and climatic uncertainty in their effect on herder production, economics and environmental outcomes. The models are calibrated using local experimental/field data, literature, case studies, secondary data and expert opinion. Model outputs are validated using published literature and expert opinion. The *StageTHREE* SGM has been developed using Matlab (Mathworks 2019) and a detailed description of the model and modelling approach can be found in Behrendt et al. (2020a).

The simulations stochastically utilise daily climate data over 2006-2019 (using nearest representative weather station data; years are uniformly distributed) and normally distributed output prices (based on region specific market data; China: 2012-2018; Mongolia: 2011-2020) over a 10-year simulation period. For each case study region the typical herder's resources are defined (including soils, grasslands, livestock, other physical and financial capital); current management practice and stocking rate as the initial state of the system. Initial stocking rates use standard Sheep Equivalent (SE) ratings for different animal types and are based on the average stocking rate for 2015-2019 at the soum level for Mongolia (due to commons rangelands grazing) and herder level for China (based on survey results).

A series of incremental reductions or increases from the initial stocking rate are then applied and modelled within each system using Monte Carlo simulation procedures with 250 iterations per stocking rate level tested. Daily, annual and cumulative changes in the state of soil, grassland and livestock resources and productivity are predicted. The benefits or costs of a herder transitioning to a new target stocking rate in response to a policy is embedded into the herder's household economics (reported as Net Present Value as an annuity and its variability). Expected response curves are fitted to key final year simulation outputs to indicate the relationship between stocking rate and the impact on expected resource, production, economic and risk outcomes.

Results and Discussion

The biophysical outputs shown in Figures 1 and 2 are centred on the final year of the simulation period, being the expected outcomes 10 years post-policy and associated change in stocking rate or flock size. In Mongolia responses are depicted against different herder flock scales (based on SE) with typical systems modelled to maintain the expected mix of sheep and cashmere goats. In China responses are shown with stocking rate as the independent variable for a single sheep enterprise as this was the predominant livestock type in the region.

Mongolia

As herders in Mongolia seasonally shift between different grazing areas the scale response curves indicate the mean weighted biophysical outcomes of all grazing areas, and notably there was found to be some differences between the seasonal grazing areas. As expected, with increases in the number of animals (i.e. total SE) being run by herders, the biophysical and environmental conditions deteriorate (Figure 1). Notably there is little expected change in the number of soil erosion emission events or total amount of soil loss during wind erosion (data not shown) in response to changes in flock scale (differences in soil erosivity and wind speed between soums influences absolute levels of wind erosion). The reason for this is due to the overwhelming influence of abiotic factors and the fact, that even with complete grazing rest, it would take many years for ground cover and biomass to increase to a level that would enable a reduction in the influence of physical processes driving wind induced soil erosion, which is consistent with other studies (Jamiyansharav et al. 2018).

For indicators of grassland condition such as fractional ground cover, biomass and grassland canopy height, they notably improve with reducing herder scale, although there is a large amount of variation around the reported means (expected responses only shown for July as this corresponds to the predominant reporting period of grassland condition, although this may not be the maximums for the whole growing season). Animal grazing does influence these outcomes, as generally the animals are in low-moderate condition, and exhibit compensatory growth during the summer. As such, any reduction in stocking rate tends to enable animals to increase their grassland consumption per head (and for longer into the year) and maintain higher body weights, selling weights and reproductive rates. This leads to significant increases in grassland consumption, and some suppression of the expected response in grassland condition to any reductions in grazing pressure.

The observed differences between the soums are due to a combination of lower rainfall and a more variable climate at Altanbulag when compared to Khashaat, and the higher stocking rates at Khashaat. Although Altanbulag herders are expected to maintain higher household incomes due to receiving slightly higher meat prices and lower costs for some inputs due to their closer proximity to Ulaanbaatar, they face higher financial risk and herders in both soums gain a net economic benefit from reducing stocking rates.

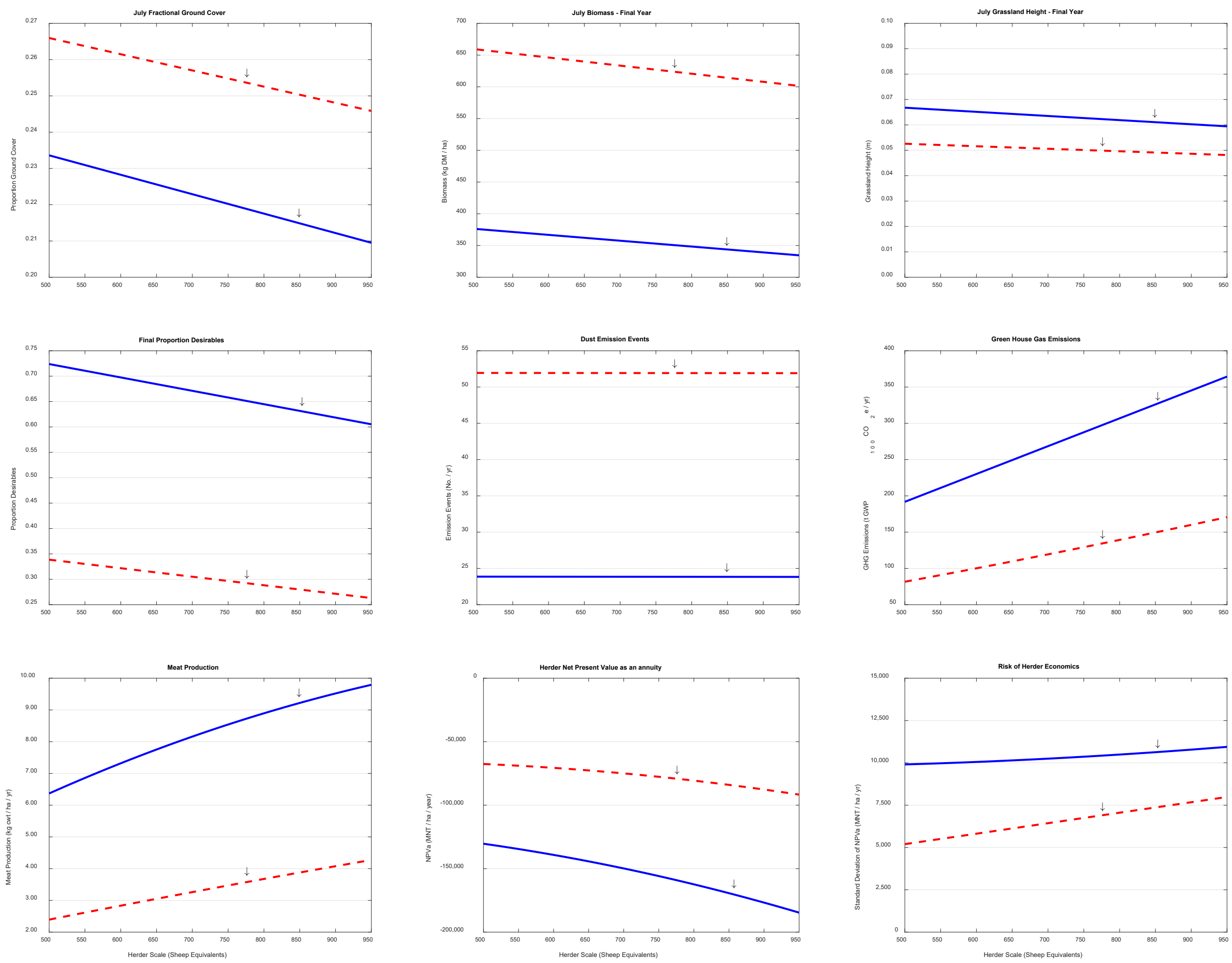

Figure 1: Relationships between the sheep equivalents kept by herders in the Khashaat (-) and Altanbulag (- -) soums of Mongolia and a range of biophysical and economic outcomes. Arrows indicate approximate position of herders' current management practice within each soum.

Inner Mongolia, China

Similar relationships are observed across the three biomes in Inner Mongolia (Figure 2). Across all three biomes grassland condition is expected to improve with reducing stocking rates. Similarly, there are no notable changes in the number of dust emission events or quantity of dust emitted in response to stocking rate reductions (again here, soil erosivity and climate influence absolute differences between biomes). Also, as for Mongolia, there is a significant decline in the level of greenhouse gas emissions with reducing stocking rates.

Notably the tested stocking rate range within the desert steppe case study area is smaller than the others due to herders within this region reducing their stocking rates over the past decade in response to successful research, farm demonstrations and knowledge exchange programs. The consequences of the current management practice of herders in the desert steppe (in regards to their stocking rates) are that any policy settings that encourage herders to respond by further reducing stocking rates will have different effects on herders here than in the typical and sandy steppes. For both herders in the typical and sandy steppes they can reduce stocking rates and be expected to increase their livelihoods and resilience. This is consistent with the established general relationships between stocking rates on green grassland and animal production per head and per hectare (Kemp et al. 2020), and subsequent system profitability (Behrendt et al. 2020a). However, desert steppe herders will be forced to trade-off livelihoods against delivering environmental services to society (Behrendt et al. 2020b).

The expected response curves developed through this modelling enables the prediction of both the economic and environmental consequences of likely responses in herder behaviour with regard to their scale and stocking rate. The modelling enables the identification of trade-offs between production, environmental and economic outcomes under uncertainty, which cannot be done cost-effectively and in a timely manner through field-based research or ex-post analysis. These ex-ante analysis help to understand and identify policies that better meet with the objectives of improving grassland condition, minimising negative externalities and improve herder livelihoods (Brown et al. 2021).

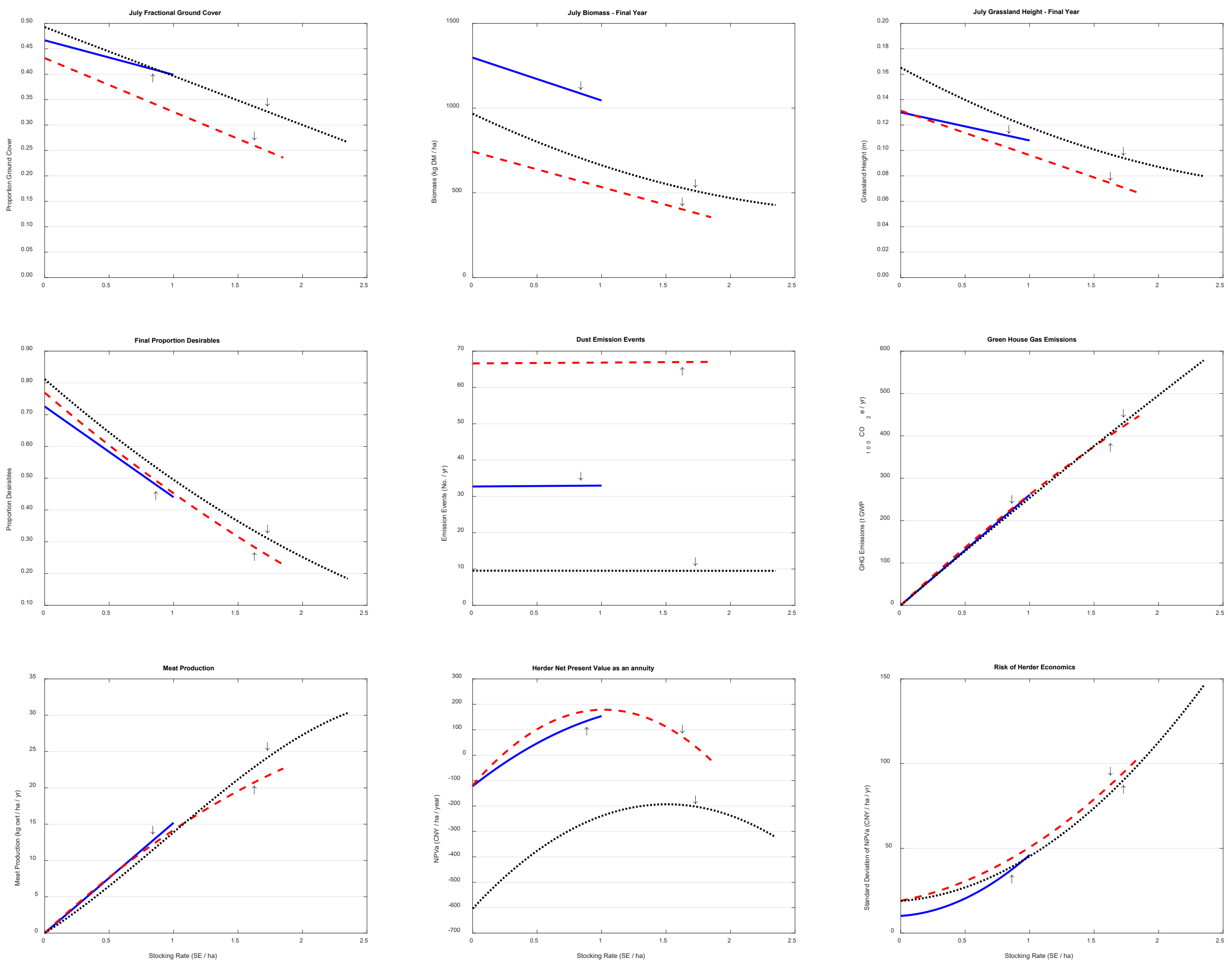

Figure 1: Relationships between stocking rate in the Desert steppe (-), Typical steppe (- -) and Sandy steppe (···) of Inner Mongolia and a range of biophysical and economic outcomes across a simulated range of stocking rates. Arrows indicate approximate position of herders' current management practice within each biome.

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