Journal of Arid Environments 128 (2016) 65–72

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Effects of goat grazing and woody charcoal production on xerophytic thickets of southwestern Madagascar

Josoa R. Randriamalala [a], Heriniaina O. Radosy [a], Samuel Razanaka [b], Herizo Randriambanona [b], Dominique Hervé [c, *, 1]

[a] Département des Eaux et Forêts, École Supérieure des Sciences Agronomiques, Université d'Antananarivo, BP 175, Ankatso, Antananarivo 101, Madagascar
[b] Centre National de Recherches sur l'Environnement (CNRE), BP 1739, Antananarivo 101, Madagascar
[c] Institut de Recherche pour le Développement (IRD), UMR GRED (IRD-UPV), BP 64501, 34394 Montpellier Cedex 5, France

ARTICLE INFO

Article history:
Received 15 May 2015
Received in revised form
1 December 2015
Accepted 5 January 2016
Available online xxx

Keywords:
Biomass
Diversity
Shrub
Structure
Regeneration

ABSTRACT

The effects of goat grazing and woody charcoal production are analysed on the diversity, structure, production and regeneration of the xerophytic thickets in southwestern Madagascar. Twenty (20 × 20) m^2 plots were sampled according to soil type (yellow sand and calcareous) and disturbance intensities (low: ungrazed and no woody charcoal production; high: grazed and with woody charcoal production). Woody charcoal production reduced shrub density and biomass and affected species composition on yellow sand soil. In contrast, goat grazing alone did not significantly affect the diversity, mean height, stem and leaf biomass or species composition of xerophytic thickets on calcareous soil. However, shrub regeneration rate was low on both grazed and ungrazed sites. Rainfall variability may be the reason for this low regeneration. Goat grazing at a moderate stocking rate (~1 head per ha) does not affect xerophytic thickets communities (plant diversity, biomass, regeneration rate). This finding indicates a need to (i) emphasize individual case studies that help to manage shrub pasture in semi arid regions, and (ii) avoid broad generalisations about the negative effects of goats on dry vegetation. Furthermore, goat breeding may be a viable alternative to woody charcoal production in these xerophytic thickets.

1. Introduction

With very few resources available in semi-arid environments, populations living in such areas make extensive use of forest resources. Forests provide goods and services such as arable land, food, fodder for livestock (especially small ruminants), timber and fuelwood (Pote et al., 2006; Abule et al., 2007; Songer et al., 2009).

Small ruminants, especially goats, dominate the breeding sector in semi-arid areas and are the main source of meat (Landau et al., 2000). Breeding small ruminants helps to improve the livelihoods of local populations and contributes to regional economies (Mahieu et al., 2008; Schlecht et al., 2011). Many studies have analysed the effects of goat grazing on semi-arid vegetation. Heavy goat grazing reduces shrub cover (Severson and Debano, 1991; Mellado et al., 2003; Jauregui et al., 2008; Bermejo et al., 2012), impairs the potential regeneration of fodder species (Moser-Norgaard and Denich, 2011; Säumel et al., 2011), and, to a lesser extent, species richness (Arévalo et al., 2007). Goat grazing can also negatively affect seed production (Sigwela et al., 2009). The characteristic variability in precipitation in many semi-arid climates usually leads to frequent and prolonged droughts that increase the negative effects of goat grazing on biomass production and plant diversity (Archer, 2004; Bermejo et al., 2012; DeMalach et al., 2014). However, when stocking density is moderate, goat herbivory can stimulate shrub shoot growth (Oba, 1998) and twig biomass production (Oba and Post, 1999). Furthermore, and again under moderate stocking conditions, goats can play a role in seed dispersion in semi-arid ecosystems (Baraza and Valiente-Benuet, 2008; Rosa Garcia et al., 2012). The effects of goat grazing on vegetation thus depend on goat stocking density (Rosa García et al., 2012) and pasture management. Appropriate pasture management, such as one including grazing rotation, can considerably reduce livestock

* Corresponding author. Present address: CNRE, BP1739, Antananarivo 101, Madagascar.
E-mail addresses: rramarolanonana@yahoo.fr (J.R. Randriamalala), vonenina@gmail.com (H.O. Radosy), samuel.razanaka@gmail.com (S. Razanaka), zombanona@yahoo.fr (H. Randriambanona), dominique.herve@ird.fr (D. Hervé).
[1] Permanent address: IRD, UMR GRED (IRD-UPV), BP 64501, 911 avenue Agropolis, 34394, Montpellier Cedex 5, France.

http://dx.doi.org/10.1016/j.jaridenv.2016.01.002
0140-1963/

pressure on pasture vegetation and contribute to biodiversity conservation.

Woody charcoal is the main source of domestic energy in many developing countries, particularly in Africa (Mahiri and Howorth, 2001; Oduori et al., 2011). The cutting and harvesting of trees for charcoal production, and, to a lesser extent, for fuelwood, are important causes of land degradation in semi-arid areas (Wezel and Bender, 2004; Masezamana et al., 2013). However, studies of woody charcoal production practices mainly focus on socio-economic questions (Pote et al., 2006; Naughton-Treves et al., 2007). Assessments of the impact of this activity on forest ecosystem diversity, structure and biomass production are scarce (Naughton-Treves and Chapman, 2002;Kouami et al., 2009). The cutting of trees and shrubs for charcoal production can reduce forest density (Wezel and Bender, 2004; Oduori et al., 2011) and wood carbonisation can be a source of uncontrolled forest fire (Wezel and Bender, 2004).

Although the xerophytic thickets of southwestern Madagascar contain many endemic species and are hot-spots of biodiversity (Moat and Smith, 2007), they are grazed by goats and are a source of woody biomass for charcoal production and fuelwood (Raoliarivelo et al., 2010). However, little is known about the effects of goat grazing and woody charcoal production on Madagascar's dry vegetation, which currently is undergoing degradation and deforestation (Seddon et al., 2000; Masezamana et al., 2013). This paper analyses the impacts of goat grazing and woody charcoal production on xerophytic thickets vegetation. Two working hypothesis were tested: (i) goat grazing alone inhibits the regeneration of xerophytic thickets and reduces the leafy biomass (twigs $\leq$3 cm diameter; stems and leaves) that can be browsed by goats, and (ii) the combination of woody charcoal production and goat grazing reduces the diversity (species richness and evenness) and biomass production of xerophytic thickets.

2. Methods

2.1. Study site

The study site is located in Soalara-Sud commune, Toliara II District, in southwestern Madagascar (Fig. 1). The climate is semi-arid with a mean annual rainfall of about 400 mm (Radosy, 2013). Over 67% of annual precipitation falls between December and February (80–90 mm per month), and the remaining 9 months are mostly dry. The natural vegetation of the study site is composed of xerophytic thickets (XT), characterised by species from the *Didieraceae* and *Euphorbiaceae* families (Cornet and Guillaumet, 1976). The two main soil types are rocky calcareous and yellow sand soils. The local population belongs mainly to the *Tanalana* ethnic group. Small ruminant breeding and woody charcoal (WC) production are the most important sources of income (Raoliarivelo et al., 2010). These two activities are carried out by almost every household in the study site (Rabeniala et al., 2009). Those who possess few small ruminants tend to devote comparatively more time to woody charcoal production (Raoliarivelo et al., 2010).

2.2. Small ruminant breeding in the study site

The breeding of small ruminants (goat, *Capra hircus* and sheep, *Ovis aries*) is the main activity of the local population and is conducted extensively in the study area. Breeders aim to possess as many heads as possible. The density of small ruminants in the study site is about one animal per hectare (Rabeniala et al., 2009). As goats constitute over 85% of the herd (Rabeniala et al., 2009), only goat pastoral practices are considered in this study. Rabeniala et al. (2009) estimated the mean number of goats per household to be 60 (2–180 goats). Goat breeding is oriented first to meat and second to milk production. In the study area, Randriamalala (2014) observed that goat diets are essentially formed by shrub leaves, shoots and twigs and identified the species most consumed by goats to be *Commiphora* sp., *Rhigozum madagascariense* Drake, *Talinella boiviniana* Baillon, *Dicoma incana* (Baker) O. Hoffm, *Diospyros latispathulata* H. Perrier, *Solanum bumeliaefolium* Dunal and *Chadsia flammea* Bojer. Goat pastureland lies on both calcareous and yellow sand soils.

Goatherds release goats from their night pens around 6 or 7 am and lead them first to a nearby water point located less than 1 km from the village (less than a 30 mn walk away) before continuing on to distant pastures. Goatherds leave the herds alone in these pastures during the day, returning around 3–4 pm to lead the herds back to their pens. Goats thus graze pasture for 10–12 h a day (Randriamalala, 2014). Goat pens are located near villages (<2 km) and goat pasture sites lie within a 3 km radius around the pens (Randriamalala, 2014). The distance from villages consequently can be used as a proxy for grazing intensity: xerophytic thickets within a 5 km radius of a village are grazed by goats while those located outside this radius are not.

2.3. Woody charcoal production in the study site

Woody charcoal (WC) production is an important source of income for the population living in the study site. All of the production is concentrated in Soalara commune and exported by pirogue from Soalara to the town of Toliara, located about 25 km away by sea (Ramaroson, 2014). WC production is initiated by cutting the trunks and main stems of trees and shrubs with hard wood and drying them for 1–7 days. The wood is then carbonised in a furnace consisting of a hole about 0.8 m deep, 3 m long and 2 m wide. The wood is put into the hole, with bigger trunks placed on top of smaller ones to make it easier to light the fire, forming a pile rising about 1 m above the ground. Once the fire is lit, the pile of wood is covered first by branches and then by soil. The carbonisation process takes 7–10 days. WC is produced exclusively on yellow sand soils because rocks in calcareous soils make it difficult to dig WC furnaces (Radosy, 2013).

WC production sites currently are located less than 4 km from the villages of Soalara commune and lie in the eastern part of the commune. The villages are located in the western part near the Mozambique Channel (Fig. 1). WC producers hire carts pulled by zebus to transport the charcoal from the production sites to Soalara harbour for export. To remain profitable for the producer, the round trip journey must be made within a day (Raoliarivelo et al., 2010). Therefore, distance from villages can again be considered as a proxy for the intensity of disturbance caused by WC production: it decreases when distance from a village increases. Distance from villages consequently is a proxy for both grazing intensity and intensity of disturbance caused by WC production.

As goat grazing activity, fuelwood for cooking is also collected on sites near the villages of the commune, both on yellow sand and calcareous soils. However, the corresponding woody biomass was not estimated in this study, which focuses only on woody charcoal. We assumed that the quantities of wood collected in this framework, mainly dead trunks, are limited by the family needs, compared to the biomass collected for WC production, which is exported to the nearest town.

2.4. Vegetation survey

Twenty (20 $\times$ 20) m^2 plots were randomly sampled according to soil types and disturbance intensities combining goat grazing and woody charcoal production. The most disturbed sites are located

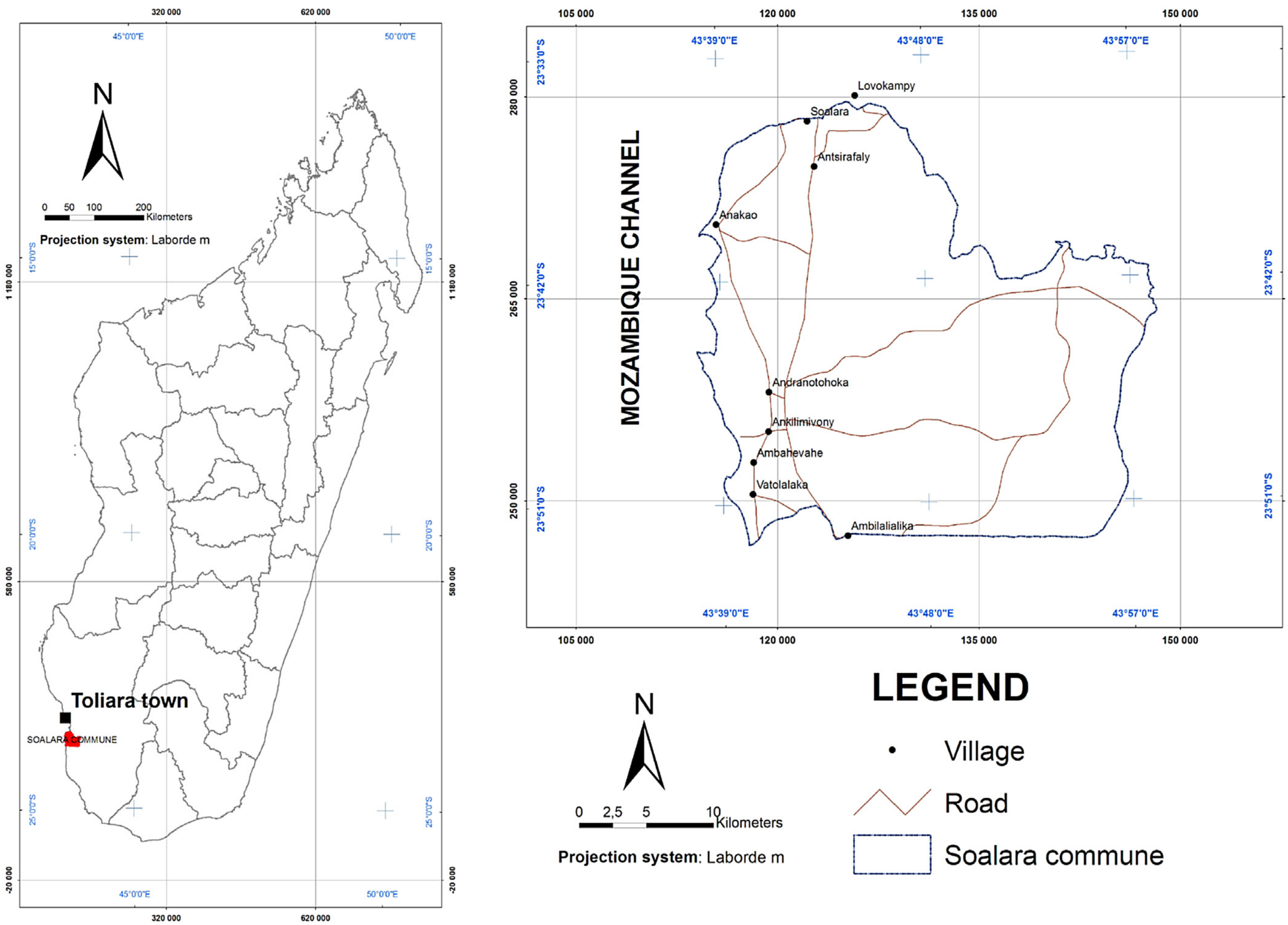

Fig. 1. Study site location.

near villages ($\leq$5 km) where goat grazing and WC production occur. Sites located far from the villages (>5 km) are less disturbed because they are not grazed or used for WC production. However, these sites are used by local people to harvest timber to build houses and pirogues.

A census of all trunks of individual shrubs greater than 1.3 m in height was made on the (20 $\times$ 20) m^2 plots. These shrubs form the overstory vegetation. Each (20 $\times$ 20) m^2 plot was then divided into four (10 $\times$ 10) m^2 plots. One of these plots was randomly sampled to make a census of individuals less than 1.3 m in height, called young individuals, which belong to the understory vegetation. Lianas measuring less than 20 cm in length also belong to this category. The line intercept method (Daget and Poissonet, 1971; Barabesi and Fattorini, 1998) was used to evaluate herbaceous plant cover along three 10 m lines that were randomly drawn in the (20 $\times$ 20) m^2 plot. The presence or absence of herbaceous plants was checked every 10 cm (Daget and Poissonet, 1971). Two (4 $\times$ 4) m^2 plots were randomly sampled in the (20 $\times$ 20) m^2 plot and all above-ground biomass was harvested. Every plant in the (4 $\times$ 4) m^2 plot was cut at ground level and sorted into two subsets ($\leq$3 cm and >3 cm stem diameter) before being weighed. Plant parts from the two subsets were oven-dried at 85 °C for 72 h. The following diversity and structure indicators were calculated for each plot: (1) species richness of overstory vegetation, which is the total number of species corresponding to individuals higher than 1.3 m in each sample unit; (2) evenness of shrubby species abundance belonging to overstory vegetation (Pielou, 1966). The Pielou index is described as $J = H/Hmax$, where H is the Shannon–Weaver index and Hmax is the maximum value of H in the community, if all of the plant species are equally frequent; (3) liana density of overstory vegetation (Dl 400 m^{-2}), which can be seen as an indicator of forest age after disturbance because old-growth forests usually contain many more types of life forms such as liana and epiphyte than secondary forests (Guariguata and Ostertag, 2001); (4) tree and shrub density of overstory vegetation; (5) mean total height of overstory vegetation; (6) species richness corresponding to young individuals belonging to understory vegetation; (7) evenness of species abundance belonging to understory vegetation (Pielou, 1966); (8) mean height and (9) density of young tree and shrub individuals in understory vegetation (<1.3 m height); (10) density of young liana individuals belonging to understory vegetation ($\leq$20 cm length); (11) cover of herbaceous plants, calculated as: $Ch = 100 \times N/(N+n)$, where N is the number of herbaceous plants intercepted and n the number of bare soil intercepted, along the three 10 m lines; and (12) regeneration rate of each shrub species found in the (10 $\times$ 10) m^2 plot, calculated as: $RR_i = n_{spi}x100/N_{spi}$ where n_{spi} is the number of young individuals (<1.3 m height) belonging to the i^{th} species in the (10 $\times$ 10) m^2 plot and N_{spi} is the number of adult individuals ($\geq$1.3 m height) belonging to the same species in the same plot (Rothe, 1964; Carrière et al., 2008; Rabarison et al., 2013). The mean regeneration rate per plot was also calculated as: $RR = (1/N) \times \sum RR_{i(i=1\text{-}N)}$ where RR is the mean regeneration rate of the

(10×10) m^2 plot; RR_i is the regeneration rate of the i^{th} species in the same (10×10) m^2 plot and N is the species number in the (10×10) m^2 plot.

2.5. Statistical analysis

Correspondence analysis was applied to the plot-species data (over and understory) to analyse species distribution according to soil and disturbance factors (Xlstat 6.03; Addinsoft, 1995–2008). One-way ANOVA with Ryan–Einot–Gabriel–Welsch Q tests (Bender and Lange, 2001), comparing the four soil type-distance from villages combinations (calcareous soil far or close to villages, and sandy soil far or close to villages), was used to analyse variations of vegetation diversity and structure variables when assumptions for parametric tests were met; if not Kruskal–Wallis non-parametric test was used with Dunn's test (Dunn, 1964) as *post hoc* test (Xlstat 6.03). By examining post-hoc comparison results, these tests allow the analysis of the single effects of separately soil type and disturbance intensity and the combined effects of both soil type and disturbance intensity on vegetation diversity and structure. Our statistical protocol could not distinguish between the effects of goat grazing from those of woody charcoal production on vegetation structure and diversity, at least on yellow sand soil that is where both activities occur and this is the main reason why we did not perform a two-way factorial ANOVA considering the statistical interaction between grazing and WC production.

Two-part tests were run to analyse variations in regeneration rates by distance from villages and by soil type (Lachenbruch, 2001; Delucchi and Bostrom, 2004). Regeneration rate data presented a large proportion of zero values (>50%), which suggests that the mean of such data may not be the most appropriate summary statistic (Delucchi and Bostrom, 2004). Two-part tests are combined tests that take into account the fact that the sum of two statistics with χ^2 distribution is a χ^2-distributed statistic with degrees of freedom equal to the sum of the degrees of freedom from each test (Delucchi and Bostrom, 2004). The null hypotheses of the two-part test are (1) the equality of zero proportion of the k samples ($k \geq 2$), and (2) the equality of means of non-zero values of the k samples. For our data, a two-proportion Z-test (TPZ) with one degree of freedom was used to compare zero proportions, and a Kolmogorov–Smirnov test (KS) was used to compare the means of non-zero values (Lachenbruch, 2001; Delucchi and Bostrom, 2004). The two-part test statistic (TPS) is given by the following formula: $TPS = Z^2 + W^2$, where Z is the TPZ statistic, W is the KS statistic and TPS is the χ^2-distributed with 2 degrees of freedom.

3. Results

3.1. Overstory species distribution (≥1.3 m)

Overstory species distribution was analysed according to soil types and disturbance intensities using Correspondence Analysis (CA). The first axis of the CA (15% of total inertia; Fig. 2) opposed XT on yellow sand soil far from villages (with low disturbance) to XT on calcareous soil. The main species characterising XT on yellow sand soil far from villages (with low disturbance) were: *Gyrocarpus americanus* Jacq. (15.13%); *R. madagascariense* Drake (7.47%); *Commiphora lasiodisca* H. Perrier (5.38%); *C. flammea* Bojer. (4.18%); *Isolona madagascariensis* (Baill.) Engl. (3.60%); *Didierea madagascariensis* Baill. (2.34%); *Commiphora simplicifolia* H. Perrier (1.87%); *Ampelosycios scandens* Thouars (1.02%); *Dioscorea heteropoda* Baker (0.93%); *Acacia bellula* Drake (0.91%) and *Cayratia triternata* (Baker) Desc. (0.82%). The main species characterising XT on calcareous soil, whatever the distance from villages, were: *Chadsia* sp. (4.33%); *Securinega perrieri* Léandri (4.20%); *Commiphora lamii*

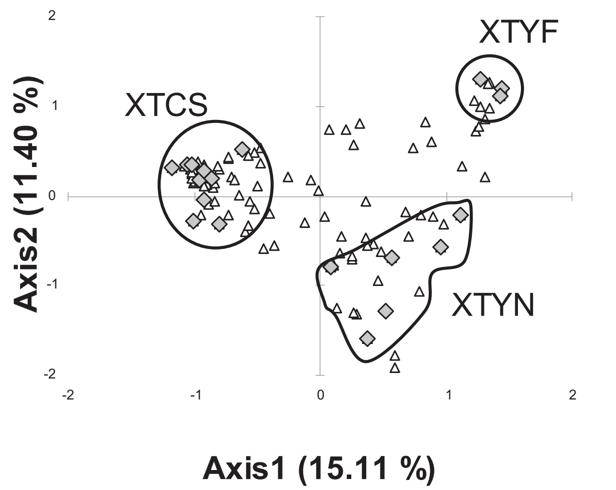

Fig. 2. Correspondence analysis of plot/species data for overstory vegetation. Numbers between brackets indicate the proportion of inertia explained by the considered factor (axis). XTYF: Xerophytic thickets on yellow sand soil far from villages; XTYN: Xerophytic thickets on yellow sand soil near villages; XTCS: Xerophytic thickets on calcareous soil; grey diamond stands for plots; white triangle stands for species.

H. Perrier (3.60%); *Diospyros manampetsae* H. Perrier (2.77%); *Operculicarya* sp. H. (2.60%); *Commiphora marchandii* Engler (2.38%); *Sclerocarya birrea* (A. Rich.) Hochst. (2.19%); *Ormocarpum bernierianum* (Baill.) Du Puy & Labat (1.89%); *Cedrelopsis grevei* Baill. (1.89%); *Lepidagathis grandidieri* Benoist (1.47%); *Dichrostachys lugardae* N.E. Br. (1.29%); *Alluaudia comosa* Drake (1.02%); *Euphorbia fiherenensis* Poisson (0.97%) and *Dicraeopetalum mahafaliense* (M. Peltier) Yakovlev (0.91%).

The second axis of the CA (11.4%; Fig. 2) separated XT on yellow sand soil far from villages from XT near villages. Species characterising the XT near villages (highly disturbed XT) were: *A. bellula* (29.02%); *Terminalia gracilipes* Capuron (6.18%); *D. madagascariensis* (5.69%); *Dalbergia xerophila* Bosser (5.02%); *Pristimera bojeri* (Tul.) N. Hallé (4.11%); *Commiphora* sp. (3.50%); *Digoniopterys microphylla* Arènes (1.48%); *Stereospermum euphorioides* Candolle (1.43%); *S. bumeliaefolium* Dunal (1.23%); *Indigofera perrieri* R. Vig. (1.21%); *Helinus ovatus* Meyer (1.20%); *Neobeguea mahafaliensis* Leroy (0.88%) and *Operculicarya decaryi* H. Perrier (0.78%).

Soil was the main driver of XT overstory species distribution. However, the combination of WC production and goat grazing significantly affected the distribution of XT species on yellow sand soil.

3.2. Xerophytic thickets overstory (≥1.3 m height) diversity and structure

Mean species richness ranged from 23 to 34 and did not vary significantly with disturbance intensity ($F = 3.032$; $df = 3$; $p = 0.060$; Table 1), although the mean species richness of XT far from villages seemed to be higher. Mean of evenness index did not vary with disturbance intensity even if it is globally higher on calcareous soil ($F = 4.882$; $df = 3$; $p = 0.013$; Table 1). The means of xerophytic thickets shrub densities far from villages were significantly higher than the means of shrub densities near villages ($F = 7.714$; $df = 3$; $p = 0.002$; Table 1). The means of liana density did not vary significantly ($\chi^2 = 4.864$; $df = 3$; $p = 0.182$; Table 1). The mean height of XT on yellow sand soil far from villages was significantly higher than the mean height of other XT ($F = 25.470$; $df = 3$; $p < 0.001$; Table 1). Finally, herbaceous plant cover of XT on calcareous soils significantly decreased when distance to villages

Table 1
Global variation of overstory vegetation diversity and structure by the four combinations of soil type and disturbance intensity. Values represent mean ± standard error of diversity and structure parameters for each treatment. ANOVA followed by Ryan–Einot–Gabriel–Welsch Q test was used for: species richness, evenness index, mean height and shrub density. Kruskal–Wallis test followed by Dunn's test as multiple comparison tests was used for liana density and herbaceous plant cover. Values in a column with different letters indicate significant differences among treatments after post-hoc comparisons at a significance level of 0.05.

Type of soil	Disturbance intensity	n	Species richness 400 m^{-2}	Evenness index	Mean height (m)	Shrub density 400 m^{-2}	Liana density 400 m^{-2}	Herbaceous plant cover (%)
Yellow sand soil	Low (far from villages)	5	28 ± 3a	0.76 ± 0.04a	3.73 ± 0.25b	145 ± 26a	34 ± 10a	22.27 ± 4.29 ab
	High (near villages)	5	25 ± 3a	0.83 ± 0.03 ab	2.35 ± 0.13a	80 ± 9b	24 ± 7a	22.73 ± 3.27 ab
Calcareous soil	Low (far from villages)	5	34 ± 2a	0.86 ± 0.01b	2.31 ± 0.04a	170 ± 15a	17 ± 2a	12.60 ± 1.61a
	High (near villages)	5	23 ± 2a	0.87 ± 0.02b	2.22 ± 0.08a	80 ± 10b	11 ± 3a	30.47 ± 4.75b
P			0.060	0.013	<0.001	0.002	0.182	0.040

increased ($\chi^2 = 8.313$; df = 3; p = 0.040; Table 1).

The combination of woody charcoal production and goat grazing affected the structure (in terms of mean height, density and biomass) of xerophytic thickets.

3.3. Above-ground biomass

The mean above ground biomass of the ≤3 cm trunk subset of XT did not vary significantly ($\chi^2 = 7.720$; df = 3; p = 0.052; Table 2). The mean above ground biomass of the >3 cm trunk subset of XT on yellow sand soil far from villages was significantly higher than the mean above ground biomass of other XT (F = 17.532; df = 3; p < 0.001; Table 2). The total above ground biomass on yellow sand soil was higher than the above ground biomass of the three other treatments (F = 13.100; df = 3; p = 0.001; Table 2). The high value of above ground biomass of less disturbed XT on yellow sand soil (far from villages) can be linked to the high shrub density associated with this treatment (Table 1). However, high shrub density of XT on calcareous soil far from villages did not lead to a significantly high above ground biomass value in the same soil type. The combination of WC production and goat grazing did not affect stem and leaf biomass (≤3 cm fraction) while it contributed to reducing the above ground biomass of XT on yellow sand soil. However, goat grazing alone did not affect stem and leaf biomass or above ground biomass of XT on calcareous soil.

3.4. Understory species distribution, diversity and structure

Understory species distribution was analysed using a second Correspondence Analysis (CA). The first axis of the CA (12% of total inertia; Fig. 3) opposed plots on calcareous soil to those on yellow sand soil). *Suregada boiviniana* Baillon (14.04%); *Ruellia* sp. (7.45%); *Chadsia* sp. (7.16%); *Cedrelopsis Grevei* Baill. (5.64%) and *Operculicarya* sp. H. (1.34%) characterised XT understory on calcareous soil. XT understory on yellow sand soil was characterised by *Barleria humbertii* Benoist (13.09%); *A. scandens* Thouars (3%); *Croton geayi* Leandri (2.48%); *G. americanus* (2.29%); *R. madagascariense* Drake (1.91%); *D. madagascariensis* (1.62%); *D. incana* (Baker) O. Hoffm. (1.43%) and *P. bojeri* (Tul.) N. Hallé (1.43%). The second axis of the CA (10.68% of total inertia) did not allow species to be distinguished according to the two types of soil or the two distances from villages (Fig. 3). Thus, soil was shown to be the only driver of xerophytic thickets understory species distribution. Xerophytic thickets understory diversity and structure parameters did not vary significantly (p > 0.05; Table 3). Woody charcoal production and goat grazing did not affect XT understory vegetation.

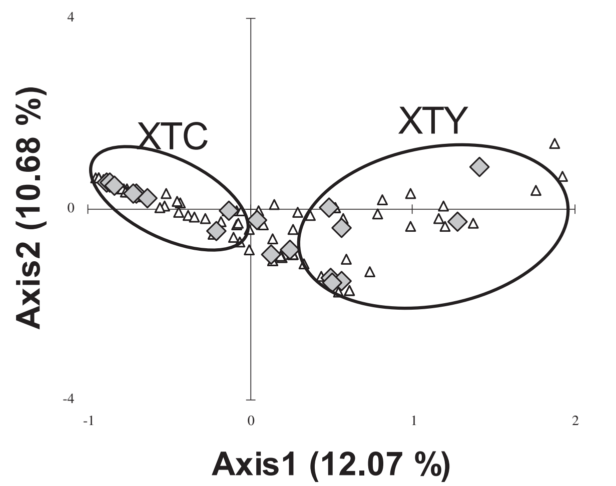

Fig. 3. Correspondence analysis of plot/species data for understory vegetation. Numbers between brackets indicate the proportion of inertia explained by the considered factor (axis). XTY: Xerophytic thickets on yellow sand soil; XTC: Xerophytic thickets on calcareous soil; grey diamond stands for plots; white triangle stands for species.

Table 2
Variation of above ground biomass by the four combinations of soil type and disturbance intensity. Values represent mean ± standard error of biomass (kg m^{-2} of dry mass) for each treatment. ≤3 cm stands for leafy biomass that can be browsed by goats, >3 cm stands for woody biomass. ANOVA followed by Ryan–Einot–Gabriel–Welsch Q test was used for woody (>3 cm) and overall biomass. Kruskal–Wallis test followed by Dunn's test as multiple comparison tests was used for leafy biomass (≤3 cm). Values in a column with different letters indicate significant differences among treatments after post-hoc comparisons at a significance level of 0.05.

Type of soil	Disturbance intensity	n	Biomass		
			≤3 cm	>3 cm	Total
Yellow sand soil	Low (far from villages)	10	1.71 ± 0.20a	7.10 ± 1.03b	8.81 ± 1.12b
	High (near villages)	10	1.04 ± 0.30a	1.15 ± 0.35a	2.19 ± 0.61a
Calcareous soil	Low (far from villages)	10	1.65 ± 0.25a	2.56 ± 0.71a	4.21 ± 0.93a
	High (near villages)	10	1.08 ± 0.22a	1.99 ± 0.31a	3.07 ± 0.45a
P			0.052	<0.001	0.001

Table 3
Global variation of understory vegetation diversity and structure by the four combinations of soil type and disturbance intensity. Values represent mean ± standard error of diversity and structure parameters for each treatment. ANOVA followed by Ryan–Einot–Gabriel–Welsch Q test was used for: species richness, evenness index, mean height and shrub density. Kruskal–Wallis test followed by Dunn's test as multiple comparison test was used for liana density. Values in a column with different letters indicate significant differences among treatments after post-hoc comparisons at a significance level of 0.05. None of the variables displayed significant differences across treatments.

Type of soil	Disturbance intensity	n	Species richness (100 m^{-2})	Evenness index	Mean height (m)	Shrub density (100 m^{-2})	Liana density (100 m^{-2})
Yellow sand soil	Low (far from villages)	5	8 ± 2a	0.78 ± 0.04a	0.32 ± 0.04a	24 ± 8a	10 ± 6a
	High (near villages)	5	9 ± 2a	0.67 ± 0.11a	0.39 ± 0.07a	114 ± 88a	18 ± 13a
Calcareous soil	Low (far from villages)	5	15 ± 2a	0.77 ± 0.05a	0.38 ± 0.06a	67 ± 18a	3 ± 2a
	High (near villages)	5	13 ± 2a	0.76 ± 0.06a	0.26 ± 0.03a	60 ± 16a	6 ± 4a
P			0.090	0.697	0.392	0.332	0.751

3.5. Regeneration

Regeneration rates of XT shrub species were low overall (<100%). Regeneration rate means did not vary significantly with distance from villages or soil type (Table 4). Woody charcoal production and goat grazing did not affect XT regeneration rates.

4. Discussion

4.1. Soil, main factor driving species distribution

Correspondence Analysis (CA) applied to overstory vegetation identified three classes of XT: (i) XT on yellow sand soil near villages, (ii) XT on yellow sand soil far from villages, and (iii) XT on calcareous soil. CA applied to understory vegetation identified two vegetal clusters: (i) those on yellow sand soil and (ii) those on calcareous soil. Soil is the main driver of XT species distribution. Previous research has shown that abiotic factors like soil and rainfall are the main drivers of semi-arid vegetation communities (Parker, 1991; Anderson and Hoffman, 2007; Zemmrich et al., 2010). The effects of woody charcoal production and goat grazing can only be detected on XT on yellow sand soil. Goat grazing did not affect XT vegetation communities on calcareous soil, where woody charcoal is not produced.

4.2. Xerophytic thickets structure affected by woody charcoal production and goat grazing

In the study site, woody charcoal production and goat grazing affected the structure of XT on yellow sand soil (shrub density and height). In many semi-arid areas ($P < 600$ mm $year^{-1}$), shrub density has been widely observed to decrease as distance to villages decreases (see Pote et al., 2006 in South Africa; Oduori et al., 2011 in northeastern Somalia; Wezel and Bender, 2004 in Cuba). Species richness, evenness index and mean height of XT on calcareous soil did not vary significantly with grazing intensity. These results confirm those of Anderson and Hoffman (2007), who showed that sheep and goat grazing in a semi-arid area in South Africa ($P < 400$ mm $year^{-1}$) did not lead to decreases in species richness. Similarly, Fernandez-Lugo et al. (2009) did not find significant increases in species richness during a four-year period when goats were not allowed to graze Canary Island pasture vegetation ($P = 450$ mm $year^{-1}$). In the same way, no significant differences were found between the mean heights of browsed and unbrowsed semi-arid vegetation consumed by goats in Kenya (Oba and Post, 1999). It has been generally observed that when an ecosystem experiences disturbance, species composition evolves while variables such as species richness and productivity remain stable (Briske et al., 2003). It has even been hypothesised that species fluctuations may represent a compensatory mechanism that contributes to ecosystem stability (homeostasis) in numerous ecosystems (Ernest and Brown, 2001).

However, the mean shrub density of XT on calcareous soil significantly increased with distance from villages. This may be due to the collection of fuelwood that occurs on sites near villages, both on yellow sand soil and calcareous soil. In fact, goats may cause decreases in plant cover (Severson and Debano, 1991; Mellado et al., 2003; Allsopp et al., 2007) by (i) eating leaves of shrub or woody forb (Ramirez, 1999) and to a lesser extent shrub twigs, and (ii) killing some seedlings belonging to fodder species (Moser-Norgaard and Denich, 2011; Säumel et al., 2011). However, goats do not eat the trunks of ligneous fodder species (shrub or forb; Randriamalala, 2014). They therefore cannot be the direct cause of decreases in shrub density. Conversely, herbaceous plant cover is higher in calcareous soil where goat grazing alone occur; this is because decreased shrub plant cover resulting from a decrease of shrub species density favours the development of herbaceous species (Ayyad and Elkadi, 1982; Jauregui et al., 2008). Moreover, herbaceous plants are not important in goat diets in terms of quantity (intake weight) and few herbaceous species are found in the consumed fodder species (Ramirez, 1999; Cissé et al., 2002; Randriamalala, 2014). Consequently, goat grazing does not affect herbaceous plant cover or hinder its development.

4.3. Woody charcoal production reduces above-ground biomass

Goat grazing did not affect stem and leaf biomass (≤3 cm diameter). This result is supported by those of Oba and Post (1999), who showed that goat herbivory stimulates twig biomass production of shrub fodder species in arid vegetation in Kenya ($P < 200$ mm $year^{-1}$), and confirms that goats do not contribute to shrub density decrease in the study site. The edible biomass intake

Table 4
Xerophityc thickets species regeneration rate. Values without brackets represent the mean regeneration rate (%). Values between brackets are first quartile (%), median (%) and third quartile (%) of mean species regeneration rate, respectively.

Distance from villages	Type of soil			*p* by soil type
	Yellow sand soil	Calcareous soil	χ^2 of Two-part test by soil type	
Near villages	121 (0; 0; 56)	235 (0; 43; 175)	2.18	>0.05
Far from villages	44 (0; 0; 50)	99 (0; 22; 60)	1.06	>0.05
χ^2 of Two-part test by distance from villages	0.55	0.85		
p by distance from villages	>0.05	>0.05		

of the actual goat herd (about 1 individual ha^{-1}) does not exceed the stem and leaf biomass production of XT on the study site. However, trunk biomass (>3 cm diameter) and total above ground biomass on yellow sand soil increased with distance from villages. Such above ground biomass variation can be attributed to WC production activity that occurs essentially on yellow sand soil. This activity contributes to eradicating shrub species with hard wood, indicating that WC production on the study site is not sustainable. Species suitable for WC production may disappear within a finite period that can be estimated (Ramaroson, 2014).

4.4. Poor regeneration of xerophytic thickets

The diversity and structure of XT understory and its regeneration were not affected by goat grazing and WC production. The means of XT species regeneration rates did not vary significantly with distance from villages or soil type.

These results confirm those of Oba (1998), who showed that goat browsing at a moderate stocking density (13 tropical livestock units per km^{-2} equivalent to about 1.5 goat ha^{-1}; 1 TLU = 11–12 goats) in an arid zone in Kenya (P < 250 mm year^{-1}) did not negatively affect juvenile shrubby fodder species (*Acacia tortilis* (Forssk.) Hayne). Oba and Post (1999) also found that goat grazing at stocking densities ranging from 5 to 25 TLU km^{-2} stimulated the twig biomass production of shrubby fodder species in the same area. However, our results contradict those of Moser-Norgaard and Denich (2011), who showed that browsing livestock, mainly goats, contribute to removing the seedlings of fodder tree species along ephemeral rivers in Namibia (P = 15–75 mm year^{-1}). The extreme aridity of their study site (P < 100 mm year^{-1}) may be the cause of this weak resilience of tree fodder species to livestock, whose density was not high (2.1–8.5 TLU km^{-2}). A concentration of browsing pressure on the main water channels of these ephemeral Namibian rivers may be the cause of the loss of seedlings (Moser-Norgaard and Denich, 2011).

Mean species regeneration rates in the study site (44–235%) are comparable to the tree seedling/large tree ratio associated with 8 shrub species of arid subtropical thickets in South Africa (0–1200%; P = 300 mm year^{-1}; Adie and Yeaton, 2013), the sapling/non-sapling ratio associated with the 7 most abundant ligneous species of semi-arid woody vegetation in Senegal (0–367%; P < 400 mm year^{-1}; Vincke et al., 2010), and the juvenile/adult plant ratio associated with 2 fodder species in Namibia (25–127%; P < 100 mm mm year^{-1}; Moser-Norgaard and Denich, 2011). However, XT regeneration is poor even in sites with low disturbance (ungrazed and no WC production). In fact, species regeneration rates were generally under 100%, and half of the species belonging to overstory vegetation on yellow sand soil and a quarter of those on calcareous soil were associated with no seedlings. Furthermore, half of all species belonging to overstory vegetation were associated with a regeneration rate of less than 50%. This poor regeneration of XT is not due to goat grazing and may be explained by rainfall variability and climate aridification. In fact, global climate aridification in Ferlo, Senegal, during the 20th century, caused woody vegetation cover degradation and resulted in global tree density depletion (Vincke et al., 2010). Moreover, rainfall variability causing drought periods favours tree/shrub mortality, especially among young individuals (≤5 cm diameter at breast height; Suresh et al., 2010). Arid ecosystems (P < 300 mm) are so constrained by the amount and variability of precipitation that these events may influence plant and animal dynamics more than plant competition and plant–herbivore interactions (Briske et al., 2003). The southwestern region of Madagascar underwent climate aridification in the late Holocene period, which caused the extinction of fauna species and important changes in vegetation (Burney, 1993). This aridification process may be continuing today and be weakening vegetation resilience, which may result in density reduction and seedling mortality. When goat grazing alone is considered, the dynamics of xerophytic thickets appear to be those of a *non-equilibrium* system which is driven primarily by stochastic abiotic and external factors, such as variable rainfall, resulting in highly variable and unpredictable primary production (Briske et al., 2003; Vetter, 2005). To distinguish the effects of goat grazing from those of climate variation on the xerophytic thickets ecosystem, rainfall variability in the study site over the last 40–50 years should be analysed, repeated measures of vegetation parameters (diversity, structure and species composition) over time should be taken, and annual rainfall measured over at least two years.

5. Conclusion

Woody charcoal production reduced shrub density and above ground biomass of XT on yellow sand soil and affected XT species distribution. Our second hypothesis regarding the weak resilience of XT to WC production activity was partially validated and it was shown that this activity is unsustainable. On the other hand, goat grazing alone was not found to significantly affect XT species regeneration or stem and leaf biomass production. The first hypothesis about negative effects of goat grazing on XT vegetation therefore was not validated. Nevertheless, the regeneration of XT is poor; the number of seedlings is insufficient to replace existing mature individuals when they become senescent and die. XT in the study site are formed by ageing vegetal communities which may disappear as existing individuals die. Goat grazing is not the cause of this poor regeneration because it also occurs on ungrazed sites. We hypothesize that climate aridification is causing this poor XT regeneration. To test this hypothesis, rainfall variability should be analysed, and further vegetation studies should be conducted. To highlight the effects of interannual rainfall variability, these studies should measure diversity, structure, biomass and floristic composition at least two different years.

Author contribution

J.R.R. designed the field work, collected and analysed the data, wrote the manuscript.

H.O.R. collected and analysed the data, wrote the manuscript.

S.R. and H.R. contributed to site selection with previous research on dry forest.

D.H. validated the protocol and organized the field work as head of FPPSM project, wrote the manuscript.

And all contributed to the interpretation of results and comments on the manuscript.

Acknowledgement

We wish to thank the FPPSM Project “Forests, Parks, Poverty in South Madagascar” from FSP/PARRUR, French Ministry of Foreign Affairs MAE (2011-2014), which financed the fieldwork.

References

Abule, E., Snyman, H.A., Smit, G.N., 2007. Rangeland evaluation in the middle Awash valley of Ethiopia: II. Woody vegetation. J. Arid. Environ. 70, 272–292.

Adie, H., Yeaton, R.I., 2013. Regeneration dynamics in arid subtropical thicket, South Africa. S. Afr. J. Bot. 88, 80–85.

Allsopp, N., Gaika, L., Knight, R., Monakisi, C., Hoffman, M.T., 2007. The impact of heavy grazing on an ephemeral river system in the succulent karoo, South Africa. J. Arid. Environ. 71, 82–96.

Anderson, P.M.L., Hoffman, M.T., 2007. The impacts of sustained heavy grazing on plant diversity and composition in lowland and upland habitats across the Kamiesberg mountain range in the Succulent Karoo, South Africa. J. Arid.

Environ. 70, 686–700.
Archer, E.R.M., 2004. Beyond the "climate versus grazing" impasse: using remote sensing to investigate the effects of grazing system choice on vegetation cover in the eastern Karoo. J. Arid. Environ. 57, 381–408.
Arévalo, J.R., Chinea, E., Barquin, C., 2007. Pasture management under goat grazing on Canary Islands. Agric. Ecosyst. Environ. 118, 291–296.
Ayyad, M.A., Elkadi, H.F., 1982. Effect of protection and controlled grazing on the vegetation of a Mediterranean desert ecosystem in northern Egypt. Vegetatio 49, 129–139.
Barabesi, L., Fattorini, L., 1998. The use of replicated plot, line, and point sampling for estimating species abundance and ecological diversity. Environ. Ecol. Stat. 5, 353–370.
Baraza, E., Valiente-Benuet, A., 2008. Seed dispersal by domestic goats in a semiarid thornscrub of Mexico. J. Arid. Environ. 72, 1973–1976.
Bender, R., Lange, S., 2001. Adjusting for multiple testing-when and how? J. Clin. Epidemiol. 54, 343–349.
Bermejo, L.A., de Nascimento, L., Mata, J., Fernández-Lugo, S., Camacho, A., Arévalo, J.R., 2012. Responses of plant functional groups in grazed and abandoned areas of a Natural Protected Area. Basic Appl. Ecol. 13, 312–318.
Briske, D.D., Fuhlendorf, S.D., Smeins, F.E., 2003. Vegetation dynamics on rangelands: a critique of the current paradigms. J. Appl. Ecol. 40, 601–614.
Burney, D.A., 1993. Late Holocene environmental change in arid southwestern Madagascar. Quat. Res. 40, 98–106.
Carrière, S.M., Randrianasolo, E., Hennenfent, J., 2008. Aires protégées et lutte contre les bioinvasions : des objectifs antagonistes ? Le cas de *Psidium cattleianum Sabine (Myrtaceae)* autour du parc national de Ranomafana à Madagascar. Vertigo 8, 1–14.
Cissé, M., Lya, I., Nianogo, A.J., Sané, I., Sawadogo, J.G., N'Diaye, M., Awad, C., Fall, Y., 2002. Grazing behavior and milk yield of Senegalese Sahel goat. Small Rumin. Res. 43, 85–95.
Cornet, A., Guillaumet, J.L., 1976. Divisions floristiques et étages de végétation à Madagascar. Cahier ORSTOM. Série Biol. 9, 35–42.
Daget, P., Poissonet, J., 1971. Une méthode d'analyse des prairies, critères d'application. Ann. Agron. 22, 5–41.
Delucchi, K.L., Bostrom, A., 2004. Methods for analysis of skewed data distributions in psychiatric clinical studies: working with many zero values. Am. J. Psychiat 161, 1159–1168.
DeMalach, N., Kigel, J., Voet, H., Ungar, E.D., 2014. Are semiarid shrubs resilient to drought and grazing? Differences and similarities among species and habitats in a long-term study. J. Arid. Environ. 102, 1–8.
Dunn, O.J., 1964. Multiple comparisons using rank sums. Technometrics 6, 241–252.
Ernest, S.K.M., Brown, J.H., 2001. Homeostasis and compensation: the role of species and resources in ecosystem stability. Ecology 82, 2118–2132.
Fernandez-Lugo, S., de Nascimento, L., Mellado, M., Bermejo, L.A., Arévalo, J.R., 2009. Vegetation change and chemical soil composition after 4 years of goat grazing exclusion in a Canary Islands pasture. Agric. Ecosyst. Environ. 132, 276–282.
Guariguata, M.R., Ostertag, R., 2001. Neotropical secondary forest succession: changes in structural and functional characteristics. For. Ecol. Manag. 148, 185–206.
Jauregui, B.M., Rosa-Garcia, R., Garcia, U., WallisDeVries, M.F., Osoro, K., Celaya, R., 2008. Effects of stocking density and breed of goats on vegetation and grasshopper occurrence in heathlands. Agric. Ecosyst. Environ. 123, 219–224.
Kouami, K., Yaoni, N., Honan, A., 2009. Impact of charcoal production on woody plant species in West Africa. A case study in Togo. Sci. Res. Essays 4 (9), 881–893.
Lachenbruch, P.A., 2001. Comparisons of two-part models with competitors. Stat. Med. 20, 1215–1234.
Landau, S., Perevolotsky, A., Bonfils, D., Barkai, D., Silanikove, N., 2000. Utilization of low quality resources by small ruminants in Mediterranean agro-pastoral systems: the case of browse and aftermath cereal stubble. Livest. Prod. Sci. 64, 39–49.
Mahieu, M., Archimède, H., Fleury, J., Mandonn, N., Alexandre, G., 2008. Intensive grazing system for small ruminants in the Tropics: the French West Indies experience and perspectives. Small Rumin. Res. 77, 195–207.
Mahiri, I., Howorth, C., 2001. Twenty years of resolving the irresolvable: approaches to the fuelwood problem in Kenya. Land Degrad. Dev. 12, 205–215.
Masezamana, H.N., Andrianarisoa, J.H., Raoliarivelo, L.I.B., Randriamalala, R.J., 2013. Identification et analyse d'activités alternatives à la fabrication de charbon de bois dans le district de Toliara II. Q096 project final report, DERAD, Eastern and Southern Africa Partnership Program, Antananarivo.
Mellado, M., Valdez, R., Lara, L.M., Lopez, R., 2003. Stocking rate effects on goats: a research observation. J. Range Manag. 56, 167–173.
Moat, J., Smith, P., 2007. Atlas de la végétation de Madagascar. Royal Botanic Garden-Kew.
Moser-Norgaard, P.M., Denich, M., 2011. Influence of livestock on the regeneration of fodder trees along ephemeral rivers of Namibia. J. Arid. Environ. 75, 371–376.
Naughton-Treves, L., Chapman, C.A., 2002. Fuelwood resources and forest regeneration on fallow land in Uganda. J. Sustain. For. 14, 19–32.
Naughton-Treves, L., Kammen, D.M., Chapman, C., 2007. Burning biodiversity: woody biomass use by commercial and subsistence groups in western Uganda's forests. Biol. Conserv. 134 (2), 232–241.
Oba, G., 1998. Effects of excluding goat herbivory on *Acacia tortilis* woodland around pastoralist settlements in northwest Kenya. Acta Oecol. 19 (4), 395–404.
Oba, G., Post, E., 1999. Browse production and offtake by free-ranging goats in an arid zone, Kenya. J. Arid. Environ. 43, 183–195.
Oduori, S.M., Rembold, F., Abdulle, O.H., Vargas, R., 2011. Assessment of charcoal driven deforestation rates in a fragile rangeland environment in North Eastern Somalia using very high resolution imagery. J. Arid. Environ. 75, 1173–1181.
Parker, K., 1991. Topography, substrate, and vegetation patterns in the northern Sonoran Desert. J. Biogeogr. 18, 151–163.
Pielou, E.C., 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13, 131–144.
Pote, J., Shackleton, C., Cocks, M., Lubke, R., 2006. Fuelwood harvesting and selection in valley thicket, South Africa. J. Arid. Environ. 67, 270–287.
Rabarison, H., Rakotondrafara, A., Razafimandimbison, S.G., Ratsimbason, M., Rakotonandrasana, Stéphan R., Rajeriarison, C., Randrianarivelojosia, M., 2013. Evaluation du risque d'extinction des *Cedrelopsis (Rutaceae)* de Madagascar. Scr. Bot. Belg. 50, 41–49.
Rabeniala, R., Raoliarivelo, L.I.B., Masezamana, H.N., Andrianarisoa, J.H., Randriamalala, R.J., 2009. Gestion de pâturage pour le cheptel de petits ruminants (ovins et caprins) dans une zone semi-aride du district de Toliara II. Q906 project final report, DERAD, Eastern and Southern Africa Partnership Program, Antananarivo.
Radosy, H.O., 2013. Résilience des fourrés xérophiles face au pâturage des petits ruminants et à la fabrication de charbon de bois dans la Commune Rurale de Soalara-Sud (District de Toliara II, Région Atsimo-Andrefana). Mémoire DEA, ESSA-Forêts, Université d'Antananarivo, Madagascar.
Ramaroson, R.T., 2014. Durabilité écologique de la production de charbon de bois dans le Sud Ouest malagasy, cas des fourrés xérophiles de la commune de Soalara Sud (Toliara II, Atsimo Andrefana). Mémoire DEA, ESSA-Forêts, Université d'Antananarivo, Madagascar.
Ramirez, R.G., 1999. Feed resources and feeding techniques of small ruminants under extensive management conditions. Small Rumin. Res. 34, 215–230.
Randriamalala, H., 2014. Etude des comportements alimentaires des caprins en zone semi aride de Madagascar, cas de la commune rurale de Soalara Sud. Mémoire DEA, ESSA-Forêts, Université d'Antananarivo, Madagascar.
Raoliarivelo, L.I.B., Rabeniala, R., Masezamana, H.N., Andrianarisoa, J.H., Randriamalala, R.J., 2010. Impact de la fabrication de charbon de bois sur la production et la disponibilité fourragère de pâturage en zone subaride, cas de la Commune de Soalara-Sud, Toliara II. Q909 project final report, DERAD, Eastern and Southern Africa Partnership Program, Antananarivo.
Rosa García, R., Celaya, R., García, U., Osoro, K., 2012. Goat grazing, its interactions with other herbivores and biodiversity conservation issues. Small Rumin. Res. 107, 49–64.
Rothe, P.L., 1964. Régénération naturelle en forêt tropicale : le *Dipterocarpus dyeri* (Dau) sur le versant cambodgien du golfe du Siam. Bois Forêt des Tropiques 8, 386–397.
Säumel, I., Ziche, D., Yub, R., Kowarik, I., Overdieck, D., 2011. Grazing as a driver for *Populus euphratica* woodland degradation in the semi-arid Aibi Hu region, northwestern China. J. Arid. Environ. 75, 265–269.
Schlecht, E., Dickhöfer, U., Predotova, M., Buerkert, A., 2011. The importance of semi-arid natural mountain pastures for feed intake and recycling of nutrients by traditionally managed goats on the Arabian Peninsula. J. Arid. Environ. 75, 1136–1146.
Seddon, N., Butchart, S., Tobias, J., Yount, J.W., Remi Ramanamyanonjy, J., Randrianizahana, H., 2000. Conservation issues and priorities in the Mikea forest of south-west Madagascar. Oryx 34 (4), 287–304.
Severson, K.E., Debano, L.F., 1991. Influence of Spanish goats on vegetation and soils in Arizona chaparral. J. Range Manag. 44 (2), 111–117.
Sigwela, A.M., Kerley, G.I.H., Mills, A.J., Cowling, R.M., 2009. The impact of browsing-induced degradation on the reproduction of subtropical thicket canopy shrubs and trees. S. Afr. J. Bot. 75, 262–267.
Songer, M., Aung, M., Senior, B., DeFries, R., Leimgruber, P., 2009. Spatial and temporal deforestation dynamics in protected and unprotected dry forests: a case study from Myanmar (Burma). Biodivers. Conserv. 18, 1001–1018.
Suresh, H.S., Dattaraja, H.S., Sukumar, R., 2010. Relationship between annual rainfall and tree mortality in a tropical dry forest: results of a 19-year study at Mudumalai, southern India. For. Ecol. Manag. 259, 762–769.
Vetter, S., 2005. Rangelands at equilibrium and non-equilibrium: recent developments in the debate. J. Arid. Environ. 62, 321–341.
Vincke, C., Diédhiou, I., Grouzis, M., 2010. Long term dynamics and structure of woody vegetation in the Ferlo (Senegal). J. Arid. Environ. 74, 268–276.
Wezel, A., Bender, S., 2004. Degradation of agro-pastoral village land in semi-arid southeastern Cuba. J. Arid. Environ. 59, 299–311.
Zemmrich, A., Manthey, M., Zerbe, S., Oyunchimeg, D., 2010. Driving environmental factors and the role of grazing in grassland communities: a comparative study along an altitudinal gradient in Western Mongolia. J. Arid. Environ. 74, 1271–1280.