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SUMMARY OF DOCTORAL THESIS

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Title: Spatial distribution of cattle foraging behavior on contrasting landforms in Horqin Sandy Land of northern China

（中国北部ホルチン沙地の対照的な地形における牛の採食行動分布）

Overgrazing can alter ecosystem function and reduce the nutrient content and yield of vegetation, especially in arid and semi-arid regions. Overgrazing of rangelands often results from uneven distribution of grazing pressure due to either under- or overstocking. Fencing has widely been used to manage grazing pressure, by breaking large tracts into several smaller areas, thus preventing patchy degradation of grasslands and maintaining the productivity of vegetation and livestock.

To prevent grassland degradation, the spatial distribution of livestock grazing must be understood. Previous grazing experiments have used the number of livestock per unit area to investigate the effects of grazing on herbage production, soil properties, plant communities, and other factors. However, this approach cannot provide detailed information regarding how livestock graze, especially in terms of seasonal changes in the spatial distribution of grazing pressure on grassland. In addition, an underlying assumption of these previous studies is the even distribution of grazing pressure, which is not characteristic of actual livestock grazing behavior.

The trade-off between the energy expended in searching for and reaching the forage source and the potential energy gain provided by the herbage determines the movement of livestock during their grazing activities and consequently the spatial distribution of livestock grazing pressure. Therefore abiotic factors, such as topography and access to drinking water, as well as biotic factors, such as pasture quality and quantity, are critical factors that influence the spatial variation of herbage and the energy expended during livestock's acquisition of sufficient forage. These elements in turn influence the spatial distribution of grazing pressure and its seasonal dynamic.

The grassland in the arid and semi-arid regions of northern China has degraded severely since the 1970s. This degradation has contributed to several environmental problems, one of the most striking of which is dust storms. In particular, the Horqin Sandy Land, in the central eastern region of China's Inner Mongolia province, suffers from desertification and is a material source for the dust storms that have ravaged Beijing and other, distant areas. The landform of the Horquin Sandy Land is characterized by sand dunes interwoven with interdune lowlands; this intricate topography complicates understanding of the relationship between livestock grazing and land degradation in this region.

Various grazing behaviors, such as foraging, resting, and walking, have different consequences on grassland. Using traditional methods to track and record these behaviors is laborious and rarely provides continuous and long-term data. However, the development of the Global Positioning System (GPS), accelerometers, and machine learning now make it possible to elucidate the relative effects of different grazing behaviors. Therefore, the current study used GPS and machine learning techniques to reveal the spatial distribution of foraging and non-foraging behaviors of cattle in the Horqin Sandy Land.

In this research, we first developed a method to classify cattle grazing into component foraging and nonforaging behaviors according to GPS location and tri-accelerometry data. We then investigated seasonal changes in the spatial distribution of grazing pressure and the relative contributions of the sand dune and interdune regions to this seasonality. Finally, we modeled the probability to be forage of everywhere in the ranch and analyzed the factors that influenced the likelihood of use.

First, we tested various models for classifying various behaviors as foraging or nonforaging behaviors; these models were based on GPS location data solely, tri-axis accelerometry data only, and the combination of these two datasets; in addition, we assessed various time intervals with each model.

When the time interval was greater than 300–800 s, the overall accuracy of the GPS model was 85% to 90%, which approximated the accuracies of the tri-axis accelerometry model (96%) and the combined GPS-tri model (96%). In the GPS model, the linear backward or forward distance was the most important determinant of behavior classification, and nonforaging behavior accounted for less than 30% of all grazing behavior when livestock traveled more than 30–50 m over a 5-min interval. For the tri-axis accelerometry model, the anteroposterior acceleration (–3 m s-2) of neck movement was the most accurate determinant of livestock behavior classification. The instantaneous acceleration of livestock body movement classified livestock behaviors more precisely than did GPS location-based distance metrics. However, when a tri-axis model is unavailable, a GPS model yields sufficiently reliable classification accuracy as long as an appropriate time interval is defined.

Second, we determined the foraging density and the area associated with foraging behavior for both the dune and lowland regions. Overall, the time that livestock spent foraging increased from 63% in July to 67% in August and 69% in September, and nonforaging behavior decreased in a compensatory manner in both dune and lowland regions. In lowland, the log-transformed average foraging density (i.e., total number of foraging behaviors in 5 days measured at 50-s intervals per 10 × 10 m grid) increased significantly from 0.61 in July to 0.66 in August and 0.88 in September; in contrast, on sand dunes, this parameter remained constant throughout this period. The relative area of lowland foraged by cattle was 31% in July, 35% in August, and 36% in September. In comparison, the proportion for sand dunes increased from 45% in July to 47% in August and 51% in September. In lowland, foraging density was negatively correlated with biomass ($P = 0.07$), total digestible nutrients ($P < 0.05$), and crude protein ($P = 0.06$) and positively correlated with acid detergent fiber ($P < 0.05$), whereas no such relationships occurred in sand dunes. Our results indicate that topographic features should be considered when managing livestock, especially during periods with low herbage quality and quantity.

Third, we used resource function selection to model the probability of a landform to be foraged by cattle and then examined the factors that influenced this probability. The factors associated with a high probability of being grazed by cattle were forest land, areas with high NDVI, and areas close to watering sites; conversely areas at high elevation had a low probability of being grazed. The high-probability areas moved further from watering sites as the grazing period progressed from early to late. During the early grazing season, the probability of being grazed was negatively related to elevation and positively related to NDVI. During the late grazing period, the individual influences of NDVI and elevation on the probability of being grazed decreased, and instead the interaction between NDVI and elevation influenced this probability.

The findings from this study show that the instantaneous acceleration of livestock body movement more precisely classified livestock behaviors than did GPS location-based distance metrics. When a tri-axis model is unavailable, a GPS model yields sufficiently reliable classification accuracy as long as an appropriate time interval is defined. The foraging duration was greater in lowland than dunes areas in both early and late grazing periods. On both sand dunes and lowland, foraging time increased as the grazing period progressed from early to late. In lowland areas, the increase in foraging time resulted from increases in both average foraging density and foraging area. However, increased foraging time on sand dunes was due solely to increases in foraging area. Resource selection function modeling can successfully predict the probability that cattle will graze a particular area; this probability is comparable to the observed duration of grazing.

In the Horqin Sandy Land, cattle spent more time foraging on interdune lowland than on sand dunes. However, foraging time increased over the grazing season as resource availability declined in both lowland and dune regions. This increase in foraging time over the grazing season reflects changes in the cattle's behavior patterns that is, extending foraging areas away from water sources in lowland areas and climbing sand dunes to obtain additional resources.