Effects of Herding on Rangeland Use Efficiency in Kenya

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Abstract
Within each foraging itinerary, herders can intervene in the forage selection process, encouraging herds to use highly palatable and less palatable rangeland resources. Such a herding strategy could prevent rangeland degradation and increase livestock productivity. The objectives of this study were to examine forage availability and identify factors influencing stocking rates around night resting places on a ranch in Laikipia County, Kenya.

Forage availability was measured along six regularly spaced transects around night resting places corralling one herd of camels, one mixed herd of goats and sheep, and two herds of cattle, with biomass sampling points at 50-, 150-, 250-, and 350-meter distance from the night resting places. Every four days, herbaceous biomass was collected at each sampling point and classified into monocotyledonous plants, dicotyledonous plants, and litter. Pooled samples of biomass were analyzed for their nutrient content. Activities of herders and herds were monitored. Stocking rates were calculated for the sampling points using georeferenced data of foraging itineraries recorded in 20-second intervals, area densities of herds measured by a hand-held global positioning system receiver, and live weights of all animals determined monthly.

Except for the herd of camels, the distance to the night resting places had no effect on stocking rates. Not forage nutritive value, but palatability of dominant species on sampling points mainly influenced stocking rates, and thus forage availability. All livestock species sought patches dominated by *Cynodon dactylon*, possibly being overgrazed. Patches dominated by either *Andropogon contortus* or *Themeda triandra* were underused, as indicated by biomass accumulation. Thus, the efforts of the hired herders in this study did not lead to the desired herding effects. Therefore, motivating herders to design foraging itineraries utilizing diverse vegetation patches intentionally is crucial to an efficient use of rangeland resources, while meeting the nutritional requirements of animals.

Introduction
Herders can control the foraging areas and diet selection of herds over daily foraging itineraries to stimulate feed uptake of both highly palatable and less palatable plants, while meeting the nutritional requirements of the animals and potentially mitigating rangeland degradation (Meuret and Provenza 2014). In line with this, herders can encourage goats to browse, and sheep to be intermediate feeders, and thus reducing the dietary overlap between different livestock species (Samuels et al. 2016).

Most prior work has analyzed the impacts of herders on daily foraging itineraries, but has not considered the availability of forage resources (e.g. Coppolillo 2000; Turner and Hiernaux 2002). Many other studies have related the distribution of livestock to the rangeland resources around livestock concentration locations at the landscape level, with little attention directed to herd movements with respect to vegetation resources in close proximity of livestock concentration locations (e.g. Turner et al. 2005; Butt 2010). The lack of intensive and continuous monitoring of interactions between hired herders, herds of different animal species, and their environment at patch level limits the understanding of resource utilization patterns and variables shaping daily foraging itineraries under restricted mobility. Examining the variability among individual vegetation patches around night resting places and their influencing factors can raise awareness of factors affecting rangeland health and livestock productivity.

In Laikipia County, Kenya, most of the land is under large-scale ownership and many landowners are engaged in livestock and crop production and in wildlife tourism and management (Bond 2014). On privately owned ranches, herders have been employed to daily tend to livestock (Yurco 2017). These herders take the animals to foraging areas and watering places, and overnight, the animals are corralled in night resting places, built from brushes of *Acacia* species. The presence of diverse livestock species, heterogeneous forage resources, and relatively well predictable sizes of herds and movements of herders on ranches provide an interesting study scene to describe the relationships between vegetation, livestock, and humans in semi-arid rangelands at patch level. Therefore, an in-depth case study approach was employed with the overall objective to improve the

understanding of vegetation dynamics and stocking rates, and with this daily foraging itineraries designed by hired herders around night resting places in a semi-arid rangeland at patch level. The results of this study can imply strategies to improve rangeland use efficiency on ranches.

Methods and Study Site

To examine the relationships between herd movements directed by herders and forage resources at patch level, six regularly spaced transects around night resting places with biomass sampling points at 50-, 150-, 250-, and 350-meter distance from the night resting places were established between June and September 2018. The two dominant plant species recorded at each sampling point defined vegetation patches. Baseline conditions were determined at each characterized sampling point, before one herd of camels (n = 44), one mixed herd of goats and sheep (n = 93), and two herds of cattle (n = 89; n = 86) were moved to the night resting places. Thereafter, measurements at each sampling point were carried out every four days during the use of the night resting places, and thrice after the herds were moved to another night resting place. These representative quadratic sampling areas of one square meter, with at least one-meter distance among them, were randomly chosen. Samples were taken at about 1.5 cm above ground level and sorted by monocotyledonous plants, dicotyledonous plants, and litter. Dry matter, crude nutrients, fiber fractions, and organic matter digestibility were determined for the pooled samples. Forage analyses were done according to VDLUFA (2012).

Additional data was collected through participant observation, and perceptions were collected through in-depth interviews and informal conversations with herders to complement the quantitative research findings.

The length of daily foraging itineraries was determined by two global positioning system devices, each carried by a randomly selected animal of each herd and recording the position of the animal every 20 seconds. Area densities of herds were measured by a global positing system device from the ground by walking around the herd at 20-minute intervals, and in case of the herd of camels every 40 minutes. All animals were weighed monthly. To calculate the stocking rates at each sampling point, the time herds spent on each sampling point, area densities of herds, and live weights were used. Calculations were carried out in QGIS (Version 3.0.3) and in Microsoft Excel (Version 2016).

With the help of the GLIMMIX procedure of SAS (Version 9.4), the driving forces behind the stocking rates were analyzed. The full model for each herd and night resting place consisted of the quantitative fixed effects date, the dry matter weight of the herbaceous biomass fractions (monocotyledonous plants, dicotyledonous plants, and litter), the specific nutritional quality, mean height of herbaceous biomass, cumulative amount of precipitation and maximum ambient air temperature. Furthermore, the examination of the qualitative fixed effects included transect, distance to the night resting place, identified vegetation patch, palatability, and sampling point description. In addition to the relevant effects, spatial and temporal autocorrelations were modelled by introducing additive random effects into the model. Non-significant effects ($P \geq 0.05$) were dropped from the models to obtain a reduced model. The corrected Akaike information criterion was used to evaluate the developed models.

The ranch Ol Maisor, located in the Rift Valley at about 1,870 m above sea level and covering an area of approximately 11,500 ha, was selected due to its relatively good infrastructure and facilities.

Results

The dominant plant species encountered on the sampling points were *Indigofera volkensii*, *Cynodon dactylon*, *Melhania ovata*, *Themeda triandra*, *Andropogon contortus*, *Lintonia nutans*, and *Solanum incanum*. Vegetation dynamics around the night resting places differed between sampling points. After the abandonment of the night resting places, vegetation patches dominated by *C. dactylon* were possibly overgrazed, as indicated by relatively low dry matter weights (about 35 g/m^2), and those dominated by either *A. contortus* or *T. triandra* were most likely underused (about 560 g dry matter/m^2).

The herd patterns over daily foraging itineraries were principally related to the interventions and positions of herders and vegetation structure. Constant area densities of the herd with lactating cows over daily foraging itineraries between recorded positions of the herder suggest that the herder was in control of the herd patterns from every position. Over daily foraging itineraries, the herder slowed the movement speed of animals down by forming a foraging front, most likely mitigating rapid selection. The animals of the other herd of weaner cattle at the front of the usual circular herd pattern probably carried out rapid selection due to the following animals, while the animals in the middle and at the back of the herd fed on the forage resources left by the leading animals.

Herders were allowed neither to keep their own livestock nor to have any kind of share in the animals on-site. They explained that they had utilized forage resources more flexible before working on the ranch. The owners and the herders admitted that the forage and livestock management was not optimal. Herders did not fully incorporate their knowledge to improve the exploitation of different vegetation patches, because they left the herds every so often to expand contacts, buy leaves of the plant *Catha edulis* or any other item, or go hunting. Herders added that they spared no effort to satisfy the feeding requirements of a herd with lactating cows to increase milk yields, as they were entitled to milk for their personal use. They also felt proud of well-nourished and healthy animals, which they showed other herders, workers, and officials.

Each herd visited the sampling points around the night resting places to a variable extent. All herds showed a patchy utilization of forage resources around night resting places, frequently travelling to the same sampling points, especially in the morning and in the late afternoon. The effects of distance to the night resting place and palatability were important drivers for the stocking rates of the herd of camels, according to the selected generalized linear mixed models. The stocking rates of the mixed herd of goats and sheep around the night resting places were strongly influenced by palatability and dry matter weight of dicotyledonous plants around the night resting places. Both herds preferably utilized patches dominated by the highly palatable species *I. volkensii* and *C. dactylon* ($P < 0.01$). The stocking rates of the herds of cattle around the night resting places were significantly associated with the effects of transect, palatability, and dry matter weight of monocotyledonous plants. Both herds of cattle predominantly sought vegetation patches dominated by the highly palatable grass *C. dactylon* ($P < 0.01$). Across all months, organic matter digestibility of *C. dactylon* (ranging from 607 to 696 g/kg dry matter) was greater than the one of the other dominant plant species (averaging 503 g/kg dry matter). The transect that was established from the night resting place towards another night resting place was frequently visited by one herd of cattle ($P < 0.01$).

Discussion [Conclusions/Implications]

When aiming at an efficient utilization of forage resources in a semi-arid rangeland ecosystem, the foraging system has to be flexible to adapt to the highly dynamic spatial and temporal variability (Savory and Butterfield 2016). The rangeland management on the ranch under study implemented a rotational foraging system, in which the foraging area is subdivided into units that are recurrently utilized by livestock, using hired herders. It seems likely that when the quality and quantity of forage resources differed at the micro level, a rotational foraging system is suitable to respond to heterogeneity compared to continuous foraging methods. This view on rotational foraging systems is contested by Briske et al. (2008), who argue that the area has to maintain sufficient forage resources to carry animals during periods of forage scarcity, irrespectively of the management system. However, this work has not considered the knowledge of herders, who are able to improve the performance of animals by altering the movements of herds (Odadi et al. 2017). Likewise, Salomon et al. (2013) acknowledge that herders are aware of seasonally palatable vegetation patches. Since the herds around the night resting places went into distinct directions on the same day, and each herd spread out in diverse directions on different days, hired herders most likely coordinated daily foraging itineraries. Therefore, the results of this study also provide support to arguments that herd activities are significantly influenced by herders (Zengeya et al. 2015), as animals spread out in the absence of hired herders. This indicates the continuous interaction between herders and herds over daily foraging itineraries (Liao et al. 2018) and their ability to intervene in the forage selection process.

Neither the vegetation dynamics nor the stocking rates around the night resting places showed either an evenly distributed foraging intensity as described by Homewood and Rodgers (1991), a decreasing one with distance in all directions or skewed toward the water source as proposed by Spencer (1973), or an increasing one with distance in two opposite directions as assumed by Western (1975). Although the distance to the water source most likely limited the length of the daily foraging itineraries of the mixed herd of goats and sheep, the stocking rates were not skewed toward the water sources. The distance in case of the herd of camels and the directions in case of the other herds were not gradually predictable. This study demonstrates that highly palatable sampling points around the night resting places were visited considerably more than those characterized by less palatable forage resources. This is consistent with previous work at finer scales (Provenza 1996). Hence, the relatively high stocking rates around night resting places did not change the diet selection process of animals, but rather increased the rate at which palatable species were defoliated, as also reported by Bailey and Brown (2011). This was evidenced by low plant heights and dry matter weights of the palatable forage *C. dactylon* that grows on abandoned night resting places. Moreover, the diversification of animal species does not relieve foraging pressure on either severely grazed or browsed plant species, but it potentially maximizes the exploitation of rangeland resources.

Previous research has found that animals forage more efficiently, when the daily distance they travel was reduced (Sevi et al. 1999). A herding system as practiced on the ranch under study has the potential to respond to naturally varying forage resources and to induce functional heterogeneity by building night resting places. To exploit the rangeland resources more efficiently, hired herders have to be motivated to intervene in the diet selection process of animals all day to avoid high stocking rates on specific vegetation patches around night resting places, while diluted impacts of stocking rates on others reduce palatability, and to encourage goats to browse. It is therefore important to ascertain the underlying reasons behind little incentives. Simple measures that could be taken to facilitate an efficient use of rangeland resources may include hiring two permanently employed herders per herd, introducing an offspring-sharing system, and negotiating agreements with neighboring landowners to increase herd mobility in case of need. The investigation of an optimal grazer-browser-intermediate feeder ratio may contribute to the increase in resource use efficiency.

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