論 文 の 内 容 の 要 旨

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論文題目　Effect of grazing strategy under high climatic variability on vegetation in Mongolian rangeland
（モンゴル放牧草原における気候変動性の高い環境での放牧戦略が植生に与える影響）

It is generally recognized that, by providing access to vegetation with adequate forage quality and quantity, traditional mobile pastoralism has adapted well to arid and semi-arid rangeland ecosystems with spatially and temporally stochastic rainfall regimes. However, the pastoralists' strategies for spatial movement have been changing in response to external forces such as changes in political and economic regimes. In the steppe region of Mongolia, the shift toward a market economy since the early 1990s has dissolved the system of *negdel*, the cooperative agricultural and stock-raising associations under the socialist regime. Because this dissolution has the potential to cause overstocking and concentration of livestock in particular areas, increased risk of grazing-induced pasture degradation has become a major concern in rangeland management sectors.

For the last two decades, rangeland ecologists have been discussing the relative importance of biotic and abiotic factors in controlling vegetation dynamics. According to non-equilibrium concept, which emerged as a new paradigm to describe ecosystems in highly variable and poorly predictable environments, vegetation dynamics are driven primarily by abiotic factors such as rainfall, rather than by internal biotic regulation (e.g. grazing impact). Although a number of studies have emphasized the non-equilibrium nature of most rangelands, they have produced inconsistent results and there is still no consensus on the relative importance of grazing impact. Alternatively, recent studies have suggested that a continuum of systems exists, rather than a stark dichotomy between equilibrium and

non-equilibrium rangelands. Moreover, theoretical studies have predicted that, in addition to climatic variability, resource variations occurring in space and time as a result of landscape heterogeneity should be taken into account in assessments of grazing impact. However, there have been few empirical studies of the role of resource variations in either mitigating or enhancing the impacts of grazing on vegetation.

This thesis explores the impact of grazing strategies on vegetation in Mongolian rangelands under high climatic variability. Specifically, I focused on key resource areas, defined in terms of the key factor determining livestock population, and thus the ability to forage during drought. Based on the prediction proposed by Illius and O'connor (1999) that animal numbers are regulated in a density-dependent manner by the limited forage availability in key resource areas, I established the hypothesis that grazing impacts would be greater in key resource areas than in other areas even in Mongolian rangelands. The study had three aims: (1) by using vegetation survey and satellite image analysis, to quantify the spatial and temporal arrangement of resources represented by vegetation (Chapter 2); (2) to clarify the pastoralists' strategies for the proper use of varying resources (Chapter 3); and (3) to examine the relationship between these strategies and vegetation degradation (Chapter 4). Finally, I discuss the implications of the results of these empirical studies for appropriate rangeland management schemes under high levels of climatic variability (Chapter 5).

The study area was located in the Saintsagaan *sum* (district), which includes the city of Mandalgobi (45°46′N, 106°16′E) in Mongolia's Dundgobi province. Mandalgobi is located in the desert-steppe ecological zone. According to the prediction that non-equilibrium dynamics predominate in areas where mean annual precipitation is less than 250 mm and precipitation coefficient of variation exceeds 33%, the study site was considered to be in a highly variable environment.

I quantified the spatial and temporal distribution of the vegetation by combining the vegetation survey and satellite image analysis. First, I established 246 quadrats (each 20 × 20 m) within the study site (20 × 20 km) and recorded the percentage cover of all plant species in each quadrat. The vegertation data were subjected to detrended correspondence analysis and then classified by using a cluster analysis into the following four community types that differed in species composition and abundance: (1) *Caragana* community, dominated by the legume shrubs *Caragana microphylla*, perennial grass *Cleistogenes squarrosa*, and perennial forb *Allium mongolicum*; (2) *Allium* community, dominated by the perennial forb *Allium polyrrhizum*; (3) *Achnatherum* community, dominated by the large, dense bushy grass *Achnatherum splendens* and the annual forb *Salsola collina*; and (4) *Reaumuria* community, dominated by the halophytic semi-shrubs *Reaumuria soongorica*, *Salsola passerina*, and *Kalidium foliatum*.

Next, I analyzed the spatial distribution of the four community types and their temporal changes by using satellite images of two periods (a drought summer with low precipitation in 2009 and a normal

summer with average precipitation in 2010) and thematic maps (e.g. geomorphology map). The *Achnatherum* and *Caragana* communities, respectively, were clearly extracted as having the highest and second-highest normalized difference vegetation index (NDVI) values. *Reaumuria* and *Allium* communities, both of which had low NDVI values, were differentiated by using texture information. The *Allium* community covered the largest area, while *Achnatherum* and *Reaumuria* the smallest, among the four communities. The four communities (*Caragana*, *Allium*, *Achnatherum* and *Reaumuria*) were spatially arranged along the sequence of land catena, that is, on denudation plain, hillslope, pediment, and depression, respectively. Biomass, as estimated from the NDVI values, was significantly lower in the drought summer than in the normal summer. However, the *Achnatherum* community maintained a relatively high NDVI, even during drought, compared with those of the other communities. These results suggested that both topographic heterogeneity and climatic variability contribute to providing resource variations in space and time, and that among varying resources, *Achnatherum* community has a function of key resource area during droughts.

The pastoralists' patterns of use of heterogeneous vegetation resources were clarified by using interview surveys. First, I interviewed four leaders of *bags* (villages) as key informants to clarify the pastoralists' resource selection during drought and normal summers. The result confirmed that pastoralists used different resources in normal and drought summers: during normal summers all types of community were used, but during drought the main community used was the *Achnatherum* community.

Second, to determine the movement patterns at the study site, I interviewed 77 pastoralists who stayed in the Saintsagaan *sum*. I asked pastoralists the numbers of livestock they had, the places they visited during drought (2009) and normal (2010) summers, and the basis of their pasture selection during droughts. I used a cluster analysis of interview data to divide the the pastoralists' movement patterns into the following two broad groups: (1) mobile wealthy pastoralists, tending to have larger flocks and move longer distances; and (2) less-mobile poor pastoralists, having smaller flocks and moved shorter distances. While the former groups could move to remote pasture dominated by perennial grasses with high palatability and quick response to rainfall, the latter groups were compelled to stay in home pasture and to utilize *Achnatherum* community with low palatability but high tolerance to dry conditions which retains high levels of vegetation cover even during drought. These results indicated that pastoralists used the resource variations occurring in space and time, and that the lack of uniformity in the pastoralists' movement patterns would also have affected the spatial distribution of the impact of grazing on vegetation. Those also suggested that the risk of grazing-induced vegetation degradation would increase, especially in the *Achnatherum* community with narrow distribution ranges along the bottoms of river valleys, where less-mobile poor pastoralists concentrate during drought to reduce the cost of mobility.

To examine whether the grazing strategies were mitigating or enhancing the impact of grazing on vegetation, I performed a vegetation and soil survey. I set up 20 quadrats (each 1 × 1 m) each within a grazed and an ungrazed plot in each community (*Caragana*, *Allium*, *Achnatherum* and *Reaumuria*). I identified all species present in the quadrats, estimated their percentage cover and calculated the dissimilarity indices between the ungrazed and grazed plot in each community. I then compared the dissimilarity indices among the four communities. The dissimilarity index of the *Achnatherum* community was the highest, indicating that species composition was significantly more affected by grazing in the *Achnatherum* community than in the other communities. The number of dung pellets was also highest in the *Achnatherum* community, suggesting that this community was subject to the highest grazing intensity. These results suggested that the distribution of grazing impact was uneven across communities, and that the *Achnatherum* community was affected more by grazing than were the other communities, supporting the predictions of theoretical studies that equilibrial forces exist over a limited part (i.e. key resource area) of the non-equilibrium environment.

The key finding of this thesis is that grazing-induced degradation, that is, the equilibrium nature is detectable over key resource areas even in non-equilibrium environments by taking into account resource variations at a landscape scale in relation to the scale of local rangeland use. Therefore, to develop effective rangeland management systems the debate needs to be shifted from the equilibrium versus non-equilibrium dichotomy toward a greater awareness of resource variation. I showed that the impact of grazing on the *Achnatherum* community was high; because this community occupies a small area, its degradation could reduce livestock populations by diminishing the ability of the ecosystem to provide spatial buffers during climatic disturbance. These findings suggest that if rangeland management is focused only on maintaining resource accessibility, then grazing-induced degradation of resources can occur. Therefore, controlling livestock numbers remains indispensable to rangeland management, even in highly variable environments.

Variations in grazing strategies have generally not been concerned in assessments of degradation. However, I showed that such variations were tightly related to the spatial pattern of grazing-induced degradation. This finding suggests that rangeland managers should take into account variations in grazing strategies depending on pastoralists' economic situations, because such variations should need different countermeasures for sustainable rangeland use.

In conclusion, this thesis clearly shows that grazing strategies and resource variations interact tightly under high climatic variability. This empirical evidence offers a major first step toward sustainable rangeland management in semi-arid regions.