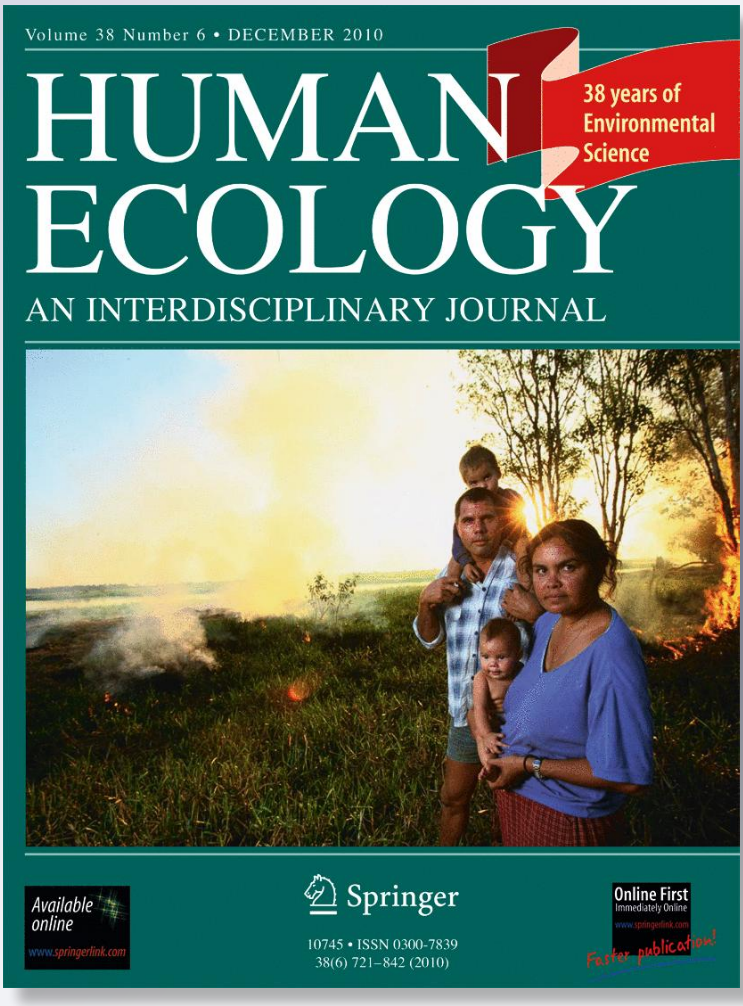
An Integrated Approach to Modeling Grazing Pressure in Pastoral Systems: The Case of the Logone Floodplain (Cameroon)

Human Ecology
An Interdisciplinary Journal

ISSN 0300-7839
Volume 38
Number 6

Hum Ecol (2010) 38:775-789
DOI 10.1007/s10745-010-9361-z



Springer

Hum Ecol (2010) 38:775–789
DOI 10.1007/s10745-010-9361-z

An Integrated Approach to Modeling Grazing Pressure in Pastoral Systems: The Case of the Logone Floodplain (Cameroon)

Mark Moritz · Eric Soma · Paul Scholte · Ningchuan Xiao · Leah Taylor · Todd Juran · Saïdou Kari

Published online: 18 November 2010

Abstract The discussion about the impact of pastoral systems on ecosystems has been profoundly shaped by Hardin's "tragedy of the commons" argument that held pastoralists responsible for overgrazing the range. Recent studies have shown that grazing ecosystems are much more complex and dynamic than was previously assumed and that pastoralists adaptively manage these systems. However, we still have little understanding how everyday herding affects ecosystems at the landscape level. We conducted a study of daily herd movements and grazing strategies in a mobile pastoral system in the Logone floodplain, Cameroon. We integrated GPS/GIS technology, video recordings of animal behavior, and ethnographic methods to develop a more accurate measurement of grazing pressure that takes into account both livestock densities and grazing behavior. We used the resulting grazing pressure data to evaluate existing conceptual models of grazing pressure at a landscape level. We found that models that predict that grazing pressure is skewed towards the direction of water most accurately reflect the situation in the Logone floodplain in the dry season. However, we found that the higher grazing pressure is not only the result of a higher density of cattle but also a change in the grazing behavior of animals after watering. Finally, we caution that the models of grazing pressure in the dry season cannot simply be extrapolated to the landscape level because mobile pastoralists do not remain in one central place.

M. Moritz (✉) · E. Soma · N. Xiao · L. Taylor · T. Juran
Ohio State University,
Columbus, OH, USA
e-mail: moritz.42@osu.edu

P. Scholte
Kitabi College of Conservation & Environmental Management (KCCEM),
Gikongoro, Rwanda

S. Kari
The Centre d'Appui a la Recherche et au Pastoralisme (CARPA),
Maroua, Cameroon

Keywords Pastoral systems · Grazing pressure · Pastoral mobility · GPS/GIS · Africa

Introduction

The discussion about the impact of pastoral systems on ecosystems has been profoundly shaped by Hardin's arguments about the tragedy of the commons (1968). In the Sahel, pastoralists have been held responsible for overgrazing the range and thus exacerbating the hardship they endured during the droughts of the early 1970s and 1980s (Lamprey 1983; Picardi and Seifert 1976; Sinclair and Fryxell 1985). However, studies conducted within the non-equilibrium rangeland ecology paradigm have shown that grazing ecosystems are much more complex and dynamic than was previously assumed and that pastoralists have adaptively managed these systems (Behnke *et al*. 1993; Ellis and Swift 1988; Niamir-Fuller 1999; Oba *et al*. 2000; Sullivan and Rohde 2002).

Ethnographic studies have shown how pastoralists adaptively change their migratory movements in response to changes in rainfall, forage availability and insecurity (e.g., McCabe 2004; Schareika 2003; Stenning 1957). Others have documented the in-depth knowledge that pastoralists have of their environment and how this shapes their everyday grazing strategies (Bollig and Schulte 1999; Krätli 2008: Schareika 2003). Bollig and Schulte (1999), for example, have shown that pastoralists' knowledge of their environment is fine-grained and complex and built up around the interaction between herds and vegetation. However, we have little understanding about how daily herd movements and grazing strategies at the micro-level shape spatiotemporal patterns in grazing pressure and ecological processes at the landscape level. New GPS/GIS technology allows researchers to link grazing strategies to landscape ecology by examining how patterns in daily herd movements lead to spatiotemporal variation in grazing pressure at landscape level (Butt 2009, 2010; Coppolillo 2000, 2001).

Over the last 15 years we have studied pastoralist adaptations to ecological and socio-political changes in the Far North Region of Cameroon (Scholte *et al*. 1996; Moritz *et al*. 2002; Scholte *et al*. 2006). We focused on the Logone floodplain, a Key Resource Area that is used by mobile pastoralists from the entire region during the dry season (Scholte and Brouwer 2008). We concluded, amongst other things, that pastoralists are able to tune grazing pressure to available grazing resources, following an Ideal Free Distribution (Scholte *et al*. 2006). We did not establish, however, how they manage their resources by organizing daily grazing. The present study complements the landscape approach that we have conducted so far and examines patterns in everyday herding and grazing pressure at a fine spatiotemporal scale, meters instead of kilometers, minutes and hours instead of weeks and months.

We collected detailed GPS data in combination with observations and video-recordings of animal behavior to develop more accurate measurements of grazing pressure taking into account both livestock densities and grazing behavior. We used these measurements to evaluate existing conceptual models of grazing pressure at a landscape level. The dry season grazing lands in the Logone floodplain are an ideal place to evaluate these conceptual models because they match the simplifying assumptions of the models. The vegetation quality and quantity is relatively homogenous, there are no agricultural fields or crop residues, and pastoralists have hardly any interactions with farmers or fishers, who are mostly absent from the floodplain during the dry season.

This article makes methodological contributions by integrating different analytical approaches including GPS/GIS technology, video recordings of individual animal behavior, and ethnographic methods to improve the measurement and understanding of spatiotemporal variation in grazing pressure in pastoral systems. We argue that GPS/GIS technology cannot be used as a stand-alone method and that the integration of multiple methods is critical. In particular, we will show that observations of animal behavior and ethnographic methods are necessary to interpret the data collected with GPS technology. Because of our integrated approach we have been able to develop a better and more accurate measurement of grazing pressure, which not only takes into account livestock densities, which is the current way of measuring grazing pressure, but also grazing behavior. The article also makes a critical theoretical contribution showing that GPS/GIS technology needs to be matched by ethnographic understandings of pastoral systems. Current models of grazing pressure that use a central place model are appropriate for sedentary agro-pastoralists but they misrepresent the herd management practices of mobile pastoralists, who are continuously on the move in response to changing environmental conditions, and risk reaffirming the mainstream view of pastoralists overgrazing the range.

Landscape Models of Grazing Pressure in Pastoral Systems

Mobility is a key pastoral strategy to cope with spatiotemporal variation in rainfall and forage (Ellis and Swift 1988; Niamir-Fuller 1999). Some have argued that mobility is the defining feature of pastoral systems in that animals are taken to forage, rather than the other way around (Dyson-Hudson and Dyson-Hudson 1980). It is important to make a distinction between different kinds of pastoral movements, in particular between seasonal migratory movements between pasture zones and daily movements of herds to pastures (Schareika 2003; Stenning 1957). Pastoralists' decisions about migratory movements are based not only on ecological factors (Adriansen 2005), but also social and political concerns, including insecurity (McCabe 2004). Similarly, daily movements of herds to pastures are complex and shaped by multiple factors, including the presence of standing crops in fields and the availability of crop residues (Boutrais 1999; De Boer and Prins 1989; Turner and Hiernaux 2002).

Although the goal of this article is to understand how patterns in grazing intensity of daily herd movements in the dry season shape grazing pressure at the landscape level, herd movements should be understood within the larger context of the annual transhumance in which mobile pastoralists move to different pasture zones within and between seasons. For example, when there are no longer good pastures within the radius of the distance that a herd can travel in one day, mobile pastoralists move to different pastures (Schareika 2003). This distinguishes mobile pastoralists from sedentary agro-pastoralists who remain in one area throughout the year (Coppolillo 2001; Turner and Hiernaux 2002).

In his review of models of grazing for pastoral systems, Coppolillo (2001) has compared the analytical value of unconstrained and constrained central-place models in studying grazing systems in which animals are herded and have to return to the homestead at the end of the day. Unconstrained models, in which animals range freely and are not tied to a specific place, have been used to describe grazing systems in North America, Australia, and Europe, including systems in which animals are enclosed in fenced pastures (e.g., Barbari *et al*. 2006) and wild herbivore populations (see review in Bailey *et al*. 1996). Coppolillo (2001) argues that a central-place model best describes the daily movements of herds in agro-pastoral grazing systems in East Africa. Coppolillo (2001) reviewed different central-place models in the literature of African pastoral systems (Homewood and Rodgers 1991; Spencer 1973; Western 1975) (Fig. 1). These conceptual models predict how daily herd movements lead to patterns in grazing pressure on a landscape level in the rainy and dry seasons. In these models, there are only two variables that produce different patterns in grazing pressure: seasonality and herd management. First, water scarcity constrains herd movements in the dry season, in contrast to the rainy season when water can be found throughout the bush in small ponds. Second, when herders actively manage their herds, they force their animals to spend more time grazing farther away from the camp, whereas when there is no active herd management grazing pressure is assumed to be constant no matter what the distance from the camp.

All models assume that pastoralists start from one central place: the settlement. The settlement can be permanent (year-round) in the case of sedentary agro-pastoralists or

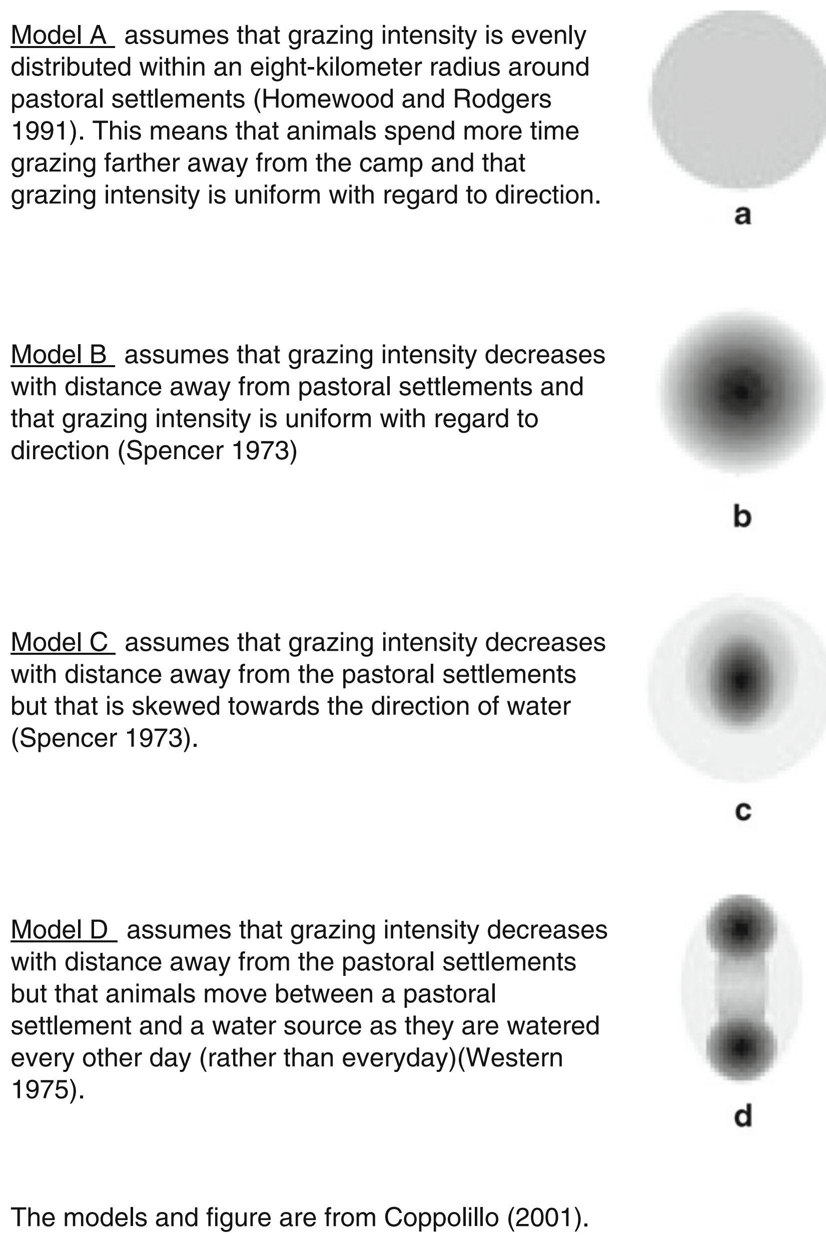


Fig. 1 Conceptual models of grazing pressure. The models and figure are from Coppolillo (2001)

temporary (seasonal) in the case of mobile pastoralists. All models assume that the animals are cattle; they have to be modified for other species that have different forage and watering needs (Spencer 1973). Finally, the models assume that everyday herd movements cumulatively have an effect on the landscape over time. So far, it has been difficult to evaluate these models but with new GPS technology and GIS analytical tools this has come within reach.

Most studies of pastoral mobility and grazing pressure have been based on density data at relatively coarse spatiotemporal scales (e.g., Basset 1986; McCabe 2004; Niamir-Fuller 1999; Stenning 1957). Turner and Hiernaux (2002) have found that the coarser scale fails to take into account the spatial heterogeneity in grazing resources and obscures how other variables shape daily herd movements and spatiotemporal patterns in grazing intensity. They found no support for the models of point-centered radiation of grazing intensity, primarily because of the heterogeneous environment of southwestern Niger (Turner and Hiernaux 2002).

Recently, the analysis has become more fine-grained triggered by the use of GPS technology, which has enabled researchers to track animals and collect more detailed spatial data (e.g., Adriansen and Nielsen 2005; BurnSilver *et al*. 2003; Butt 2009; Butt *et al.* 2009; Coppolillo 2001; Schlecht *et al*. 2004; Turner and Hiernaux 2002). By following herds with a GPS, placing collars on animals, or giving GPS devices to herders, researchers have been able to describe daily herd movements in African pastoral systems (Adriansen and Nielsen 2005; Butt 2009; Butt *et al*. 2009; Gautier *et al*. 2005; Sonneveld *et al*. 2009; Turner and Hiernaux 2002). Several studies have measured the effectiveness of using GPS and GIS technologies to understand the grazing behavior of animals (Barbari *et al.* 2006; Turner and Hiernaux 2002). In the last couple of years GPS technology has become even more powerful and cheaper allowing measurements of livestock density at a much finer spatiotemporal scale.

Methodology

We conducted a study of daily herd movements of mobile pastoralists during the dry season in the Logone floodplain of Cameroon in order to examine spatiotemporal patterns in grazing intensity, using a combination of spatial and ethnographic methods and analyses. We collected detailed GPS tracking data in combination with observations and video-recordings of animal behavior. We found that the new GPS technology also allows us to collect data on grazing behavior in addition to livestock densities, which is commonly used as a proxy for grazing pressure (Butt 2009; Coppolillo 2001).

Study Area and Population

Two phytogeographic zones characterize the Far North Region of Cameroon: Sudanian in the southern grades and Sahelian in the Logone floodplain. Although the Sahelian zone is characterized by lower rainfall, the seasonal flooding of the Logone River makes this zone one of the most important dry season grazing lands in the Chad Basin. Thousands of pastoralists from Cameroon and neighboring Chad, Niger, and Nigeria with more than 200,000 cattle trek each November to the Logone floodplain when the water retreats to exploit the excellent quantity and quality of the grasslands (Scholte *et al.* 2006). At the start of the rainy season (June), pastoralists return to the higher elevated dunes of the Diamaré or neighboring countries that complement the Logone floodplain; the former provide grazing in the rainy season, the latter in the dry season (Fig. 2).

The Logone floodplain is flooded annually by water from the Logone River and its branches in September and vegetation is typically covered with 0.2 m to 0.8 m and, in depressions, up to 1.2 m of water (Scholte 2007; Westra and De Wulf 2007). When the water recedes, the floodplain opens for grazing. Pastoralists find nutritious regrowth and surface water on the floodplain far into the dry season when pastures in surrounding areas have dried up.

The vegetation in the floodplain is relatively homogenous in terms of forage quantity and quality because of the extreme flatness of the area. The treeless grasslands in the floodplain are dominated by perennial grasses: Echinochloa stagnina (*burgu*), Echinochloa pyramidalis (*taagol*), Vetiveria nigritana (*sodornde*), Oryza longistaminata (*naDDere*), and Hyparrhenia rufa (*wodeeho*). Fires are generally set at the start of the dry season to stimulate regrowth. The quality and quantity of vegetation in the floodplain are mainly determined by annual variations in flooding depth and extent; the deeper the depressions, the higher the forage quantity (Scholte 2007). There is a weak coupling between herbivores and vegetation as the vegetation is controlled by flooding and naturally protected against overgrazing because much of the biomass is stored underground and the vegetation is inaccessible during 6 months of the year (Scholte and Brouwer 2008).

The mobile pastoralists who use the floodplain belong to different Arab and FulBe groups. The FulBe group consists of Jamaare'en, Mare'en, Alijam'en, Adanko'en, Anagamba'en, and Uuda'en. All the groups in the floodplain are highly specialized in animal production. In most groups the key animals are cattle, but they also keep sheep and goats to cover small expenses, and donkeys and horses for transport. Most mobile pastoralists move an average of ten times within the floodplain over the course of the dry season (seven transit camps and three sojourn camps).

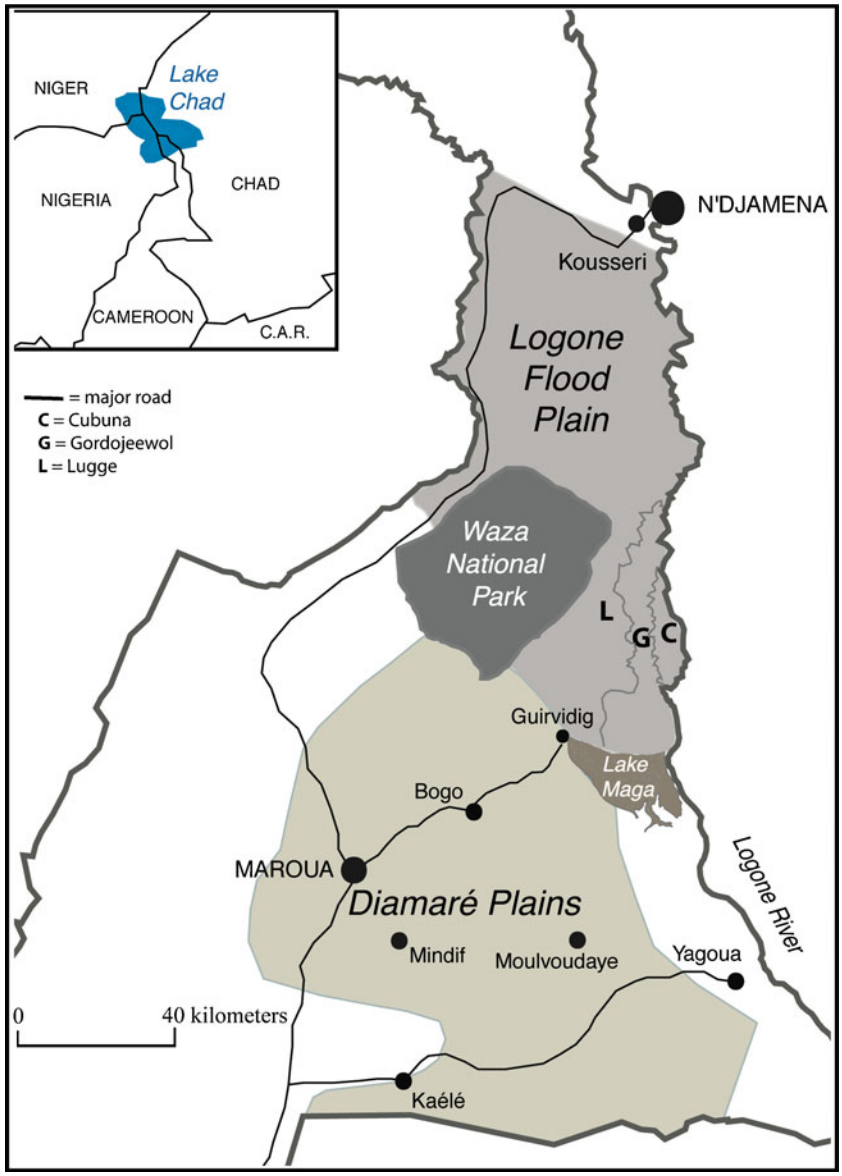


Fig. 2 Study Area in the Far North Region of Cameroon

Herd Management in a Mobile Pastoral System

The Far North Region of Cameroon has a semi-arid climate with a single rainy season and a highly variable spatiotemporal rainfall pattern. During the eight-month dry season, cattle lose considerable weight and become more susceptible to diseases. Animal losses are the highest during this season. The primary goal of pastoralists is to overcome the difficulties of the dry season. This is achieved through a focus on animal nutrition, in particular increasing weight in the rainy season, so that animals have enough reserves to survive the long dry season, and preventing weight loss in the dry season (Schareika 2003).

Traditionally, pastoralists prevented weight loss of their animals through transhumance, taking their animals to the rangelands with the highest quality and quantity of forage. Mobile pastoralists in the Far North Region use opportunistic grazing strategies that closely track resources, which are highly appropriate and effective ways to cope with the variable, unpredictable, and heterogeneous environments of Africa's drylands (Behnke *et al*. 1993; Ellis and Swift 1988; Niamir-Fuller 1999).

The general transhumance pattern of mobile pastoralists in our study can be described as follows. During the rainy season (*duumol*), July-August, most mobile pastoralists camp in the Mindif-Moulvoudaye and the Pétté areas. Within a week of the end of the rains in September-October, pastoralists move *en masse* to the Logone floodplain using existing transhumance routes. In the cold dry season (*dabbunde*), November-January, most mobile pastoralists are in the study area. They divide their herds and send the strongest animals on a separate transhumance with young herders (called *luci*). In the hot dry season (*ceedu*), February-May, most of the mobile pastoralists leave the study area and move either further north in the floodplain or south to the shores of Lake Maga. At the beginning of the rainy season (*seeto*), June, pastoralists follow the clouds and move wherever rains have fallen and fresh forage can be found, a strategy called *tijaago* 'watching the clouds'.

Seasonality also influences daily herd movements in the floodplain. In the cold dry season (November-January) when most pastures are still under water, cattle will graze close to the camp where there is much forage. Later in the dry season (February-May) cattle will graze progressively farther away from the camp and will be watered more often during the day, starting from once a day up to three or four times a day depending on the heat.

Pastoralists are continuously monitoring the well-being and nutritional status of their animals, comparing them with the condition of animals in the same and other areas, and making decisions about moving to ensure that animals have access to relatively good pastures. To increase herd production and reproduction animals have to graze as much as possible and mobile pastoralists in the floodplain take their animals to pasture day and night. Herders actively control the animals during the day; they frequently stop the herd and stimulate the animals to graze in specific areas.

Spatial Data Collection

Recent developments in GPS technology have made it relatively cheap and straightforward to track the daily movements of cattle and to build better models of grazing pressure in pastoral systems. We used the Garmin DC 20 in combination with the Garmin Astro 220 to track the daily herd movements of cattle. The DC 20 was originally designed for hunters to track their dogs, but because of its design—sturdy, waterproof, lightweight (170 g), and easy to attach with a harness—the device performed well with cattle. The only drawback is the battery, which lasts for approximately 14 h. That is enough to capture daily herding movements but the battery must be fully recharged after each round of data collection, for which we used a car battery and solar recharger. The DC 20 records geographic coordinates at 3-second intervals if the animal is moving. When the animal is not moving the GPS does not record spatial information until the animal is moving again or after 1 min (whichever comes first). The device also records distance, speed, true direction, and elevation. We downloaded the data via the Astro 220 into Garmin's MapSource software and exported the data to ArcGIS 9.3 (ESRI 2009) for further analysis.

The spatial and observational data were collected in March 2009 in three mobile pastoralists camps that are located along a transect that runs more or less east—west: Cubuna, a Jamaare'en camp in the east; Gordojeewol, a Mare'en camp in the center; and Lugge, an Arab camp in the west. All three camps are sojourn camps in which pastoralists stayed for more than 30 days. The camps consist of multiple herds and households. In each camp we tracked herds for three successive days and nights. We had five DC-20 units tracking three herds during the day and two at night. In a few cases we lost tracks during the downloading of data from the DC 20 due to battery failure. In total we collected 33 cattle tracks or orbits (21 day, 12 night) with approximately 180,000 data points (Table 1).

We collected observational data by following a tracked-herd in each of the three locations from the moment it left camp (around 7:00) until it returned to camp (around 18:00). In one camp, Cubuna, we also video recorded the tracked-animal for 2 min about every 20 min throughout the day. Field observations and video allowed us to interpret the GPS data by linking behavioral data with spatial data.

We tracked one animal per herd considering it representative of the herd. Herders actively manage the animals and keep them within a space that ranges from 100 to 1,000 square meters. Although animal behavior is not synchronous, the range and frequency of behavior are similar in relatively small units of space and time, such as a 50 × 50-meter area or a 1-minute observation. Butt *et al.* (2009:320) placed GPS collars on multiple cattle within the same herd and showed that the grazing orbit of a single animal was representative of the orbit of the herd.

Measuring Grazing Intensity, Grazing Pressure, and Grazing Frequency

Most studies have used time spent, density, or the number of observations per unit of space as indicator of grazing intensity (e.g., Adriansen and Nielsen 2005; Coppolillo 2001), others used bite rate counts (Coppolillo 2000). In our study we used another indicator of grazing intensity as we found that an animal's speed is a reliable indicator of grazing intensity; the slower the animal moves the more it grazes and higher the grazing intensity. To determine at

Table 1 Number of tracks per camp zone

	Cubuna	Gordojeewol	Lugge	Total
Day	7	7	7	21
Night	5	1	6	12
Total	12	8	13	33

The daily and nightly movements of the animal we videotaped in Cubuna, March 13, 2009 what speed the animal was no longer grazing we synchronized and compared the GPS data with the video data. We found that when the animal is moving 2 km/h or faster it no longer grazes, when the animal is moving between 1 and 2 km/h it is grazing lightly, and when it is moving slower than 1 km/h the animal is grazing intensively. This method does not allow us to distinguish between standing still with and without grazing. However, during our observations animals stood without grazing for less than 10 min or about 1.5% of an 11-hour herding day.

Here we make a conceptual and analytical distinction between Grazing Intensity (GI) as the grazing behavior of one individual animal (and by extrapolation one herd) and Grazing Pressure (GP) as the cumulative impact of multiple daily herd movements on grazing lands at the landscape level.

Grazing Pressure (GP) is then a combination of the grazing behavior of the animals, the number of animals, and the number of times that animals are grazed in a particular unit of space. Here we keep the number of animals or herds in each location constant and examine the data from the seven sample herds in each location in order to distinguish between the effects of Grazing Intensity (GI) and Grazing Frequency (GF) on Grazing Pressure (GP). To distinguish between these two sources of variation we created a raster that shows the Grazing Frequency (GF), which shows how frequently a patch (or cell) is used. Grazing Frequency (GF) is referred to as livestock density in most other studies of grazing pressure (Butt 2009; Butt *et al.* 2009; Coppolillo 2000, 2001). We then compared the Grazing Frequency (GF) raster with the Grazing Intensity (GI) raster with 250-meter grid cells in order to examine the effects of both on Grazing Pressure (GP).

To further interpret the GPS data from the herd tracks we used field notes from observations, video recordings, and panchromatic satellite image of the study area (Worldview-1 with a 0.6-meter resolution, February 2009). This allowed us, for example, to document when and where herds were watered.

Results

Prior to discussing the spatiotemporal patterns in daily herd movements, we describe the daily herding routine of the herd from Cubuna that was video recorded over the course of one day. The description serves to illustrate the daily herd movements and herders' management in the Logone floodplain in the dry season.

An Example of Daily Herd Movements

Cubuna is a camping zone near the Logone River. In the dry season of 2009 there were three camps of FulBe Jamaare and FulBe Mare pastoralists. On March 13, 2009 we tracked and video recorded one animal from 6:20 in the morning to 17:50 in the evening. Herders did not coordinate daily herd movements, but they generally went into the same direction. The patterns of daily herd movements were the result of combined decision-making by animals and herders; for example, animals decided the direction in the morning, while herders decided where the animals were watered.

Early in the morning the calves are released from the calf rope one by one and allowed to nurse, after which the herder milks the cows.

- 6:20. The animals slowly walk out of the camp and graze in the immediate surroundings of the camp.
- 6:40. The animals start to move steadily in a southwest direction. The herds form a long line. The herders finish their meal, pack their things, and leave the camp to catch up with the herds.
- 7:40. The herder stops the animals to make them graze. At this point the animals in the herd stay relatively close together and all the other herds from the camp are close by.

For the rest of the morning the animals in the herd continue to walk and graze slowly. They spread out and form a line. The different herds from the camp also spread out.

- 11:15. The herd slowly changes direction heading towards the watering place and at 11:45 the animals pick up the pace. Multiple herds use the same watering place and herders take turns watering their animals, so that some have to slow down their herds.
- 12:30. The animals are watered in the Logone River at a watering place called *Yaarnirde Lugge Banana*. The watering lasts only a couple of minutes. After which the animals regroup and are taken to a nearby depression called *Coofol Ganganji*.
- 14:00. The herds from the different camps are again much closer together. The pace of the animals is much slower and they graze more intensively, mostly on Echinochloa stagnina (*burgu*) that is growing in the depression.
- 15:15. The herd enters the Logone River for a second watering and stands on a sandbank in the river for a while.
- 16:00. The herds continue to move slowly and graze intensively. The herders of the different camps socialize. The wind has gone down and it is starting to cool slightly.
- 17:30. All the herds walk at a brisk pace back to the camp and 20 min later arrive back in the camp. The cows are milked and after milking the calves are again attached to the calf rope.

21:15. The animals leave the camp and start moving southwards. They do not move very far, about 700 m and then move back to the camp where they arrive 2 h and 15 min later at 23:30.

During this day the video-recorded animal spent 6 h and 24 min grazing heavily, 38 min grazing lightly, and 4 h and 34 min walking for a total of 11 h and 36 min. It walked 16,440 m and the maximum distance from the camp or herding radius was 4,659 m. At night the animal walked 2,227 m and was only 698 m from the camp.

Patterns in Daily Herd Movements

The daily herd movements described above are representative of the patterns in the other 20 tracks in the three different locations (Table 2). Overall there was little variation in the total herding time and average speed of the herds during the day. Herds left for pasture around 7:00 and returned around 18:00, spending on average 11 h in the bush. We found no statistically significant differences between the three locations in average speed of the animals and total herding time, but there were significant differences in distance and radius between the three locations (respectively p = 0.023 and p = 0.004, ANOVA, SYSTAT 12). The average distance covered was 15 km, but some herds travelled over 20 km, while others travelled only 10 km. Similarly the average herding radius during the day was 4,417 m, but some herds were more than 7,500 m from the camp and others only 2,200 m. The herds in Lugge covered the largest distance and travelled the farthest away from the camp, primarily because the good watering places were located farther from this camp than from the other two locations.

We interviewed pastoralists about decision-making with regard to the direction of the daily movements and were told that most of the time the animals decide what general direction they go in the morning. One of the patterns that we found is that herds go in similar directions in Cubuna and Lugge, which is partially explained by the location of the watering places. In Gordojeewol herds did leave more often in different directions, as there were more watering places all around the camp, including the Lorome Mazera and the Logomatya rivers and numerous depressions that still contained water. When we collected the data in the dry season the herds were watered twice a day around 12:00 and 15:00. The watering time affects the direction of the herds as herders aimed to reach water between 12:00 and 13:00. This means that they could not move too far from the watering places.

Patterns in Nightly Herd Movements

Night grazing complements day grazing and pastoralists consider it extremely important in terms of nutritional intake and general health of the animals. There have been very few studies of night grazing (but see Ayantunde *et al*. 2000) and none of nightly herd movements. We were able to track 12 herds at night and found a number of differences between herding during the day (*oorgo*) and herding at night (*mirgo*) (Table 3). The animals are not actively herded at night; herders only follow the herd to protect it from cattle thieves. At night the animals graze for only a few hours (2 h and 15 min on average at night versus 11 h and 9 min during the day) and do not go far (average herding radius is 775 m at night versus 4,417 during the day). The total distance walked is much shorter at night (average is 2,526 m versus 15,000 m during the day). At night the animals follow almost the same path from and to the camp (while during the day they more or less orbit) and they travel in a different direction than during the day in the search of different forage. The animals are not watered and graze most intensively the farthest away from the camp at

Table 2 Descriptive statistics for daily herd movements (N = 21)

	Start time	End time	Total herding time	Mean speed (km/h)	Total distance (m)	Herding radius (m)
Mean	6:59	18:05	11:05	2.29	15,000	4,417
Minimum	6:11	15:49	10:11	1.92	9,726	2,190
Maximum	8:08	19:55	11:45	2.60	20,511	7,564
Median	6:46	18:07	11:06	2.28	14,260	4,018
SD	0:35	0:48	0:27	0.20	3,032	1,708
ANOVA			NS	NS	p = 0.023	p = 0.004

There is some statistically significant variation in the total distance and herding radius of the daily herd movements. The herds in Lugge cover longer distances and move farther away from the camps than the herds in the other two locations. The average distance and radius in Lugge are respectively: 17,328 and 6,008 m

Table 3 Descriptive statistics for nightly herd movements ($N = 12$)

	Start time	End time	Total herding time	Mean speed (km/h)	Total distance (m)	Herding Radius (m)
Mean	21:44	23:59	2:15	2.01	2,526	775
Minimum	21:06	0:08	1:52	1.45	1,203	535
Maximum	22:39	23:52	2:33	2.47	4,088	1,015
Median	21:50	23:56	2:13	2.04	2,466	798
SD	0:29	0:51	0:12	0.29	711	171
ANOVA			NS	NS	NS	NS

There is little variation across the two locations of Lugge ($N = 6$) and Cubuna ($N = 5$) in nightly herd movements. We did not include Gordojeewol ($N = 1$) in the statistical analysis

night. Unfortunately we were unable to make any observations at night because of the risks of raids. We do not know to what extent insecurity affects night grazing but we suspect that herders did not let the animals travel beyond shouting distance from the camps. We found little variation when we compared the data on night herding time, speed, distance, and radius from Lugge ($N = 6$) and Cubuna ($N = 5$) and none was statistically significant.

Patterns in Grazing Intensity (GI)

When we compared the video images with the tracking data we found that speed is a reliable indicator of how much an animal grazes and that the slower an animal moves the more intensively it grazes. Although we did not collect bite rate counts in the field, analysis of the video images show that with speeds lower than 1 km/h (heavy grazing) the bite rate is much higher than with speeds between 1 and 2 km/h (light grazing). This allowed us to make a raster with Grazing Intensity (GI) for all herds in the three locations. The spatial pattern that emerges at the landscape level from these daily herd movements shows that there is a higher grazing intensity near the campsite and the watering places (Figs. 3 and 4).

There is considerable variation in animals' speed over the course of the daily movements, which is the result of the interplay between herders and their animals. During our observations we found that herders control the speed of the animals and generally force them to move less and graze more. The result is continuous changes in speed and grazing intensity throughout the day. Because speed changes constantly, we used a 5-minute running average to look for patterns in speed and thus grazing intensity (Fig. 5). We found four general patterns in the changes in Grazing Intensity (GI). First, early in the morning the speed is low when animals graze in the immediate surroundings of the settlement when the herders are having their meal. Second, speed is high at the beginning and the end of the day, when herds either travel to or return from pasture. Pastoralists told us that, early in the morning, animals 'decide' on the time and direction of movements as the winds bring smells of fresh forage. When cattle start moving in the morning, they move briskly and are slowed down by the herder who forces them to graze. At the end of the day, lactating animals want to return quickly to their nursing offspring. The herders slow them down, but at some point the animals are no longer interested in grazing and only want to return home. Third, there is an increase in speed right before and after watering. While herders choose where the watering takes place, the animals 'decide' when it is time to drink. When animals have 'decided' to water, they pick up speed, only to be slowed down by herders in order to take turns watering their animals. After watering herds travel at a brisk pace for 5 to 15 min to nearby pastures, where they slow down and start grazing more intensively. Fourth, in the afternoon animals graze more intensively for longer stretches after the first watering around 12 noon than in the mid-morning and late afternoon. This means that the higher grazing pressure near watering sources is not only the result of a greater number of herds that water there, but also a change in grazing behavior of the animals after watering.

Patterns in Grazing Frequency (GF)

Spatial variation in Grazing Pressure (GP) can be due to changes in the intensity with which animals graze and/or the number of animals that graze at a particular patch as herds and animals within the herd disperse and contract over the course of the day. For example, in the early morning (7:00–8:00) when speed is relatively high and grazing less intense, the animals and herds are closer together than in the mid-morning (9:00–11:00) when speed is lower and both animals and herds are dispersed. To distinguish between these two sources of variation in Grazing Pressure (GP), we created a raster that shows the Grazing Frequency (GF), which shows how frequently a cell in our grid is used by herds (Fig. 6). In all three locations, we found a higher Grazing Frequency (GF) near

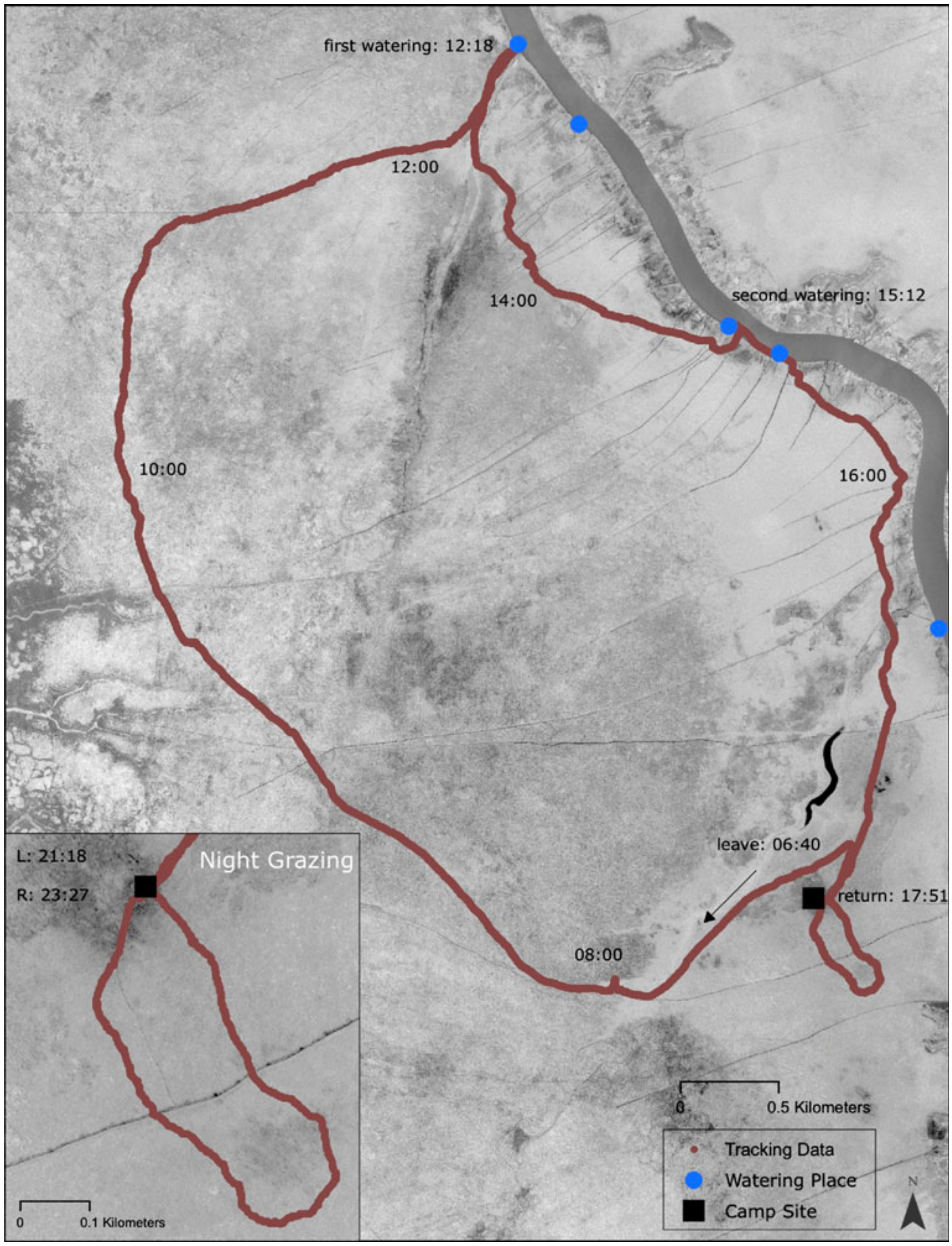


Fig. 3 Daily and nightly herd movements in Cubuna

the campsite and the watering places. In Lugge we also found a high Grazing Frequency (GF) on the route to the first watering place, which was at a considerable distance from the camp.

Patterns in Grazing Pressure (GP)

We compared the Grazing Frequency (GF) raster with the Grazing Intensity (GI) raster with 250-meter grid cells in order to examine the effects of both on Grazing Pressure (GP) (Fig. 7). We found that some of the Grazing Pressure (GP) is due to high frequency of use by multiple herds (GF) especially near the camp and the water sources. However, not all the high grazing pressure can be explained in terms of Grazing Frequency (GF), some of it is due to changes in grazing behavior that result in higher Grazing Intensity (GI). We hypothesize that the change in the grazing behavior of the animals is related to the watering because the shift in grazing intensity is most clear in Cubuna where water is only available in the Logone River. In Gordojeewol and Lugge the pattern was still visible but less prominent because animals were able to drink in small depressions before the first watering (*yaarnugo*). Pastoralists gave different reasons for the behavioral changes, including that the watering was a point of return that signaled to animals that they would not travel to more distant and potentially more attractive pastures.

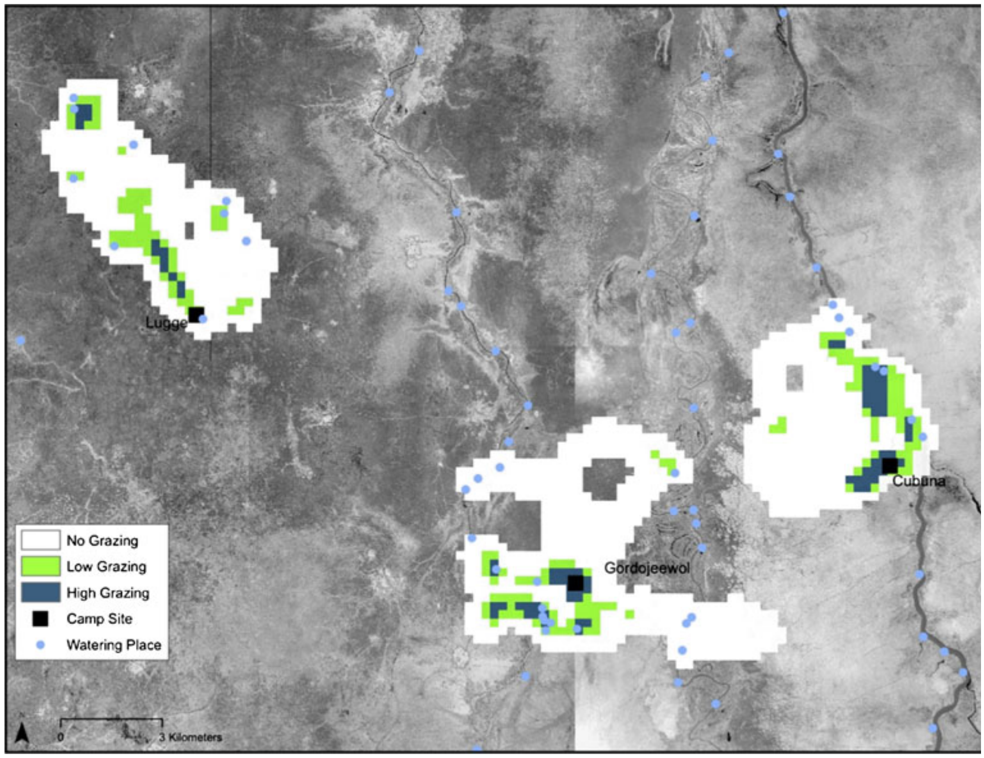


Fig. 4 Grazing Intensity (GI) in three camp zones. We used a surface density measure with a kernel function that takes into account the values of surrounding cells to create a raster with a 250-meter grid for Grazing Intensity (GI), i.e., the average speed of the herds, in March 2009.

Discussion

This is a micro-level study of spatiotemporal variation in daily herd movements and grazing pressure. By combining detailed GPS data with observational and ethnographic data of daily herd movements in the dry season grazing lands of the Logone floodplain, an environment that matches the assumptions of the models, we were able to evaluate existing models of grazing pressure in African pastoral systems. Our map of Grazing Pressure (GP) in the three locations shows higher grazing pressures in the immediate surroundings of the camp and near watering places. Our map best fits the spatial representation of model D which assumes that grazing intensity decreases with distance away from the pastoral settlements and that animals move between a pastoral settlement and a water source as they are watered every other

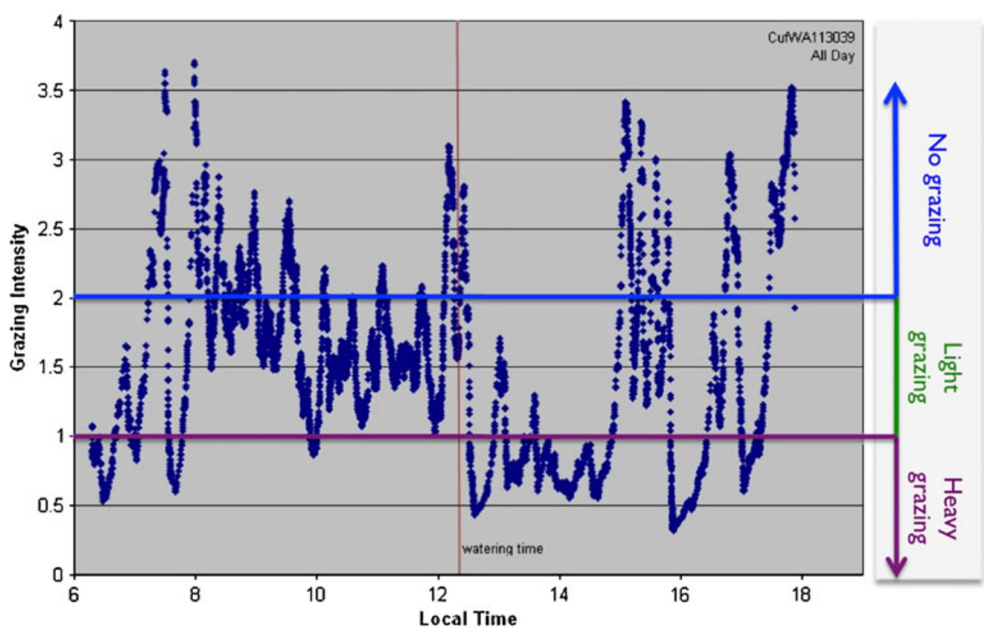


Fig. 5 Changes in Grazing Intensity (GI) during daily herd movements. The speed of the videotaped animal as a 5-minute running average from the moment the herd left in the morning until it returned at night shows the temporal variation in speed

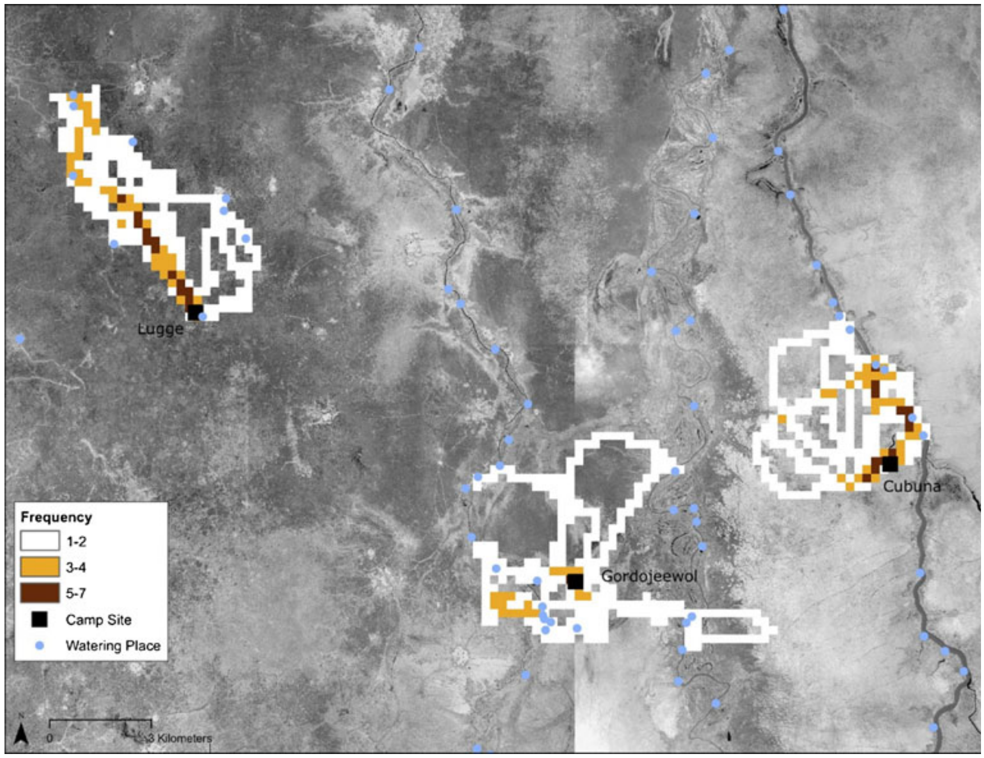


Fig. 6 Grazing Frequency (GF) in three camp zones. The 250-meter grid with Grazing Frequency (GF), i.e., the number of herds that frequented a patch, shows a higher grazing frequency near campsites and the watering places in March 2009

day (Fig. 1). However, in the Logone floodplain animals are watered everyday in the dry season and we find that higher Grazing Pressure (GP) near watering sources and settlements is the result of higher densities of cattle (GF) and a change in grazing behavior after watering (GI).

Developing a Diachronic Model of Grazing Pressure

Landscape models of grazing pressure are strongly shaped by seasonality (Butt 2009; Coppolillo 2000, 2001; Schareika 2003). Because we collected the data in the dry season, the

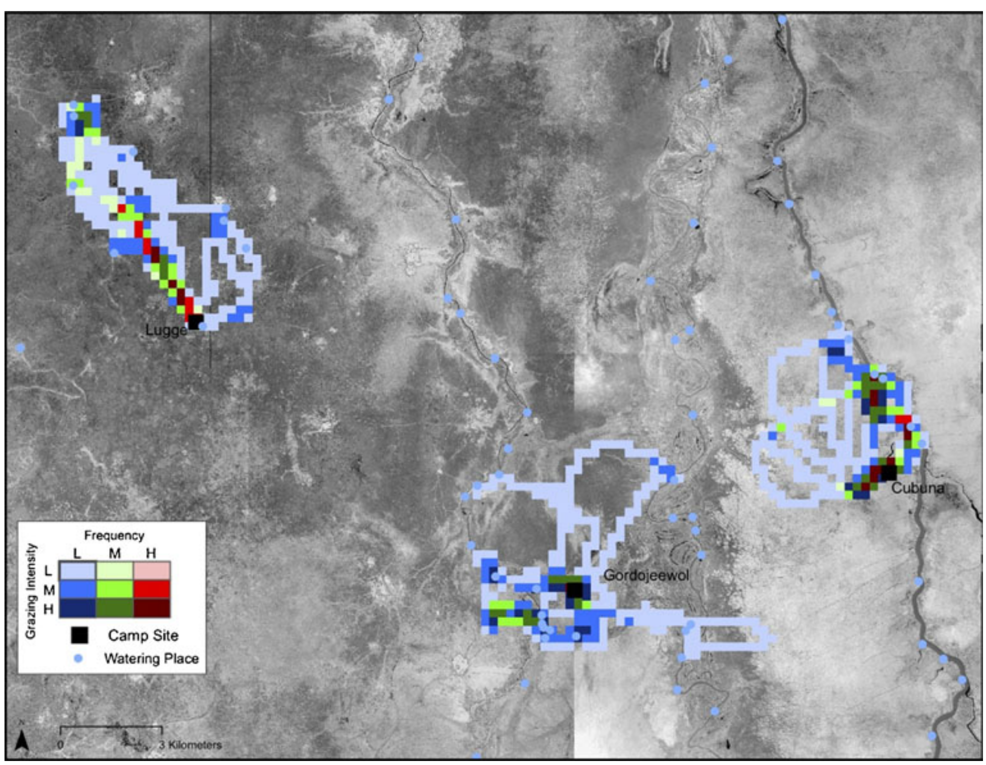


Fig. 7 Grazing Intensity (GI) & Grazing Frequency (GF) combined. The combined Grazing Intensity (GI) and Grazing Frequency (GF) map shows that both contribute to higher Grazing Pressure (GP) near the camps and the watering places, but also that we find higher Grazing Frequency (GF) on the routes to and from the camps in March 2009

only time large numbers of cattle are present in the floodplain, the location of the watering places had a strong effect on the daily herd movements and spatiotemporal patterns in grazing pressure at the landscape level as animals were watered twice a day around 12:00 and 15:00. In order to develop a general model of grazing pressure at the landscape level, we have to understand how seasonality shapes the daily herd movements and variation in grazing pressure.

We know from our ethnographic research in the Logone floodplain that in the cold dry season (*dabbunde*) there is an abundance of forage and animals graze in standing water in the immediate surroundings of the camp. However, as the dry season progresses, the herds travel increasingly farther as forage is diminishing in the immediate surroundings of the camps. The number of waterings per day also increases as the dry season progresses. In the cold dry season the animals are grazing while standing in water and thus do not need to be watered. Later in the hot dry season (*ceedu*), they are watered once, twice, and up to four times a day. The location of the watering places also changes as the dry season progresses. Early in the dry season water can be found throughout the floodplain, then only in depressions and rivers, and finally only in the rivers. In general, cattle graze more intensively when there is more and better forage (Krätli 2008; Schareika 2003). Grazing intensity is thus a function of forage quality and quantity. The daily herd movements and patterns in grazing intensity are also affected by the availability of forage, which is affected by burning and grazing. As the dry season progresses, and more forage has been burned and consumed, cattle have to travel farther and farther to get to good forage. Thus, rather than thinking of the four different models of grazing pressure discussed above as separate models, it may be better to think of these four models as diachronic models that represent spatiotemporal changes in grazing pressure as the dry season progresses (Fig. 8).

Methodological Contributions

A number of researchers studying livestock movements have used GPS technology that can be left on an animal for multiple days or months without recharging the battery and/or offloading the data (Adriansen and Nielsen 2005; Sonneveld *et al*. 2009). The GPS devices used in these studies are much heavier (ranging from 1 to 1.5 k) than the DC 20 we used and they collect fewer data points. The spatiotemporal scale of the analyses is much coarser as a result. The GPS technology that we used provided extremely detailed data at a fine spatiotemporal scale: seconds and meters, rather than kilometers and hours. This method has advantages and disadvantages. The disadvantage is that it is more labor intensive. Researchers need to be in the field to put the collars on and take them off, recharge the batteries, and offload the data to a computer (Butt 2009). But the advantage is that it allows the researchers to collect observational data and interview data, which are critical to interpreting the spatial data. When we used the DC 20 for the first time in 2008, we were unable to interpret the detailed data set except for the simplest analysis of herding radius and distance, because we did not collect observational data of daily herd movements and grazing behavior. We found that the use of mixed methods in the study of pastoral mobility and resource use is essential (Turner and Hiernaux 2002).

The integration of GPS/GIS, video recordings of animal behavior, and ethnographic methods of participant obser-

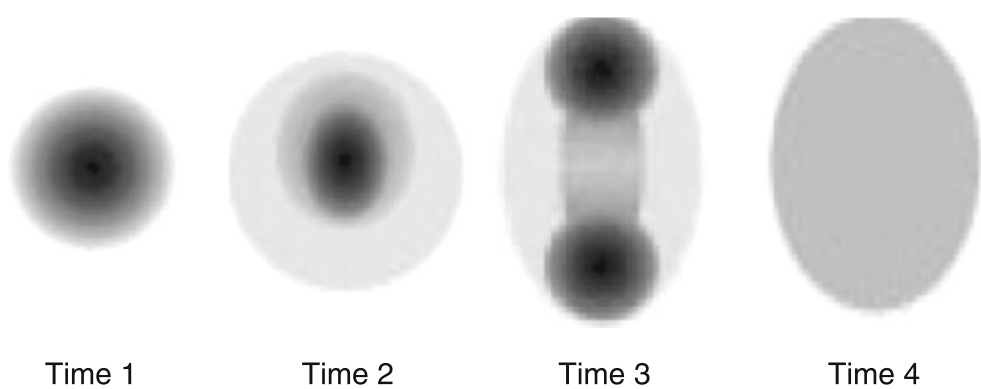


Fig. 8 A diachronic model of grazing pressure. Rather than thinking of these four different models of grazing pressure as separate models, it may be better to think of these four different models as diachronic models that represent spatiotemporal changes in grazing pressure as the dry season progresses. For example, using observational data from our study of mobile pastoral systems in the Logone floodplain, we can explain the phases as follows. At time 1, the cold dry season, there is water and forage throughout the bush and herds do not travel far. At time 2, herds travel farther away but water can still be found throughout the floodplain in depressions. At time 3, the hot dry season, herds have to travel a limited number of watering places in the rivers and forage most intensively in the pastures near the watering place. At time 4, at the end of the dry season, the vegetation has been evenly grazed throughout the floodplain and pastoralists move to their rainy season grazing areas

vation and semi-structured interviews allowed us to analyze detailed spatial data and behavioral data at the micro-level and evaluate models of grazing pressure at the landscape level. However, despite our increased understanding of the relation between daily herd movements and landscape level patterns of grazing pressure, we caution that these models of grazing pressure need to be understood within the larger ethnographic context of mobile pastoral systems.

Modeling Mobile Pastoralists in Open Systems

Our study focused on mobile pastoralists who are continuously on the move throughout the year in search of forage and water. Mobile pastoralists use a central place, but this central place is moved frequently. We therefore cannot aggregate data of daily herd movements from different seasons and places into one single model of grazing pressure at a landscape level. Moreover, mobile pastoral systems in the Far North Region of Cameroon and much of the Chad Basin are open systems. Mobile pastoralists do not remain in one zone or one country throughout the year or even one season. They are continuously looking for better grazing areas and move whenever they find areas that are relatively better for their animals. This makes the modeling of grazing pressure in mobile pastoral systems challenging since there is always the caveat that pastoralists can move out of the area that is modeled (see also BurnSilver *et al*. 2003).

Improved GPS technology allows the collection of detailed and sophisticated data on livestock densities, movements and, as we show in this article, behavior. However, we argue that increasingly sophisticated technology needs to be matched with appropriate concepts and models that are grounded in ethnographic research of pastoral systems. Current models of grazing pressure generally assume that pastoralists remain in one central place throughout the year, which results in inaccurate predictions of the impact of grazing pressure on landscape ecology. This is problematic because too often pastoralists are associated with causing a "tragedy of the commons," and therefore grazing pressure is not a neutral term. Measurements and models of grazing pressure should accurately reflect the herd management practices of pastoralists. Central to the herd management practices of mobile pastoralists is the freedom of movement which results in a continuous redistribution of livestock and grazing pressure over available resources within and beyond the Logone floodplain and reduces the risk of overgrazing and rangeland degradation (Scholte *et al*. 2006).

Acknowledgements This research has been supported by the National Science Foundation (BCS-0748594), the National Geographic Society (8306-07), and the College of Social and Behavioral Sciences and the Anthropology Department at the Ohio State University. We want to thank Mouazamou Ahmadou for video recording, and the Ministry of Scientific Research and Innovation (MINRESI) and the Ecole de Faune de Garoua for granting research permission and research affiliation (2008–2010), Bilal Butt, Matthew Turner, and two anonymous reviewers for comments on an earlier version of this paper, and all the pastoralists for helping us with our research. All maps are made by Eric Soma.

References

Adriansen, H. K. (2005). Pastoral mobility: a review. Nomadic Peoples 9(1 & 2): 207–214.

Adriansen, H. K., and Nielsen, T. T. (2005). The geography of pastoral mobility: a spatio-temporal analysis of GPS data from Sahelian Senegal. GeoJournal 64: 177–188.

Ayantunde, A. A., Williams, T. O., Udo, H. M. J., Fernandez-Rivera, S., Hiernaux, P., and van Keulen, H. (2000). Herders' perceptions, practice, and problems of night grazing in the Sahel: case studies from Niger. Human Ecology 28(1): 109–130.

Bailey, D. W., Gross, J. E., Laca, E. A., Rittenhouse, L. R., Coughenour, M. B., Swift, D. M., *et al.* (1996). Mechanisms That Result in Large Herbivore Grazing Distribution Patterns. Journal of Range Management 49(5): 386–400.

Barbari, M., Conti, L., Koostra, B. K., Masi, G., Guerri, F. S., and Workman, S. R. (2006). The Use of Global Positioning and Geographical Information Systems in Management of Extensive Cattle Grazing. Biosystems Engineering 95(2): 271–280.

Bassett, T. J. (1986). Fulani herd movements. Geographical review 26 (3): 234–248.

Behnke, R. H., Scoones, I., and Kerven, C. (eds.) (1993). Range ecology at disequilibrium: new models of natural variability and pastoral adaptation in African Savannas. Overseas Development Institute, London.

Bollig, M., and Schulte A. (1999). Environmental change and pastoral perceptions: degradation and indigenous knowledge in two African pastoral communuties. Human ecology 27(3): 493–515

Boutrais, J. (1999). Journées de bergers au Nord-Cameroun. In Poncet, Y., and Bernus, E. (eds.), Les temps du Sahel: en hommage à Edmond Bernus. IRD Institut de recherche pour le développement, Paris, pp. 55–80.

BurnSilver, S. B., Boone, R. B., and Galvin, K. A. (2003). Linking pastoralists to heterogenous landscape: the case of four Maasai ranches in Kahiado District, Kenya. In Fox, J., Rindfuss, R. R., Walsh, S. J., and Mishra, V. (eds.), People and the environment: approaches for linking household and community surveys to remote sensing and GIS. Kluwer, Boston (MA), pp. 173–199.

Butt, B. (2009). Seasonal space-time dynamics of cattle behavior and mobility among Maasai pastoralists in semi-arid Kenya. Journal of Arid Environments 74(3): 403–413 doi:10.1016/j.jaridenv.2009.09.025.

Butt, B. (2010). Pastoral resource access and utilization: quantifying the spatial and temporal relationships between livestock mobility, density and biomass availability in southern Kenya. Land degradation and development xxx(x): xx–xxx doi:10.1002/ldr.989.

Butt, B., Shortridge, A., and WinklerPrins, A. M. G. A. (2009). Pastoral Herd Management, Drought Coping Strategies, and Cattle Mobility in Southern Kenya. Annals of the Association of American Geographers 99(2): 309–334.

Coppolillo, P. B. (2000). The Landscape Ecology of Pastoral Herding: Spatial Analysis of Land Use and Livestock Production in East Africa. Human ecology 28(4): 527–560.

Coppolillo, P. B. (2001). Central-place analysis and modeling of landscape-scale resource use in East African agropastoral system. Landscape Ecology 16(3): 205–219.

De Boer, W. F., and Prins, H. H. T. (1989). Decisions of cattle herdsmen in Burkina Faso and optimal foraging models. Human Ecology 17: 445–464.

Dyson-Hudson, N., and Dyson-Hudson, R. (1980). Nomadic pastoralism. Annual Review of Anthropology 9: 15–61.

Ellis, J. E., and Swift, D. M. (1988). Stability of African pastoral ecosystems: alternative paradigms and implications for development. Journal of Range Management 41(6): 450–459.

Gautier, D., Bonnerat, A., and Njoya, A. (2005). The relationship between herders and trees in space and time in northern Cameroon. The geographical journal 171(4): 324–339.

Hardin, G. (1968). The tragedy of the commons. Science 162(3859): 1243–1248.

Homewood, K., and Rodgers, W. A. (1991). Maasailand ecology: pastoralist development and wildlife conservation in Ngorongoro, Tanzania. Cambridge University Press, Cambridge.

Krätli, S. (2008). Cattle Breeding, Complexity and Mobility in a Structurally Unpredictable Environment: The WoDaaBe Herders of Niger. Nomadic Peoples 12(1): 11–41.

Lamprey, H. F. (1983). Pastoralism yesterday and today: the overgrazing problem. In Bourliere, F. (ed.), Ecosystems of the world 13: tropical savannas. Elsevier, Amsterdam, pp. 643–666.

McCabe, J. T. (2004). Cattle Bring Us to Our Enemies: Turkana Ecology, Politics, and Raiding in a Disequilibrium System. Michigan University Press, Ann Arbor.

Moritz, M., Scholte, P., and Kari, S. (2002). The demise of the nomadic contract: arrangements and rangelands under pressure in the Far North of Cameroon. Nomadic Peoples 6(1): 127–146.

Niamir-Fuller, M. (ed.) (1999). Managing mobility in African rangelands: the legitimization of transhumance. Intermediate technology, London.

Oba, G., Stenseth, N. C., and Lusigi, W. J. (2000). New Perspectives on sustainable grazing management in arid zones of sub-saharan Africa. BioScience 50(1): 35–51.

Picardi, A. C., and Seifert, W. W. (1976). A Tragedy of the Commons in the Sahel. Technology Review 78(6): 42–51.

Schareika, N. (2003). Know to move, move to know: ecological knowledge and herd movement strategies among the Wodaabe of Southeastern Niger. FAO Inter-Departmental Working Group on Biological Diversity for Food and Agriculture, Rome.

Schlecht, E., Hulsebusch, C., Mahler, F., and Becker, K. (2004). The use of differentially corrected global positioning system to monitor activities of cattle at pasture. Applied Animal Behaviour Science 85(3–4): 185–202.

Scholte, P. (2007). Maximum flood depth characterises above-ground biomass in African shallowly flooded grasslands. Journal of Tropical Ecology 23: 63–72.

Scholte, P., and Brouwer, J. (2008). The Relevance of Key Resource Areas for Large-scale Movements of Livestock: developing the KRA-concept based on examples from Sahelian floodplains. In Prins, H. H. T., and van Langevelde, F. (eds.), Resource Ecology: spatial and temporal aspects of foraging. Springer, Wageningen, pp. 211–232.

Scholte, P., Kari, S., and Moritz, M. (1996). The involvement of nomadic and transhumance pastoralists in the rehabilitation and management of the Logone flood plain, North Cameroon. IIED Drylands Programme Issues Paper 66: 1–21.

Scholte, P., Kari, S., Moritz, M., and Prins, H. (2006). Pastoralist Responses to Floodplain Rehabilitation in Northern Cameroon. Human ecology 34(1): 27–51.

Sinclair, A. R. E., and Fryxell, J. M. (1985). The Sahel of Africa: ecology of a disaster. Canadian Journal of Zoology 63: 987–994.

Sonneveld, B. G. J. S., Keyzer, M. A., Georgis, K., Pande, S., Ali, A. S., and Takele, A. (2009). Following the Afar: Using remote tracking systems to analyze pastoralists' trekking routes. Journal of Arid Environments 73(11): 1046–1050.

Spencer, P. (1973). Nomads in alliance: symbiosis and growth among the Rendille and Samburu of Kenya. Oxford University Press, London.

Stenning, D. J. (1957). Transhumance, migratory drift, migration; patterns of pastoral Fulani nomadism. Journal of the Royal Anthropological Institute 87: 57–73.

Sullivan, S., and Rohde, R. (2002). On non-equilibrium in arid and semi-arid grazing systems. Journal of Biogeography 29(12): 1595–1618.

Turner, M. D., and Hiernaux, P. (2002). The use of herders' accounts to map livestock activities across agropastoral landscapes in Semi-Arid Africa. Landscape Ecology 17(5): 367–385.

Western, D. (1975). Water availability and its influence on the structure and dynamics of a savannah mammal community. East African Wildlife Journal 13: 265–286.

Westra, T., and De Wulf, R. R. (2007). Monitoring Sahelian floodplains using Fourier analysis of MODIS time-series data and artificial neural networks. International Journal of Remote Sensing 28(7): 1595–1610.