Indigenous Ecological Knowledge as the Basis for Adaptive Environmental Management: Evidence from Pastoralist Communities in the Horn of Africa

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Abstract

The proliferation of woody plants has been observed on rangelands globally and has significant impacts on subsistence livestock production. However, adaptation strategies to such environmental changes remain largely unexamined. This paper investigates pastoralists' adaptations to such environmental changes in the Borana zone of southern Ethiopia by integrating pastoralists' ecological knowledge, surveys of plant species composition, and census data on livestock holdings. The results indicated that a proliferation of woody plants and corresponding decline in herbaceous species would have negative impact on forage values for cattle and sheep, whereas goats would remain relatively unaffected, and camels would benefit. While census data showed declines in household herd size from 2000 to 2014, pastoralists have been adapting to the proliferation of woody plants by doubling their goat holdings, and wealthier households are investing in camels. These changes in livestock holdings based on indigenous ecological knowledge will mitigate the negative impacts of vegetation shifts on livestock production, and facilitate adaptive environmental management in the pastoral systems.

Key words: adaptive environmental management; pastoral system; indigenous ecological knowledge; livestock holding; Ethiopia

1. Introduction

Savanna ecosystems, which are characterized by an open canopy of trees and shrubs with an unbroken layer of herbaceous plants, cover one-fifth of the world's land surface and are ecologically and socioculturally important (Riginos, 2009). These lands support millions of pastoralists whose livelihoods depend primarily on their forage resources (Wiegand et al., 2006). In recent decades, the species composition and physiognomic structure of savannas throughout the world have experienced significant changes for a variety of reasons, including suppression of fires, increased livestock density, and climatic changes (Anadón et al., 2014; Briggs et al., 2005; Buitenwerf et al., 2012; Gartzia et al., 2014; Gillson & Hoffman, 2007; Naito & Cairns, 2011). It is widely accepted by both herders (Angassa and Oba, 2008) and ecologists (Gemedo-Dalle et al., 2006) that pastoral livelihoods are affected when woody plants replace graminoids and forbs on rangelands (Kgosikoma et al., 2012; Solomon et al., 2007). In places where cattle are the dominant livestock type, a reduction in the amount of palatable herbaceous forage species results in a shortage of food to meet animals' nutritional demands, thus negatively affecting subsistence herding communities. Addressing this problem is important to the food security of pastoralists, particularly those who keep cattle-dominated herds.

Pastoralism has long been considered a livelihood strategy that is well adapted to the disequilibrium inherent to rangeland ecosystems (Behnke et al., 1993). Pastoralists have developed a wide range of adaptive strategies to respond to socio-environmental change, which are summarized in terms of five broad categories: mobility, storage, livelihood diversification, communal pooling, and market exchange. These strategies allow risk to be spread across space, time, and asset sectors (Agrawal, 2010). Indigenous herding systems emphasize flexibility over stability, so that the entire pastoral system can maintain functionality while recovering from socio-environmental shocks (Leslie and McCabe, 2013). However, many pastoralists are reporting unprecedented rates and magnitudes of rangeland vegetation shift toward a woody plant-dominated regime, which has severe impacts on the fundamental resource base for livestock production (Angassa and Oba, 2008). Therefore, it is imperative to search for alternative adaptation strategies that would bear similarities to traditional pastoralism while involving novel elements to address the challenges of rangeland vegetation regime shifts.

Indigenous ecological knowledge is an essential component of adaptive environmental management (Berkes, 1998; Kassam, 2009; Turner and Clifton, 2009). Pastoralists' decisions regarding the movement and diversification of livestock are based primarily on their ecological knowledge (Knapp and Fernandez-Gimenez, 2008). Given the depth of pastoralists' knowledge of their rangelands, they can make critical contributions to policies related to rangeland management. Specifically, pastoralists hold a rich body of knowledge on forage plant species and rangeland vegetation dynamics (Kaye-Zwiebel and King, 2014; Kgosikoma et al., 2012). Documentation and analysis of pastoralists' ethnobotanical knowledge and perception of rangeland vegetation regime shift can provide context-specific and empirically-grounded recommendations for policies that will facilitate adaptation to woody plant proliferation, and thereby enhance the resilience of both human communities and the savanna ecosystems of which they are part.

Boran pastoralists, who herd livestock on the savannas of southern Ethiopia, have developed rich ethnobotanical knowledge based on subsistence livestock production and rangeland management (Gemedo-Dalle et al., 2005). This knowledge, including an awareness of the palatability of forage species for their different livestock types (cattle, camels, sheep, and goats), is the basis for context-specific adaptation to the proliferation of woody species in their rangelands (Angassa and Oba, 2008). Unfortunately, previous investigations of Boran knowledge related to the palatability of forage plants have been far too generalized to provide insights for adaptation (Angassa and Oba, 2010). For example, the first comprehensive ethnobotanical study in Borana documented 327 plants (Gemedo-Dalle et al., 2005), including 188 with reported forage values for livestock, but did not report differences in palatability between domestic animal species. Lack of animal-specific data on forage palatability is a barrier to the development of effective policies to guide pastoralists' livestock management.

Furthermore, there is a clear disconnection between studies of rangeland vegetation dynamics and those of livestock holdings. On the one hand, substantial research has focused on changes in rangeland vegetation and provided strong ecological evidence for the proliferation of woody plants in Borana (Angassa and Oba, 2008; Tefera et al., 2007). On the other hand, surveys of livestock holdings have found fluctuations over time and a general shift from grazers towards browsers (Homann et al., 2008; Megersa et al., 2014b). However, studies of woody plant proliferation are yet to be integrated with those of changes in livestock holdings so as to determine if the changes in vegetation referred as 'bush encroachment' are a significant threat to pastoralists' livelihoods, or if these pastoral communities are adapting to these environmental changes by shifting their livestock holdings. Building on pastoralists' knowledge of the palatability of forage species, as well as their perceptions of vegetation change, we can simulate the effects of woody plant proliferation on each livestock species and determine if outputs correspond with pastoralists' ongoing adaptation strategies in terms of the composition of their herds.

Thus, the overarching goal of this paper is to investigate the implications of rangeland vegetation shifts on livestock production in the Borana Zone of southern Ethiopia, and to assess the connection between shifts in herd composition and environmental changes on the rangelands. We began by asking pastoralists about forage plant species and their palatability to cattle, sheep, goats and camels. Next, we conducted a vegetation survey to measure current species composition. We used pastoralists' assessments of forage value and our own measurements of plant abundance to simulate change in species composition, and measure the impacts on palatability for the four livestock species. After that, we compared these projections with data on livestock holdings between 2000 and 2014 to determine if the trends in our simulation align with pastoralists' own decisions regarding herd composition. In closing, we consider the implications of our research findings for adaptive environmental management.

2. Study Area

The Borana Zone is located in southern Ethiopia at elevations ranging from 500 to 2500 m above sea level. The terrain varies from rugged highlands to plains dissected by seasonal river and lake beds in the lowlands (Figure 1). Approximately43,000 km^2 in size, Borana is home to over 350,000 people with a livestock population around one million (Coppock, 2010). The climate is semi-arid with relatively cool average annual temperatures (19-24°C) and a mean annual rainfall ranging from 300 mm in the lowlands to 1000 mm in the highlands. The annual precipitation distribution is bimodal, with 60% occurring during the long-rain season (April to May) and 30% during the short-rain season (September to November) (Desta & Coppock, 2002; Vrieling et al., 2016). Drought typically strikes the grazing system every five to ten years (Coppock, 1994); however, in recent decades, the frequency and intensity of droughts are increasing (Funk et al., 2008);in general, weather conditions are becoming more extreme and unpredictable (Abule et al., 2005).

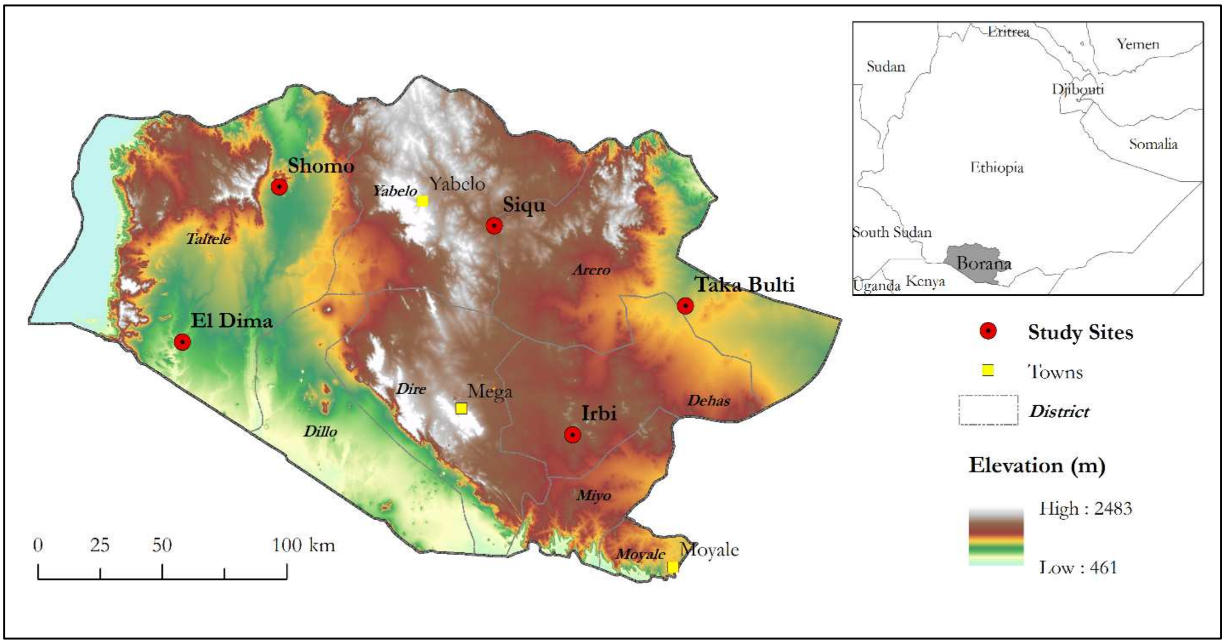

Figure 1. The Borana Zone study area and five selected study sites in southern Ethiopia

Livestock herding is the primary livelihood strategy for the Boran. There are four major livestock species (cattle, camel, goat and sheep) in the Borana Zone, which are used for various purposes including milk/meat production, cash revenues from sales of live animals, socio-cultural functions (e.g., gifts, dowry, ceremonial slaughtering), draught power and manure. Comparing to cattle and camels that are more commonly kept for milk, sheep and goats are more generally raised for meat (Megersa et al. 2014a). According to Cossins and Upton (1987), the Borana rangelands before the 1980s were very suited for cattle grazing. Consequently, livestock herding largely revolves around cattle husbandry (Homewood, 2008), and the local culture and social institutions are closely related to cattle herding (Legesse, 2000). Specifically, cattle herding is generally practiced in two forms. One form is *worra* (home-based herding), which involves the herding of lactating cows, calves, and small ruminants close to settlements. The other form is *forra* (satellite herding), where temporary camps are used to graze bulls and non-lactating cows at substantial distances from base camps. *Forra* herding allows livestock to range more widely and have access to better forage than what might be available near settlements (Homewood, 2008). These two forms of herding are not mutually exclusive, as one household can practice both simultaneously.

Boran pastoralists have been using fire as an important tool for rangeland management. When the woody plant layer becomes denser and suppresses herbaceous plant growth, pastoralists set fires to reduce woody plant cover. However, the Ethiopian government implemented a bush burning ban in the 1970s for rangeland conservation purposes. Not surprisingly, a proliferation of woody plants in Borana was reported by scientists around the same time (Coppock, 1994). By the 1990s, in some parts of Borana, woody plant cover exceeded 60%, with densities approaching 2000 woody plant individuals per hectare (Oba 1998). The species that tended to increase the most after fire suppression included *Acacia mellifera*, *Acacia reficience*, and *Commiphora* spp. (Angassa and Oba, 2008).

3. Methods

3.1. Data collection

Five *reera*[1] (communities) were selected for our study – Siqu, Shomo, Irbi, Taka Bulti and El Dima – to represent a variety of ecological zones (Figure 1). These sites cover a wide range of elevations from the bottom of the Rift Valley at 934 m in El Dima to the top of the Borana Plateau at 1695 m in Irbi. Small-group interviews were conducted from May to September of 2013 and from April to August of 2014. Interviews were conducted in Afaan Oromo and translated into English by a research assistant from the community.

In order to document ethnobotanical knowledge about the greatest variety of plants, interviews were conducted in patches of rangelands reserved for the dry season, which are known to contain the greatest plant diversity. Each interview included three to five active herders and one elder pastoralist. For each species encountered in the field, the research team asked pastoralists for its vernacular name in Afaan Oromo and to describe its palatability to cattle, sheep, goats and camels. Palatability was evaluated in relation to whether or not the plant was consumed given the availability of other plants. *Highly palatable* species were reported by pastoralists to be consumed at any time of the year, whenever they are available. *Barely palatable* species are consumed only during the dry season when there is less other forage available. *Unpalatable* species are never consumed under any circumstances. When pastoralists in the same group disagreed as to the palatability of a plant to a particular livestock type, they discussed among themselves they reached a common understanding. Because of the high number of species, the research team focused on plants that were not discussed previously during fieldwork. Thus, each plant was discussed with one community.

Voucher specimens were collected for each plant observed during interviews, and photographs were taken to facilitate subsequent identification. Voucher specimens were transported to the National Herbarium of Ethiopia, located within Addis Ababa University, for processing and identification.

[1] Administrative units in Ethiopia occur in the following descending order of extent: nation, region, zone, district (*woreda*), and sub-district (*kebele*). *Kebele* is further sub-divided into sub-*kebele* to ease execution of daily administrative and extension activities. In the Borana Zone, a sub-*kebele* is called *reera*. A *kebele* typically comprises three to five *reera*s. *Reera* is made up of geographically adjacent villages called *olla*. *Olla* is group of households settled in a location that consists of as small as three to five households to as large as 20 to 30 households.

Identifications were made by referring to the relevant volumes of the Flora of Ethiopia and Eritrea (Edwards et al., 2000a, 2000b, 1995; Hedberg et al., 2006, 2004, 2003; Hedberg and Edwards, 1995, 1989) and by comparison with existing herbarium specimens. One set of voucher specimens was deposited at the National Herbarium and duplicates were delivered to the Ethiopian Biodiversity Institute for future study and reference.

In addition to investigating the palatability of plant species, we conducted additional small-group discussions to examine pastoralists' perceptions of vegetation shifts on their rangelands in the five study sites. We asked pastoralists to identify and rank the five most common shrubs and trees, five most desirable shrubs and trees, five least desirable shrubs and trees, and ten species that are most rapidly expanding in their herding areas.

In order to measure plant abundance to serve as a starting point for simulations, we conducted vegetation surveys across three grazing zones in the pastoral communities[2]. For each of these categories, two knowledgeable community members were asked to lead the research team to a large, representative patch, and a systematic sampling approach was used to sample nine plots (Figure S1). From the point identified by the community members, we walked ten paces north to determine our first plot. Subsequent plots were located at 250-meter intervals to the north and east. Each plot consisted of three nested quadrats: 1 m x 1 m for herbs, 5 m x 5 m for shrubs, and 10 m x 10 m for trees. The number of individuals of each species within each nested quadrat was documented. Plant abundance data were collected at a total of 135 plots across the five study sites.

3.2. Quantification of palatability and ranking

[2] The Boran pastoralists typically categorize their community rangelands into three zones, including *qaye* (areas close to settlement, associated with high grazing intensity), *mata tika* (major herding areas, associated with medium grazing intensity) and *kalo* (fenced rangelands reserved for dry season grazing, associated with low grazing intensity).

An index of forage plant palatability was calculated based on pastoralists' knowledge of its seasonal consumption. Given that the dry season in Borana typically lasts four months, we estimated that highly palatable species are consumed for a period of time roughly three times longer than barely palatable species. Thus, we assigned a value of 3 to highly palatable species, 1 to barely palatable species, and 0 to unpalatable species.

We normalized and converted the rankings of plant species' relative desirability and degree of proliferation into a rescaled interval between 0 and 1, where 0 represents lowest values and 1 indicates the greatest values to a specific species. The index, I, is then calculated as:

$$I_i = 1 - (r_i-1)/n$$

where r_i represents the ordinal ranking of a species, and n is the number of plants ranked in each exercise. In the case of desirability ranking, n = 5. Therefore, the first one was assigned a value of 1-(1-1)/5 = 1, the second 1-(2-1)/5 = 0.8, the third 0.6, the fourth 0.4, the fifth 0.2. The values of undesirable plants were determined by following the same rule, but were assigned with negative values. In the case of bush expansion ranking, n = 10. In the proliferation ranking, the most proliferating species was assigned 1-(1-1)/10 = 1, the second 1-(2-1)/10 = 0.9, and the last 1-(10-1)/10 = 0.1.

3.3. Livestock holdings

In order to examine the impact of vegetation shifts on livestock production, it is necessary to measure changes in Borana pastoralists' livestock holdings. Data collected in 2000 from 150 households locatedthroughout the Borana Zone by the Pastoral Risk Management Project (Barrett et al., 2008) were compared with data from 515 households surveyed by the Index-Based Livestock Insurance Project in 2014 (International Livestock Research Institute, 2014). Although the two datasets did not target the same households, both included districts throughout the Borana Zone, and the number of cattle, sheep, goats and camels were reported at the household level. For the sake of cross-species comparisons, counts of livestock heads were converted to tropical livestock units following standard ratios (1 cattle = 0.8 camel = 10 sheep/goats).

3.4. Simulation of vegetation regime shifts

The simulation of future vegetation composition and value to livestock was based on pastoralists' assessment of palatability, perceptions of vegetation shifts, and relative abundance data from the vegetation survey. The simulation was designed to test the hypothesis that:

As the rangelands shift into states with a higher proportion of woody plants, the average palatability will be lower for cattle, but higher for sheep, goats and camels.

The simulation algorithm considered all individual plants encountered in the nested plots as equal units, because the nested sampling scheme accounted for the relative sizes of herbs, shrubs and trees. We first assembled all individual plants into the simulated pool of plants available for livestock. Based on pastoralists' first-order observation that woody plants have been replacing herbs, in each step of the simulation, two individual herbaceous plants were removed and two individual woody plants were added to the pool. In addition, the algorithm also considered pastoralists' second-order observations: 1) that grass species disappear more rapidly than forbs, and 2) that certain woody plants proliferate faster than others. Thus, in each step of the simulation, one of the herbaceous individuals removed from the pool was guaranteed to be from a grass species, while the other was selected from the entire pool of herbs. Furthermore, one of the woody plants added to the pool was randomly selected from among the ten species identified by pastoralists as proliferating the most quickly, whereas the other woody plant was randomly selected from the entire pool of woody plants. We ran a total of 100 simulations for each livestock type. The simulation and all other data analysis in this paper was conducted using R statistical software (R Development Core Team, 2014).

4. Results

4.1. Richness and palatability of plants

During interviews with Boran pastoralists, we identified 252 plant species belonging to 49 families and 158 genera (Table S1). We were able to obtain the vernacular Afaan Oromo names for 88% of these species from pastoralists. The families with the greatest numbers of species were Poaceae (40 species), Fabaceae (30), Asteraceae (22), Malvaceae (19), Acanthaceae (13), Amaranthaceae (12), and Lamiaceae (11).

Pastoralists reported different palatability for each of the 252 plants in relation to the four categories of livestock (Figure 2). Goats are known to consume the greatest number of plants, with 156 highly palatable but only 25 unpalatable. By contrast, cattle are known to be the most selective, with 87 unpalatable species and 73 plant species as highly palatable. In terms of their discrimination between plant species, sheep and camels lie between goats and cattle. Pastoralists reported 125 species as highly palatable and 57 as barely palatable to sheep, and 101 species as highly palatable and 90 species as barely palatable to camels.

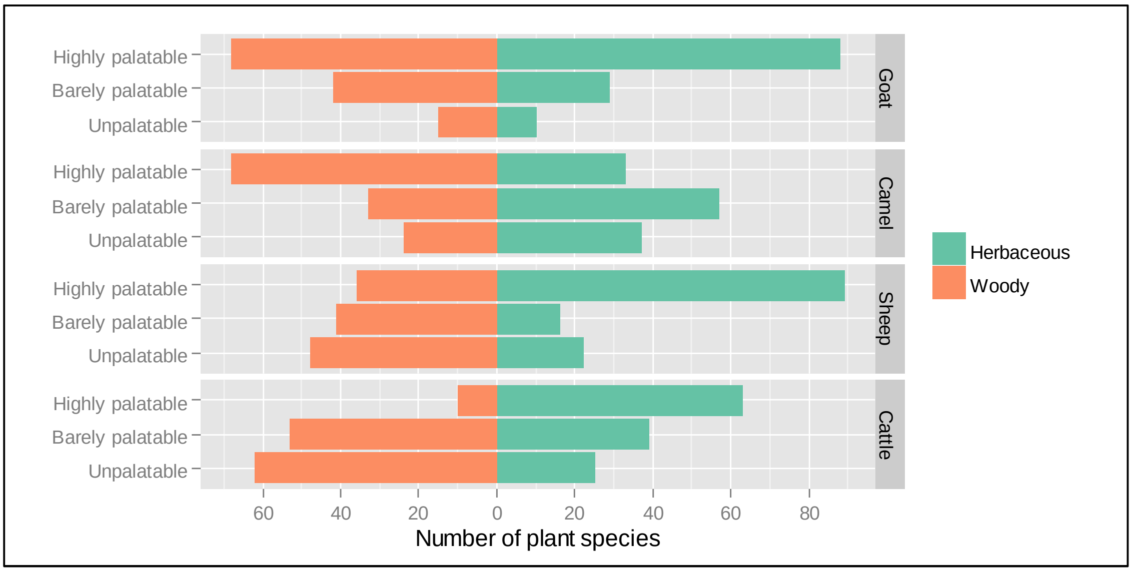

Figure 2. Palatability of herbaceous and woody plants to goat, camel, sheep and cattle.

In terms of growth forms, we documented 77 forbs, 59 shrubs, 40 grasses, 37 shrub-trees[3], 26 trees, 8 climbers, and 5 succulents. Woody plants account for 51% of species, whereas herbaceous plants are the remaining 49%. Woody and herbaceous plants exhibit different palatability to the four livestock types (Figure 2). For goats, 60% of all plants are reported as highly palatable, including 84 herbaceous and 68 woody species, suggesting that goats are generalists rather than pure browsers. For camels, 68 woody species are highly palatable compared to only 30 herbaceous plant, indicating that this species favors woody to herbaceous plants. Interestingly, another 30 herbaceous plants were reportedly unpalatable to camels, the highest count among all livestock types. Pastoralists report that sheep find many plants highly palatable (49%), but they are more likely to find herbaceous plants highly palatable (87 species) than woody plants (36 species). In other words, sheep are known to reject 46 woody species, twice that of camels and three times that of goats. Finally, cattle find very few woody plants highly palatable, and are also fairly discriminating when it comes to herbaceous species. Only 10 woody species are highly palatable to cattle, compared to 63 herbaceous plants.

4.2. Perception of woody plant proliferation

Pastoralists from the five communities named 29 woody plant species that are proliferating within their rangelands. Six of the most commonly mentioned and highest ranked species belonged to the *Acacia* genus (Table 1). Pastoralists agreed that *Acacia mellifera* is rapidly proliferating, as it was mentioned in all five small-group discussions and showed a high average rank.

[3] Shrub-tree is a growth form between shrub and tree, which is common in the Borana drylands. Certain species can either grow into a tree or shrub, depending on the site conditions.

Table 1. The most frequently mentioned and highest ranked species identified as proliferating by pastoralists (n=5)

Species	Mean Proliferation Index	Times Mentioned
Acacia mellifera	0.94	5
Acacia oerfota	0.6	4
Acacia reficiens	0.5	3
Acacia senegal	0.34	2
Commiphora africana	0.32	3
Osyris quadripartita	0.28	2
Acacia horrida	0.24	2
Acacia seyal	0.2	2
Sansevieria ehrenbergii	0.16	2
Solanum somalense	0.16	3

We hypothesized that the overall desirability for livestock production is inversely correlated with a plant's proliferation index. Specifically, we expected that plants with a high proliferation index tend to have a low desirability. Linear regression between these two indices supported our hypothesis. The result showed a significant negative correlation between desirability and proliferation index (Figure 3). Despite the fact that some proliferating species are palatable to livestock, pastoralists' perception of these species tended to be negative. In most cases, pastoralists reported that the establishment and proliferation of these woody species suppresses the growth of herbs in the understory, which are important for cattle.

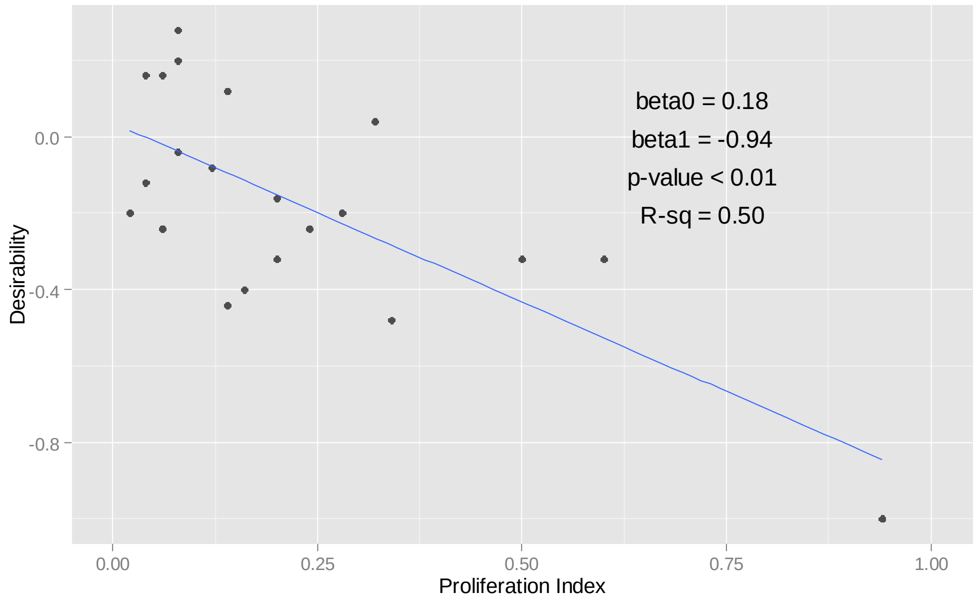

Figure 3. The relationship between proliferation index and desirability as a forage species.

4.3. Livestock holding as evidence of adaptation

According to the survey of 515 households in 2014, the average livestock holdings in the five study sites included 12.8 cattle, 4.8 sheep, 11.2 goats, and 1.2 camels (Table 2). Of the surveyed households, nearly 95% owned cattle, which is also the dominant livestock type, accounting for over 80% of TLU among the surveyed households. In addition to cattle, 87.2% of all households kept goats, contributing to 7.1% of total TLUs; 67.4% of households raised sheep, or 3% of total TLUs; and finally 33% of households reared camels, which accounts for 9.4 % of total TLUs.

Table 2. Livestock holdings at the household level in 2014

Livestock	Median	Mean	% of HH	% in HH TLU
Cattle	7	12.8	94.8	80.5
Sheep	2	4.8	67.4	3.0
Goats	8	11.2	87.2	7.1
Camels	0	1.2	33.0	9.4
TLU	8.9	15.9	99.0	100

Only 36 out of the 515 households surveyed in 2014 raised solely cattle (Figure 4), accounting for 7% of the sample. By contrast, 124 households (nearly one quarter of the sample) kept all four types of livestock. The most common combination of livestock types was cattle, sheep, and goats, without camels, kept by 198 households, accounting for 38% of the sample. Another common livestock holding was the combination of cattle and goats, accounting for 16% of sample. An additional 5% of households kept a combination of cattle, goats, and camels. In total, the majority of Boran pastoralists (69%) kept three or more livestock types.

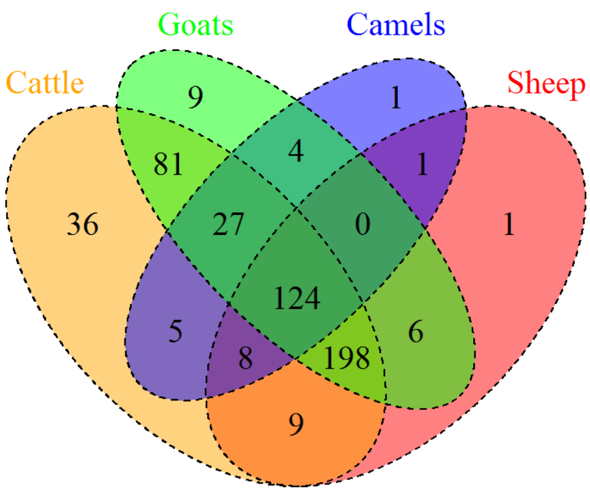

Figure 4. Livestock holdings of 515 pastoral households in the five study sites. The numbers on the Venn diagram represent the number of households owning associated types of livestock. For example, 5 households own only camels and cattle.

Comparison of the 2014 livestock holding data with that of 2000 shows a clear change in livestock holdings at the household level (Table 3). First, over those 15 years, pastoralists experienced a decline in total livestock holdings. The mean TLU declined 18% from 19.4 in 2000 to 15.9 in 2014, and a chi-square test suggests that the change is significant ($\chi^2 = 14.96$, p-value < 0.01). However, the diversity of species within livestock holdings appears to have increased, to a Shannon diversity index of 0.69, more than 10% higher than in 2000. In terms of livestock types, cattle remained dominant, but the number of heads decreased by 20% (from 15.9 head in 2014 to 12.8 in 2014). The average number of camels and sheep also decreased, by 37% and 20% respectively. However, despite overall declines in herd size, pastoralists increased the number of goats from 5.4 to 11.2 head, more than doubling their average holdings.

Table 3. Average household livestock holdings in 2000 and 2014. The numbers in brackets indicate each livestock's contribution to total TLUs held within the household.

Year	Camel	Cattle	Goats	Sheep	TLU
2000	1.9 (12.2%)	15.89 (81.9%)	5.42 (2.8%)	5.84 (3.0%)	19.39
2014	1.2 (9.4%)	12.81 (80.5%)	11.23 (7.1%)	4.8 (3.0%)	15.91

Changes in livestock holdings differ according to socioeconomic status, suggesting alternative strategies for adaptation that depend on household assets. If the households surveyed are divided between those that hold more than 30 TLUs [4] (hereafter livestock-wealthy) and those that hold less (hereafter – livestock-poor), we discern an important difference in adaptive strategy (Figure 5). Both groups reduced the number of cattle while adding more goats to their herds. However, while livestock-wealthy households increased their holdings of goats by only 9.5%, livestock-poor households own 300% more goats. Furthermore, livestock-poor households increased their holdings of sheep but reduced their holdings of camels. By contrast, livestock-wealthy households kept fewer sheep but more camels.

[4] This number corresponds to livestock holdings that allow a pastoralist household to be self-reliant according to indigenous standards of wealth group classification (Tache and Sjaastad, 2010).

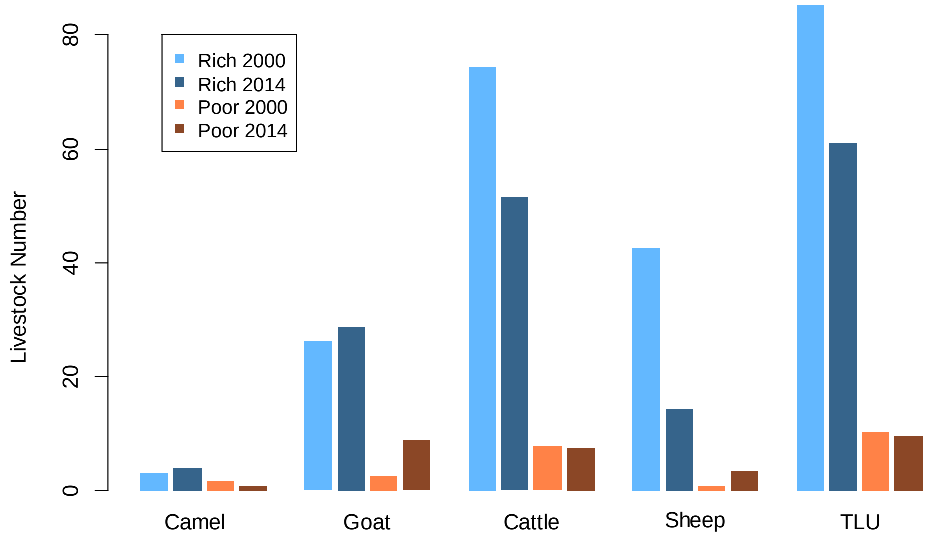

Figure 5. Livestock holdings in 2000 and 2014 by wealth groups.

4.4. Dynamics of vegetation shifts and implications on livestock production

Given the differences in palatability of rangeland plants between livestock types, changes in vegetation composition have different implications for the production of cattle, sheep, goats and camels (Table 4). For cattle, only 3 of the 29 species that were said to be proliferating were known to be highly palatable, resulting in a low mean palatability index of 0.62. By contrast, 10 of the 29 proliferating species are highly palatable for sheep. For goats, 17 of the 29 proliferating species are highly palatable, resulting in the highest mean palatability index at 2.03. For camels, 13 of the proliferating species are highly palatable, but another 12 are barely palatable species.

Table 4. The palatability of proliferating species (n=29) by livestock type.

Livestock	Highly Palatable	Barely Palatable	Unpalatable	Mean Palatability Index
Cattle	3	9	17	0.62
Sheep	10	9	10	1.34
Goats	16	11	2	2.03
Camels	13	12	4	1.76

Across 135 plots, the plant survey encountered a total of 3711 individual herbaceous plants representing 50 species and 2021 individual woody plants representing 75 species. The herbaceous plant pool was dominated by grass species including a total of 2541 individuals (68%). Within the woody plant pool, 986 individuals (39%) were the top ten proliferating species identified by pastoralists. This combination of herbaceous and woody plants served as the starting point of our simulation. The pool of plants showed higher mean palatability to small ruminants at the starting point of simulation, with mean palatability over 2.2 for both goats and sheep. Cattle started with the third highest mean palatability at 1.94. Not surprisingly, because the pool of plants was dominated grass species, the starting mean palatability was the lowest for camels at 1.5 (Figure 6).

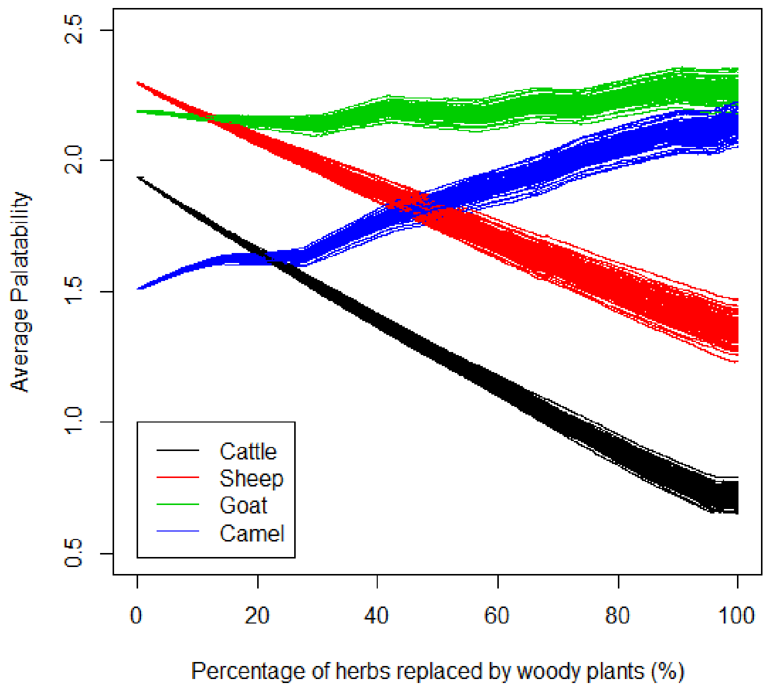

Figure 6. Simulated effects of vegetation shift toward woody vegetation domination on palatability for cattle, sheep, goats, and camels (n=100).

However, as the simulation process proceeded, mean palatability decreased for cattle and sheep, while it increased for goats and camels (Figure 6). The slope rate of linear regressions between average palatability and percentage of herbaceous plants replaced by woody plants were significant for all 100 simulations of four livestock types. However, there are substantial variations in the rate of changes for the four livestock types (Figure S2).

Under any of the projected scenarios of woody plants replacing herbs, the simulation indicates that cattle will suffer a greater reduction in forage palatability compared to the other three livestock types. Their average palatability reduction is 1.22 index units, which is a nearly 66% decrease from the current index at 1.94. This is because cattle strongly prefer herbs to woody plants. Their starting palatability is approximately 0.3 index units lower than sheep and goats; however, by the time all herbs are replaced by woody plants, mean palatability drops to 0.71.

Sheep would also be negatively affected by further proliferation of woody plants. Sheep start with the highest mean palatability because grass species dominate the plant pool, and sheep are known to consume some woody species in addition to herbs. Although sheep can consume a substantial proportion of the proliferating species identified by pastoralists, an increase in woody species availability does not compensate for the loss of the highly palatable herbs. Nonetheless, sheep's ability to consume woody plant species makes them less vulnerable to woody plant proliferation than cattle. Once all herbs are replaced by woody plants, average change in palatability for sheep is 0.95 index units, or a 40% reduction.

Simulation results suggest that goats stand to benefit from a shift toward woody vegetation. Only one simulation showed a decline in the palatability index for goats, while the other 99 suggested increasing index values. On average, palatability for goats increases from 2.19 to 2.27. Although goats find many woody plants palatable, the impact of a vegetation shift on goats is minimal because they are generalists, and will therefore show relatively high palatability indices regardless of species composition.

Finally, the simulation suggests that camels would benefit most were rangelands to become dominated by woody plants. The average palatability index for camels grows from 1.51 to 2.14 as woody plants replace herbs, a 30% increase. For camels, the loss of herbaceous plants would have minimal impact because few are highly palatable, while the increasing abundance of woody species translates into higher mean palatability. Although the mean palatability index for camels is 31% less than goats at the start of the simulation, as woody plants proliferate and replace herbs, camels gradually close the gap to 5.6%.

5. Discussion

Previous research has indicated that the proliferation of woody plants on rangelands is a serious challenge to livestock herding and pastoral livelihood security (Angassa and Oba, 2008). However, our research suggests that the proliferation of woody plants does not necessarily translate into a hopeless situation for pastoralists in Borana. Based on their ethnobotanical knowledge of forage plants and close observation of rangeland vegetation dynamics, our research indicates that pastoralists have been deliberately shifting their livestock holdings to mitigate the negative impact of woody plant proliferation on their livelihoods. Between 2000 and 2014, households have reduced their reliance on cattle by adding more goats and sometimes camels to their herds. Pastoralists' selection of livestock is critical to ensure their food security and the resilience of their ecosystem. As people whose livelihoods depend on forage plants and who interact with rangelands on a daily basis, pastoralists are attuned to even subtle, let alone dramatic, changes in vegetation. Through long-time observation and practice, they have accumulated a rich body of knowledge regarding the preferences of their animals for various forage species. As they observe rangeland vegetation dynamics, for example the replacement of herbaceous with woody plants, they make strategic adaptive decisions to reduce their cattle holdings.

Our results confirm the significance and reliability of indigenous ecological knowledge in terms of informing adaptation to environmental change. Although a palatable species from pastoralists' perspective does not necessarily mean it is nutritious to livestock, it is recognized that palatability is linked to animals' preferences for forage resources (Marten, 1978), and thus can be used to assess the impact of vegetation regime shifts on livestock production systems. Elders' knowledge of plant palatability is particularly valuable, because such knowledge is accumulated over decades of observation. The value of Elders' knowledge is confirmed by the fact that when the group of pastoralists disagreed as to the palatability of a plant, they typically deferred to the Elder present, clearly out of respect for the empirical depth of his or her knowledge.

Our palatability analysis is consistent with previous research that investigated livestock species mortality in times of drought in Borana. The vulnerabilities of livestock to an unprecedented drought in early 2010s demonstrated mean mortality rates of 6.5% for camels, 9.1% for goats, 10.5% for sheep and 26.4% for cattle (Megersa et al., 2014a). In other words, cattle are the most vulnerable species to drought, while camels are the best adapted. Interestingly, our research findings show a similar order in terms of vulnerability, where camels and goats will fare better than sheep and cattle as woody plants replace herbs (Figure 7). Therefore, reducing holdings of sheep and cattle and increasing those of goats and camels is adaptive for not only changes in the vegetation regime, but also for the projected impacts of anthropogenic climate changes, which include increasing frequency and intensity of droughts across the Horn of Africa (Funk et al., 2008).

Over the past 15 years, Boran pastoralists have reduced their cattle holdings and increased those of goats, a shift that clearly corresponds to changes in plant palatability. The flexibility to choose which livestock to keep in their herds is an important way for pastoralists to exercise agency in adapting to environmental change. In pastoral contexts, livelihoods are based on the ecological knowledge of palatability of plants to multiple livestock species, as well as the ability to recognize changes in the abundance of foraging plants. At the core of pastoral livelihoods is the capacity to adapt to such environmental changes in order to meet livestock demands for forage and thereby ensure the food security of the household. Measureable changes in livestock holdings demonstrate how adaptive development (Agrawal and Lemos, 2015) can be achieved in the pastoral contexts, in which risk exposure is mitigated without compromising the fundamentals of pastoralism within savanna ecosystems. However, it is also important to recognize that other factors may have led to changes in livestock holdings. Increasing human population, the adoption of non-pastoral livelihoods, frequent drought, and livestock disease outbreaks may be important additional factors that resulted in declines in average household herd size (Homann et al., 2008).

Our analysis of changes in livestock holdings also suggests that the socioeconomic status of a household affects pastoralists' selection of adaptation strategy. During the period of fieldwork, the price of a sheep or goat ranged from $20 to 30, a cow $200 to 300, and a camel $350 to 450. Although keeping more camels may allow pastoralists to profit and take advantage of woody plant proliferation, diversification into camel herding is more commonly observed among the wealthier households in Borana. Raising and keeping camels involves high start-up investment in terms of labor, knowledge, and wealth accumulation (Leslie and McCabe, 2013). In contrast, households with smaller herds tend to increase their holdings of goats. Raising goats is typically associated with lower social prestige among Boran communities (Boru et al., 2014), but as there are clear benefits of keeping more goats, it appears to be an acceptable (if not ideal) adaptation strategy. Not only are goats generalists and therefore easier to satisfy when there is higher variability in plant species composition on the rangelands, but their production follows a much shorter cycle than camels. It is also important to remember that no culture is static, and so the cultural value of goats may increase as they are seen to contribute to livelihood security in a rapidly changing environment.

Adding goats and camels to herds is not only a response to woody plant proliferation, but also a plausible way to reverse the ecological trend. An increase in browsing intensity by goats and camels is likely to suppress the growth of woody plants and potentially open up more space for grasses and forbs (Tsegaye et al., 2009), and could eventually provide more grazing opportunities for cattle. Maintaining a diverse herd may require more labor and complicate herding strategies, as different animals have distinct needs in terms of forage and water. However, Boran pastoralists have long accepted these challenges, and are clearly taking advantage of diverse livestock holdings to deal with environmental variability. The importance of herd diversity to livelihood security has long been recognized in other pastoral systems (Dahl and Hjort, 1976; Mace and Houston, 1989), and it seems that collective actions to promote herd diversity has the potential to enhance pastoralist well-being and ensure rangeland sustainability.

The conventional definition of resilience emphasizes two capacities of the system, which are to absorb disturbance and maintain the state of the system, and build and increase adaptation through self-reorganization (Carpenter et al., 2001; Folke, 2006; Holling, 1973). However, it is important to emphasize that resilience does not mean resistance to change (Davies et al., 2015). Pastoral systems constantly adapt and readapt themselves to maintain core functionality, i.e. livestock production for food and livelihood security. Despite a deeply-rooted cultural affinity for cattle, Boran pastoralists have already reduced their reliance on them. The strategic decision to adapt to the proliferation of woody species by shifting livestock holdings is a strong indicator of adaptive capacity and resilience (Bennett et al., 2005). Our results therefore support Salick and Ross' (2009) contention that the portrayals of indigenous peoples as 'helpless victims' in the face of environmental change do not hold-up to empirical examination.

Future research efforts need to improve the quantification of plant species' foraging values based on ethnobotanical knowledge. Our index is a starting point that will require further refinement in other contexts. More detailed interviews with pastoralists could identify the seasonal availability of forage plants, as well as their nutritional benefits. Forage species that are available in the dry season are particularly important, as they provide essential nutrients at a critical time of year. Because these species enable livestock to survive periods of stress, perhaps they should be assigned greater values. It will be also necessary to investigate the variability of ethnobotanical knowledge, especially when the research is conducted across ecological zones. Furthermore, measurements of the edible biomass of forage plants could also refine the simulation algorithm to make more accurate predictions as to the effect of vegetation shifts on the availability of palatable forage to specific categories of livestock. In addition, other than vegetation regime shifts, it is important to study other determinants of livestock composition change, such as costs of and barriers to livestock diversification. Finally, it is crucial to consider the unintended consequences of shifting livestock holdings. Camels and goats may not be equal substitutes for cattle and sheep, because they have different implications for pastoralists' household dietary intake, cash income, social status as well as cultural identity in a society that has traditionally centered on cattle herding. Understanding the broader implications of shifting livestock holdings will be crucial to facilitate adaptation to rangeland vegetation regime shifts and maintain the synergy between food security and the sustainability of savanna ecosystems.

6. Conclusions

This research makes three significant contributions to the study of adaptive environmental management by investigating how indigenous ecological knowledge informs adaptation to rangeland vegetation regime shifts in the Borana Zone of southern Ethiopia. First, our research findings show that niche differentiation provides an opportunity to raise multiple livestock types, which can make pastoralists more resilient in face of environmental shocks. Therefore, forage plant species cannot be generalized as either useful or not useful for livestock grazing in general. Pastoralists know that plants have different levels of palatability to cattle, sheep, goats and camels, and policy-makers should recognize such difference in future rangeland management policies.

Second, pastoralism will not necessarily be affected negatively as a result of rangeland vegetation regime shift. Woody plant proliferation has different implications for cattle, sheep, goats, and camels. Our simulation indicates that while cattle and sheep will encounter a decline in average forage palatability, goats will continue to enjoy high palatability, and new woody plants will be much more palatable to camels. By combining their knowledge of plant palatability with close observation of shifting species composition, pastoralists are able to adapt to environmental changes and maintain food and livelihood security. Therefore, rather than signifying the end of pastoralism, the proliferation of woody plants can represent opportunities for positive transformation in the entire pastoral systems.

Third, previous research has shown that household herd size has been in decline over the past decades. While confirming such a trend, our research findings shows significant differences in the pathways of changes in livestock holdings between different socioeconomic groups. Livestock-wealthy households have been reducing the numbers of cattle and sheep while raising more goats and camels. In contrast, livestock-poor households decide to keep more goats, on average tripling their holdings. Thus, future development interventions, especially the post-drought restocking programs, should target those livestock-poor households and facilitate changes in livestock holding that can take advantage of the shifting forage plant palatability on the rangelands.

Based on indigenous ecological knowledge, pastoralists have the potential to adapt to some of the most challenging environmental changes by adjusting their livestock holdings to fit new environmental conditions. In Borana, although cattle are still the dominant livestock type, pastoralists have been adding camels and goats to their herds over the past decades, and only 7% households raised solely cattle in 2014. Such active adaptation to woody plant proliferation is indicative of the resilience of their pastoral system. Resilience does not mean resistance to change. Rather, the ability to observe environmental changes such as rangeland vegetation shifts, and respond to those changes, such as by reshaping herd composition, is key to resilience. Furthermore, despite their deeply-rooted cultural connections to cattle, Boran pastoralists are reducing their reliance on them and raising more livestock that are better adapted to new rangeland conditions. Ultimately, this strategy mitigates the negative impact of woody plant proliferation on livestock production, and may also slow or reverse that proliferation. Thus, indigenous knowledge-based agency is essential to adaptive environmental management.

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Highlights

- Indigenous knowledge informs local solution to global environmental change.
- Vegetation dynamics simulation suggests divergent impacts on different livestock.
- Pastoralists change livestock holdings for adaptive environmental management.