論 文 の 内 容 の 要 旨

生圏システム学専攻
平成 18 年度博士課程　進学
氏　　名　　佐々木　雄大
指導教員名　　武内　和彦

論文題目　**Ecological benchmarks for sustainable management of Mongolian rangeland ecosystems**
（モンゴルの放牧地生態系における持続的土地管理への生態学的基準）

1. Introduction

Predicting the impacts of livestock grazing on natural communities has become a major concern in rangeland ecology research, especially where grazing is widespread and its impacts may be in conflict with the sustainable use of natural resources and biodiversity conservation. Major advances have been made in revealing the patterns and processes of vegetation changes associated with grazing, generalizing these patterns within a given landscape or region, and reassessing the appropriate paradigm to describe vegetation dynamics. There is uncertainty, however, as to whether the current knowledge is the key to successful environmental management of rangeland ecosystems. The central aims of this study are to link ecological theories and concepts with land management to promote species diversity, functional diversity, and the sustainable use of natural resources and to develop rigorous ecological benchmarks across Mongolian rangeland ecosystems that would forewarn land managers that actions must be taken to stabilize resilience and minimize the probability of crossing an ecological threshold.

2. Methods

Grazing gradients provide an ideal tool for examining vegetation responses to a realistic range of long-term grazing impacts. Livestock density and grazing intensity are usually highest close to livestock camps or sources of water. Many rangeland studies have sampled vegetation and soils along grazing gradients based on distance from a source of water, or from human settlements or livestock camps to determine the grazing impacts on rangeland structure and function. Throughout this study, I therefore used a grazing gradient approach to test various ecological theories and concepts, and to apply the results to land management. I also attempted to generalize our insights into ecological theories and management application by establishing grazing gradients at multiple ecological sites that are defined as a distinctive kind of land with specific physical characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation. Three study areas were situated near Kherlen Bayan Ulaan (47°12'N, 108°44'E), Mandalgobi (45°46'N, 106°16'E), and Bulgan (44°05'N, 103°32'E) in Mongolia’s Khenti, Dundgobi, and South Gobi provinces, respectively. Across the three study area, ten ecological sites were located at different landscape positions in grassland, shrubland, or halophytic shrubland vegetation physiognomies.

3. Threshold changes in vegetation along a grazing gradient in Mongolian rangelands

The concept of threshold has become important in ecology, but the nature of potential threshold responses of vegetation to grazing in rangeland ecosystems remains poorly understood. I aimed to identify ecological thresholds in vegetation changes along a grazing gradient and to examine whether threshold changes were expressed similarly at a range of ecological sites. To accomplish this, I surveyed the vegetation along grazing gradients at 10 ecological sites, each located at different landscape positions in Mongolia's central and southern rangelands. Evidence for a threshold in changes in floristic composition along the grazing gradient was examined by comparing linear models of the data with nonlinear models fitted using an exponential curve, an inverse curve, a piecewise regression, and a sigmoid logistic curve. Three nonlinear models (piecewise, exponential, and sigmoid) provided a much better fit to the data than the linear models, highlighting the presence of a discontinuity in vegetation changes along the grazing gradient. The shapes of the best-fit models and their fit to the data were generally similar across sites, indicating that the changes in floristic composition were relatively constant below a threshold level of grazing, after which the curve changed sharply. Except for two sites, the best-fit models had relatively narrow bootstrap confidence intervals (95% CI), especially around threshold points or zones where the rate of change accelerated, emphasizing that the results were robust and conclusive. The present results provided strong evidence for the existence of ecological thresholds in vegetation change along a grazing gradient across all ecological sites. This suggests that vegetation responses to grazing in the study areas are essentially nonlinear. The recognition that real threshold changes exist in real grazing gradients will help land managers to prevent the occurrence of undesirable states and promote the occurrence of desirable states, and will therefore permit a major step forward in the sustainable management of rangeland ecosystems.

4. Management applicability of the intermediate disturbance hypothesis across Mongolian rangeland ecosystems

The current growing body of evidence for diversity-disturbance relationships suggests that the peaked pattern predicted by the intermediate disturbance hypothesis (IDH) may not be the rule. Even if ecologists could quantify the diversity-disturbance relationship consistent with the IDH, the applicability of the IDH to land management has rarely been addressed. I examined two hypotheses related to the generality and management applicability of the IDH to Mongolian rangeland ecosystems: that the diversity-disturbance relationship varies as a function of landscape condition and that some intermediate scales of grazing can play an important role in terms of sustainable rangeland management through a grazing gradient approach. I quantified the landscape condition of each ecological site using an ordination technique and determined two types of landscape conditions, relatively benign and harsh environmental conditions. At the ecological sites characterized by relatively benign environmental conditions, diversity-disturbance relationships were generally consistent with the IDH and maximum diversity was observed at some intermediate distance from the source of the grazing gradient. In contrast, the IDH was not supported at most but not all sites characterized by relatively harsh environmental conditions. The intermediate levels of grazing were generally located below the ecological threshold representing the points or zones at which disturbance should be limited to prevent drastic changes in ecological conditions, suggesting that there is little "conundrum" with regard to intermediate disturbance in the studied

systems in terms of land management. I suggest that the landscape condition is one of the primary factors that cause inconsistencies in diversity-disturbance relationships. The ecological threshold can extend its utility in rangeland management because it also has the compatibility with the maintenance of species diversity. The present results thus suggest that some intermediate scales of grazing and ecological thresholds are mutually supportive tools for sustainable management of Mongolian rangelands.

5. Two-phase functional redundancy in plant communities along a grazing gradient in Mongolian rangelands

The concept of functional redundancy is at the core of theory relating changes in ecosystem functioning to species loss. However, few empirical studies have investigated the strength and form of the relationship between species and functional diversity (i.e., the presence of functional redundancy in ecological communities) in this context. In particular, ecologists know little about how local extinctions in real communities might impact functional diversity. Here, I examined the relationship between species and functional diversity in plant communities along a grazing gradient across Mongolian rangeland ecosystems. I applied a recently described measure of functional diversity that incorporates species' dissimilarities defined from plant functional traits and tested several hypothesized forms of the relationship between species and functional diversity using linear and nonlinear modeling techniques. I found a significant sigmoid logistic relationship between species richness and functional diversity in relatively benign environmental conditions. This indicates high functional redundancy at low levels of species richness followed by a rapid increase at intermediate levels, until functional diversity reaches an asymptote at high levels (i.e., two-phase functional redundancy). In contrast, I generally observed a positive linear relationship between these parameters in relatively harsh environmental conditions, indicating low functional redundancy. Observed functional redundancy probably resulted from two factors, intrinsic redundancy in species' functional traits and extrinsic redundancy caused by nonrandom compositional change that is nonrandom with respect to functional traits. Lack of either intrinsic or extrinsic redundancy may result in low functional redundancy. Two-phase functional redundancy suggests that functional traits are abruptly lost from a community below a certain level of species richness, and a community then shifts into a contrasting state that has a few limited functional groups characterized by disturbance-resistant traits, as a consequence of disturbances such as livestock grazing. The present results represent a major step forward in predicting the consequences of livestock grazing on the functioning of Mongolian rangeland ecosystems.

6. Ecological benchmarks underpinned by ecological theories: toward sustainable management of Mongolian rangeland ecosystems

The development and application of operational procedures for sustainable management of rangeland ecosystems need to be linked closely with a broader body of ecological theories. However, the current state-of-the-art in rangeland management is still disconnected from nonequilibrium concepts in ecological theory. In particular, the procedures do not fully account for the potential nonlinearity of vegetation responses to grazing, or that some aspects of vegetation dynamics might be driven by abiotic factors. The goal of this chapter is to identify an ecological benchmark that is able to link ecological theories and concepts of rangeland ecosystems

with practical management applications. I focused responses to grazing by individual species and functional groups in relation to ecological thresholds with repeated measures from the same ecological sites to account for rainfall variability across Mongolian rangeland ecosystems. In all ecological sites, even under fluctuations in rainfall, there were robust combinations of indicator species that could be used to forewarn managers that actions must be taken to minimize the probability of crossing an ecological threshold. Depending on the landscape condition of each site, functional groups that share the traits of perennial life history, grass or forb growth form, linear leaf shape, and alternate leaf attachment or the functional group of woody shrubs drastically decreased prior to the crossing of an ecological threshold. Thus, across Mongolian rangeland ecosystems the responses of certain functional groups to grazing appear to predict the crossing of an ecological threshold. However, these responses of functional groups sometimes masked important signs of species' responses prior to the threshold being reached. Therefore, at an ecological site scale it would be better to assess rangeland states in relation to ecological thresholds based on individual plant species' responses to grazing. Nonetheless, the ecological benchmarks derived in this chapter can improve a land manager's ability to prevent adverse changes in states prior to the threshold being reached.

7. Conclusions

First, this study provides strong evidence of the existence of an ecological threshold in vegetation changes along a grazing gradient across all ecological sites. Second, my findings show that the relative importance of grazing in creating species diversity varies as a function of landscape condition. The study also demonstrates that some intermediate levels of grazing can play an important role in sustainable rangeland management by contrasting with an ecological threshold which has an explicit potential to be used in rangeland management. The utility of the ecological threshold can be extended to rangeland management because it is compatible with the maintenance of species diversity. Thus, some intermediate scales of grazing and ecological thresholds are mutually supportive tools for the sustainable management of Mongolian rangeland ecosystems. Third, this study reveals a relationship between species diversity and functional diversity in plant communities along a grazing gradient across Mongolian rangeland ecosystems and provides strong evidence for the existence of two-phase functional redundancy in plant communities along grazing gradients. This complements the former finding that some intermediate scales of grazing can play an important role in the maintenance of species diversity. Disturbance by domestic livestock grazing may allow for the retention of functional complementarities and possibly ecosystem functioning on Mongolian rangelands. Finally, I described rigorous ecological benchmarks that link important ecological theories and concepts in rangeland ecosystems with practical management applications. These ecological benchmarks can improve a land manager's ability to prevent adverse state changes prior to the ecological threshold being reached and provide practical management strategies for promoting both species diversity and possibly ecosystem functioning and the sustainable use of Mongolian rangeland ecosystems.