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Effects of past and present land use on vegetation cover and regeneration in a tropical dryland forest

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ABSTRACT

Brazilian Caatinga is one of the most diverse dryland ecosystem of the world and is threatened by strong land use pressure and poor protection. In this study, we investigate the effects of past and present land use on plant community richness and structure. We used satellite information to identify 55 Caatinga forest plots with and without past vegetation clearing. We also quantified current land use, i.e. grazing by domestic animals, and selective logging. Caatinga vegetation structure, measured as vegetation cover, vegetation height, basal area and woody plant density, as well as recruitment, measured as woody plant seedling density and species richness, were negatively affected by both past and current land use. Past clear-cut not only had strong effects on most vegetation measures, but also increased current grazing which further negatively affected vegetation structure. Selective logging had little measurable effects but increased recruitment in plots previously clear-cut. Increasing time since the last clear-cut increased negative effects on vegetation, presumably because of a prolonged negative effect of grazing. Our results suggest that grazing needs to be prevented in areas degraded by clear-cut to allow vegetation restoration through natural succession and avoid further degradation and desertification.

1. Introduction

Land use change is the main cause of land degradation worldwide, but the degree of degradation will depend on land use type and on the resilience of the impacted ecosystem (Gunderson, 2000; Htun et al., 2011). The use of native forests for livestock grazing or logging not only directly impacts the vegetation but also modifies environmental conditions such as the light reaching the soil, soil compaction and wind exposure (Coffin et al., 1996; Conant et al., 2001; Zaady et al., 2013). A common consequence of such land uses in many forests is an impoverished vegetation with a lower average tree height, tree basal area, plant density and species number. This might occur either due to direct effects of land use and through indirect effects of enhancement of stressful conditions (Dorrough and Scroggie, 2008).

In dryland ecosystems, maintenance of vegetation cover critically depends on plant recruitment within existing vegetation patches, as seedlings can rarely establish on bare ground (Vieira et al., 2013). Even chronic low-intensity disturbances such as selective logging or grazing can have pervasive effects on plant diversity and composition of vegetation patches (Ribeiro et al., 2015). For example, selective logging for charcoal production may alter woody species composition because species with high wood density are preferred (Ramos et al., 2008). On the other hand, small gaps formation from selective logging can promote seedling density and diversity if the understorey is light limited (Costa and Magnusson, 2002). Grazers can modify the native vegetation by favoring unpalatable species or by causing overall mortality of seedlings due to trampling (Aschero and García, 2012; Cipriotti and Aguiar, 2005; Pereira et al., 2003). However, positive effects of grazing on native species seed dispersal and consequently seedling establishment have also been reported in dry ecosystems (Aschero and García, 2012).

The intensive and chronic land-use leads to formation of isolated vegetation patches surrounded by bare ground in several drylans around the world (Kéfi et al., 2007; Maestre and Escudero, 2009). After land abandonment, secondary forest dynamics will

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drive the assembly of a new plant community (Foster, 1992). The regeneration of a highly impacted area will depend on the presence of seed sources, vegetation cover and soil quality after land use (Verheyen et al., 2003). If regeneration does not occur because of continuous land use pressure, bare soil continuous exposure can lead to increased vegetation degradation over time and initiate a process of land desertification (Kéfi et al., 2007; Maestre and Escudero, 2009). In drylands, desertification is often the consequence of poor land management (D'Odorico et al., 2013).

The *Caatinga* is a dryland region covering most of the Brazilian Northeast and is threatened by increasing land use intensity (Leal et al., 2005; Ribeiro et al., 2015). Caatinga vegetation is characterized by a mixture of woody and herbaceous plants, with dominance of xerophytic and deciduous forest species. A common type of land use at the Caatinga is livestock grazing where animals are usually raised freely to feed on native vegetation that grows during the rainy season. In most cases, some areas are clear-cut to stimulate the growth of palatable herbaceous vegetation that livestock feed on. Other areas are converted to agriculture. Continued timber removal together with grazing are, however, considered the main causes of degradation of the Caatinga vegetation (Leal et al., 2005). Caatinga covers an area of 826 411 km^2, but around 375 116 km^2 or 45.4% have been deforested until 2009 and desertification processes have been observed in up to 15% of the area (Leal et al., 2005; MMA, 2011).

While the main drivers of degradation of Caatinga vegetation have been identified, little is known about how these drivers interact, and the relationship between land use intensity and the damage on vegetation. Understanding the effect of the different drivers of the changes on Caatinga's vegetation structure and regeneration in more mechanistic detail can help elucidating better management actions to avoid desertification and achieve conservation goals.

This study aims to investigate the effects of past and present land use on woody plant community regeneration, cover and structure. We asked the following questions: (1) how does a past clear-cut affect current vegetation structure and regeneration? (2) does increasing land-use intensity, in particular increasing intensity of grazing and selective logging, lead to increasing negative effects on plant community regeneration, vegetation cover and structure? (3) are there interactions between past and current land uses in their effect on the vegetation? and, (4) After a clear-cut, is the vegetation able to recover through time?

2. Material and methods

2.1. Study area

The study was conducted in the Caatinga vegetation located at the Brazilian northeast region (Fig. A.1a). In the typical Caatinga vegetation, ground vegetation only consists of very few grass species and the tree canopy is continuous and permanent. There are some parts of the Caatinga that are classified as deciduous thorny savanna, however, it is not the case for our study site. Specifically, the study was carried out in the State's Sustainable Development Reserve (SDR) *Ponta do Tubarão* (Fig. A.1b). The herbaceous layer is mostly composed of woody perennial herbs many of which of the Malvaceae family, and small stature cactis. Because grass species are more resilient to grazing and fire we expect the effects of land-use in our study area to be different from savannas.

The SDR is within the category IV according to the IUCN and in these types of reserves local people are allowed to live and exploit resources in a sustainable way. Yearly mean rainfall in the Caatinga is very variable and ranges from 240 to 1500 mm per year. Inside the reserve, average rainfall is 508 mm year^{-1} and rain mostly falls between January and May while on average less than 20 mm falls between October and December (data available at http://www.inmet.gov.br). The SDR has an extent of 12 960 ha that encompasses three main vegetation types: i) a Caatinga vegetation with a closed canopy cover of ~4 m height, dominated by the woody species *Mimosa tenuiflora*, *Poincianella pyramidalis*, *Pytirocarpa moliniformis* and *Croton sonderianus*; ii) a restinga vegetation, with a sparse canopy dominated by the woody tree *Sideroxylum obtusifolium*, and open spaces dominated by the small stature herbaceous species, and iii) a mangrove located near the coastline dominated by *Rhizophora mangle*. The Caatinga part of the reserve, where we carried out our study, covers 2779 ha, i.e. 21% of the total reserve area. There are also some dune areas inside the Caatinga which were excluded from our study, so that the study areas encompasses 2.010 ha of Caatinga vegetation.

There are eight traditional settlements inside the reserve boundaries with a population of ~5000 people. Families income in the three settlements at the coastline traditionally derives from fishing and wood extraction from Caatinga vegetation, to build houses, fences and boats. The families from the five countryside settlements live on small scale subsistence agriculture including raising sheep, goat and cattle, and also use wood from Caatinga vegetation for house and fence building, as well as charcoal production. Families let their animals foraging freely on vegetation (including donkeys and horses). Sometimes small forest areas are clear-cut using burning to encourage herbaceous vegetation growth.

2.2. Selection of sampling plots

Selection of sampling plots was carried out in two steps using a stratified random selection of plots' locations to ensure that we would select plots occurring in a wide range of vegetation cover. This approach assumes that vegetation cover would be negatively affected by land-use. In the first step, we classified the Caatinga vegetation inside the reserve according to current forest cover. We used Landsat TM5 satellite images of 2008 (http://www.dgi.inpe.br/CDSR/) with a resolution of ca. 30 × 30 m to classify the SDR Caatinga's vegetation into different degrees of current vegetation cover. To do so, a classification algorithm was trained using 28 control points that were first identified from satellite pictures and then visited in the field. These represented three types of areas: *open* areas with only very few remaining single trees or shrubs, *intermediate* areas with ca. 50–70% cover of trees and shrubs and a tree height up to 2 m, and *closed* areas with a dense forest canopy and tall trees with a mean canopy height of about 3–4 m. The 28 control areas were classified as one of the three types and used to train a classification algorithm based on Maximum Likelihood (ML) using all five Landsat bands (supervised classification procedure in ArcGis v10 ESRI, 2011). After training, the entire reserve was classified into the three cover classes. We classified the vegetation into cover classes only to select plots in a wide range of our vegetation and land-use variables. The land use classes did not enter the statistical analyses.

In a second step, we randomly selected 55 sampling points in the Caatinga part of the SDM, 20 in closed, 20 in intermediate, and 15 in open areas, as only 17% of the area had no forest cover. As a constraint for plot selection we set a minimum distance of 100 m between points. After selection, the minimum distance between two adjacent sampling points was 142 m (mean 3207 ± 2444 (sd) m). Each selected sampling point then served as the center of a circular sampling plot with 25 m radius (1962 m^2). This circle was used to measure current land use. Assessment of vegetation structure and plant species richness variables was carried out in a square 10 × 10 m sub-plot (100 m^2) placed at the center of the circular plot.

2.3. Land use assessment

For each of the 55 plot we assessed the following three variables describing human land-use: (i) past clear-cut, (ii) current grazing intensity and (iii) current selective logging. Evidence for *past clear-cut* (absent or present) was obtained analyzing Landsat TM5 satellite images from 1984 to 2010 (26 years). A fraction image of bare soil reflectance from each year was created using Spectral unmixing procedure in ENVI software v.5. Spectral unmixing is a method that decomposes the spectrum of mixed pixels into a collection of constituent spectra called *endmembers* and their correspondent abundances or *fraction*, indicating the proportion of each endmember present in each pixel of target landscape (Keshava and Mustard, 2002). For each plot, the development of the fraction of bare soil (between 0 and 1) was analyzed over time. Whenever there was a sudden increase in the fraction of bare ground from one year to another, the plot was considered to have been burned. From the 55 plots, 21 were classified as clear-cut in the past at least once in the previous 26 years. This satellite image classification was then verified in the subsequent field visits for vegetation assessments (see below) when we searched for evidence of past forest burning, e.g. charcoal or burned logs on the ground, and by asking local people for information. Two of the 21 plots turned out not to have been burned but were rather affected by intense logging, and were re-classified as without clear-cut. Of the remaining 19, one of the plots was cut clear using chainsaws in the past, the rest were burned. Eleven of the 19 plots with past clear-cut were located in open areas, eight in intermediate areas and none in closed areas. We also used the *time since last clear-cut* as an additional variable in separate analyses to investigate if vegetation is able to recover through time after suffering clear-cut.

All plots were visited between February and June in 2012 and 2013. As a measure of *current grazing intensity*, the number of dung pellets from goats, cattle (bovine) and horses/donkeys (equine) were counted inside the circular plots. As a measure of *selective logging intensity* we counted the number of cut trees or cut branches found inside the circular plots and measured their diameter to calculate the total basal area of selective logging (m^2 ha^{-1}).

2.4. Vegetation cover assessment by satellite

We estimated current *vegetation cover* in the circular plots using high resolution (0.5 m) satellite image GeoEye from 2010 (www.landinfo.com). Using ArcGIS v10, we calculated the percentage of vegetation cover inside each circular plot by separating visually areas covered with vegetation from areas of bare soil.

2.5. Assessment of vegetation structure, richness and density of seedlings

In the 10 × 10 m sub-plots inside each plot, we identified all woody species (shrubs and trees) higher than 20 cm height (for a list of species see Supplementary material, Table A.1). For each individual we measured height and diameter at ground level. We calculated the basal area for each woody plant individually. We defined woody plants with less than 50 cm height and less than 1 cm diameter as seedlings. For analysis, we counted the *number of seedling species* (seedling species richness) and the *number of seedlings* (seedling density) found in each sub-plot.

We also counted the number of points where vegetation was present in a total of 25 grid points in a grid with 2 m distance inside the 10 × 10 m sub-plot. At each point, we also measured vegetation height as the maximum height of a woody plant at the point.

We also calculated the following measures for current vegetation structure: a) *total basal area* (m^2 ha^{-1}), based on all woody plants, including seedlings, b) *average basal area* per plant, c) *average vegetation height* (m) based on the grid measurements, and d) woody *plant density* (without seedlings, ha^{-1}).

Because the grid measure of vegetation cover correlated well with the satellite estimate of vegetation cover described above ($N = 55$, $r = 0.82$, $p < 0.001$) we only use the vegetation cover estimates from the satellite images in the analysis.

2.6. Statistical analyses

The influence of past and current land use on current vegetation (cover, height and structure) was analyzed using generalized linear models. The full model used the explanatory variables: (i) past clear-cut; (ii) current grazing intensity and (iii) current selective logging. The vegetation parameters used as response variables were: (i) seedling density; (ii) seedling species richness, (iii) vegetation cover, (iv) total basal area, (v) average vegetation height and (vi) plant density. We fitted all combinations of land use variables for each response variable, including the second and third order interactions among them, totaling 19 models for each dependent variable. The order of fitting was clear-cut, grazing and selective logging, clear-cut*grazing, clear-cut*selective logging, grazing*selective logging, clear-cut*grazing*selective logging. The simplest model thus estimated only an intercept, and the full model estimated eight parameters. The model with lowest Bayesian information criterion (BIC) values was selected as the best model since BIC is an increasing function of the residual variance and number of parameters. We used BIC instead of the commonly used Akaike information criterion because BIC penalizes more for model complexity. We calculated ΔBIC as the difference of BIC values of each model with the minimum BIC value (best model). Models with $\Delta BIC < 2$ are mentioned in the text. The relative influence of each variable presented in the best model was calculated by first changing the order of the independent variables in the best model, and then averaging over variance explained by one term in each model (Lindeman et al., 1980). For a clearer description on how the vegetation variables responded to land use, relationships between the log-transformed variables were analyzed when necessary. To analyze if the vegetation parameters are able to recover after clear-cut, we did a correlation analyses of each response variable with time since last clear-cut using only those plots that suffered past clear-cut. All analyses were performed in R 3.1.3 statistical program (R Core Team, 2015).

3. Results

3.1. Interactions among past and current land use

3.1.1. Clear-cut and grazing

All plots presented evidence of grazing. Pellet number was 397 ± 360 in plots with past-clear cut, more than twice as many as in plots with no clear cut (156 ± 173, $F_{1,53} = 4.99$, $p = 0.03$, Fig. 1, see also Appendix A, Table A.2). On average, an approximately equal number of pellets were counted from goats, donkey/horse and cattle, but in plots with past clear-cut most pellets were from donkey/horses, while in plots without clear-cut most pellets were from goats (Table A.2). Past clear-cut did, however, only explain 8% of the variability in grazing intensity. While in both previously clear-cut and not clear-cut areas there were many plots with little or intermediate grazing intensity. There were relatively more plots with higher values of grazing intensity in the previously clear-cut plots (Fig. 1). Thus, past clear-cut was associated with higher

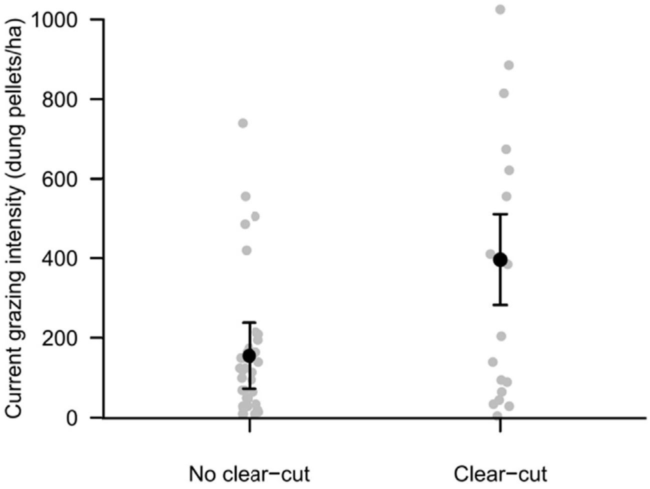

Fig. 1. Relationship between current grazing intensity and past clear-cut in 55 Caatinga plots (grey dots). The mean and 95% confidence interval are shown in black.

current grazing intensity. Interestingly, grazing intensity was positively correlated with time since the last clear-cut ($N = 19$, $r = 0.67$, $p = 0.002$, Fig. A.2a).

3.1.2. *Clear-cut and selective logging*

Forty-seven plots (85% of total plots) showed evidence of logging. The basal area logged ranged from 0 to 10.2 m^2 per hectare. Percentage extraction (basal area logged/total basal area) ranged from 0 to 32%, average ca. 5 ± 6%. In plots that were previously clear-cut selective logging was 0.93 ± 0.4 m^2/ha, not significantly different from the 1.3 ± 0.3 m^2/ha in areas without previous clear-cut ($F_{1,53} = 0.52$, $p = 0.46$). There was also no difference in the number of stems/branches cut (clear-cut: 32 ± 50, no clear-cut 64 ± 126, $F_{1,53} = 1.15$, $p = 0.29$). The number of stems/branches cut was correlated with selective logging intensity, i.e. the total basal area extracted ($N = 55$, $r = 0.82$, $p < 0.001$). The intensity of current selective logging tended to decrease with increasing time since the last clear-cut, but the relationship was marginally not significant ($N = 19$, $r = -0.43$, $p = 0.068$, Fig. A.2b).

3.1.3. *Grazing and selective logging*

The intensity of current selective logging was not correlated with grazing intensity ($N = 55$, $r = -0.12$, $p = 0.36$), even when the correlation was tested separately for plots with and without clear-cut ($p > 0.26$ for both analyses).

3.2. *Density and richness of seedlings*

Plots that did not suffer past clear-cut had on average 77% more seedlings than plots with past clear-cut (Fig. 2a, Table 1). With increasing grazing intensity, the density of seedlings decreased (Fig. 2a, Table 1). The best model explaining seedling density had no interactions and only the additive effect of clear-cut and grazing. This model explained 40% of the total variability and the relative explanation of both land-uses were 39% and 61% for clear-cut and grazing, respectively (Table 1). Importantly, the second best model ($\Delta BIC = 0.86$) included the effect of selective logging and a significant positive interaction between selective logging and past clear-cut that added 7% of explained variability (Table 1). Seedling density increased with increasing selective logging in plots that were previously clear-cut in the past. Thus, while past logging (past clear-cut) decreased the number of seedlings, current logging appeared to increase the number of seedlings in these plots. Seedling density was not correlated with time since the last clear-cut ($N = 19$, $r = -0.19$, $p = 0.44$).

Seedling species richness was also negatively affected by both past clear-cut and current grazing intensity, which together explained 45% of total variation (Table A.1, Fig. 2b). Plots that were not clear-cut in the past had on average 11.8 ± 1.1 species, 70% more than plots that suffered from a past clear-cut (7 ± 1.1 species, Fig. 2b; Table 1). Sixty-six percent (53%) of the explained variation corresponded to the effect of clear-cut and 47% to grazing. Selective logging intensity was present in the second best model ($\Delta BIC = 1.72$) but its effects was not significant (Table 1). Seedling richness was not correlated with time since the last clear-cut ($N = 19$, $r = -0.38$, $p = 0.11$).

3.3. *Vegetation structure*

There was higher vegetation cover when plots did not suffered clear-cut (82 ± 7%) in comparison with plots with clear-cut (57 ± 3%, Fig. 3a). The best model showed a significant interaction between past clear-cut and current grazing intensity, explaining 72% of total variance (Table 1). Grazing had a strong negative effect only when plots were clear-cut in the past, otherwise, grazing did not change vegetation cover (Fig. 3a). Clear-cut was responsible for 60% of the land-use effect, whereas grazing and its interaction with clear-cut accounted for 26 and 14%, respectively. Contrary to expectation, vegetation cover decreased with increasing time since the last clear-cut ($N = 19$, $r = -0.64$, $p = 0.003$, Fig. A.3a).

Vegetation cover was positively related to total basal area, but the relationship was visible mainly in plots with past clear-cut (interaction term: $F_{1,48} = 6.82$, $p = 0.012$, Fig. 3b). Plots with a basal area of more than 20 m^2/ha had a very high cover (average 81%). This was true for most plots without past clear-cut (Fig. 3b). In contrast, in plots with past clear-cut, vegetation cover steeply decreased with decreasing basal area below 20 m^2/ha (Fig. 3b).

Total basal area decreased with increasing grazing intensity (Fig. 4a, Table 1) and the model with the lowest BIC value only included grazing, explaining 61% of the total variability. Clear-cut was present in the second best model ($\Delta BIC = 0.55$), but the difference between intercepts of plots with and without clear-cut was only marginally significant ($t = -1.82$, $p = 0.075$) and the model increased only by 3% the total explained variance. Thus, total basal area was mainly affected by current grazing intensity. Plots with past clear-cut total basal area strongly decreased with increasing time since the last clear-cut ($N = 19$, $r = -0.71$, $p < 0.001$, Fig. A.3b).

Average vegetation height was 1.2 ± 0.18 m in plots with past clear-cut, 45% lower than in plots without past clear-cut (2.2 ± 0.12 m, Fig. 4b, Table 1). Current grazing decreased vegetation height (Fig. 4b, Table 1) and the additive negative effect of clear-cut and grazing explained forty-nine percent (49%), 58% of which due to clear-cut and 42% due to grazing. Selective logging was not present in any model with $\Delta BIC < 2$. In plots that suffered clear-cut, average vegetation height was negatively related to time since last clear-cut ($N = 19$, $r = -0.47$, $p = 0.04$; Fig. A.3c).

Plant density decreased with increasing current grazing intensity and was lower in plots with past clear-cut (66 ± 46 per hectare) than in plots without past clear-cut (121 ± 44, Table 1, Fig. 4c). The additive effect of both variables explained 67% where grazing was responsible for 73% of this effect. Plant density decreased with time since the last clear-cut ($N = 19$, $r = -0.57$, $p = 0.01$, Fig. A.3d).

The average basal area per individual plant was not affected by any of the land-use variables, because the model with an intercept only was the one with the lowest BIC while the second best model

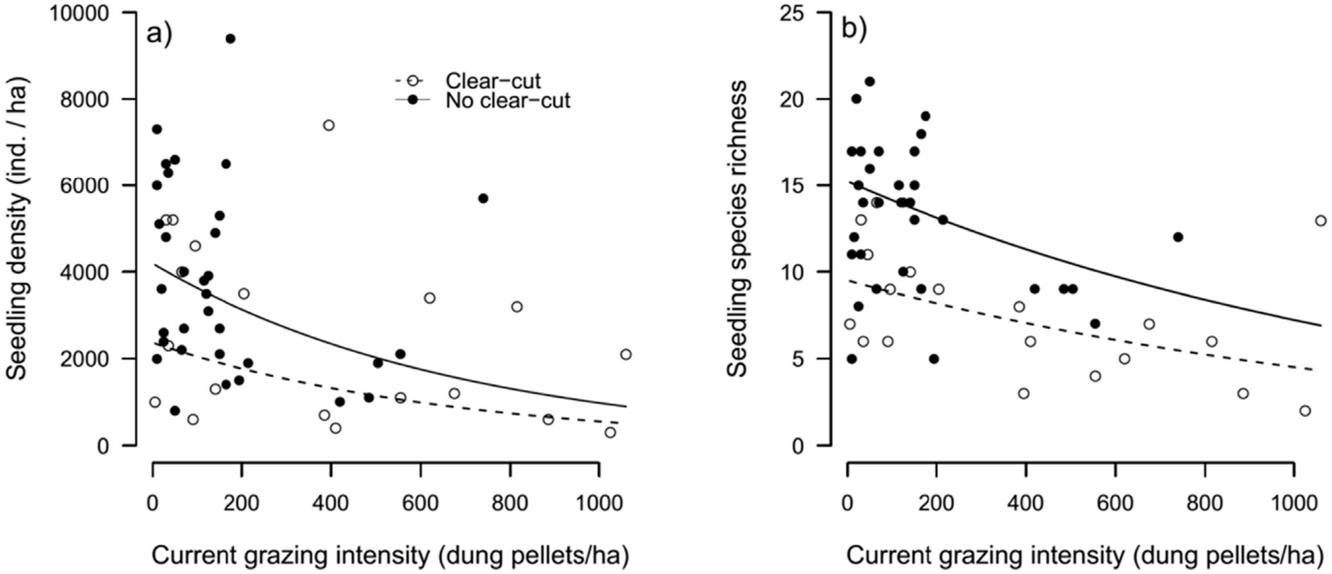

Fig. 2. Effect of land use on regeneration in 55 Caatinga plots. a) Seedling density, and (b) Seedling species richness are shown as a function of past clear-cut and current grazing intensity. The two lines represent the estimated effects of grazing in plots with past clear-cut (open circles and dashed line) and plots without past clear-cut (closed circles and solid lines).

Table 1
Results of linear models (GLM) on the effect of past (clear-cut) and current (grazing, selective logging) land use on variables related to regeneration and vegetation structure in 55 Caatinga plots. Only models with ΔBIC lower than 2 are presented. C × G represents the interaction between past clear-cut and current grazing and C × L represents the interaction between past clear-cut and selective logging. When a interaction is presented in the model, values inside interaction cells are slopes of the effect of grazing or logging when plots where clear-cut. The three-way interaction C × G × L was never significant for any of the dependent variables and are not shown. Bold values represent significant coefficients estimates ($p < 0.05$).

Response	Intercept	Clear-cut	Grazing	Logging	C × G	C × L	BIC	ΔBIC	R^2
Log (Seedling density)	**8.34**	**−0.57**	**−0.0014**	–	–	–	127.4	0	0.40
Log (Seedling density)	**8.46**	**−1.11**	**−0.0012**	−0.23[a]	–	**0.93**[a]	128.2	0.86	0.47
Log (Seedling richness)	**2.62**	**−0.45**	**−0.0007**	–	–	–	64.3	0	0.45
Log (Seedling richness)	**2.72**	**−0.47**	**−0.0007**	−0.15[a]	–	–	66.0	1.72	0.47
Vegetation cover	**84.3**	24.3	−0.55[a]	–	**−10.32**[a]	–	438.4	0	0.72
Log (Basal area)	**3.60**	–	**−0.0017**	–	–	–	59.6	0	0.61
Log (Basal area)	**3.64**	0.22	**−0.0015**	–	–	–	59.6	0	0.63
Height	**2.68**	**−0.96**	**−0.0015**	–	–	–	127.2	0	0.55
Log (Plant density)	**9.57**	**−0.37**	**−0.0016**	–	–	–	64.2	0	0.67

[a] log-transformed explanatory variables.

had a ΔBIC of 2.8. Also, average basal area per individual plant was not positively correlated with the time since last clear-cut ($N = 19$, $r = -0.28$, $p = 0.24$).

4. Discussion

We assessed the effects of past and present land use, measured as past clear-cut, current grazing, and current selective logging, on several parameters related to regeneration and vegetation structure of the Caatinga in Northeastern Brazil. Our results indicate that land use is a significant driver of the loss of vegetation cover, also reducing average height, total basal area, and woody seedling richness and density. Overall, past clear-cut and current grazing intensity have stronger negative effects in comparison to selective logging in our study site, which had a negligible effect in most cases. Importantly, the different land-uses interact, both with respect to their co-occurrence, and with respect to their effect on the vegetation. This was true in particular for grazing which was promoted by past clear-cut. Both the regenerating community and the established vegetation were most strongly negatively affected in plots that suffered past clear-cut and had high grazing intensity.

Vegetation cover was mainly affected by the interaction between past clear-cutting and grazing, where cover was reduced only in previously clear-cut plot with high grazing intensity while vegetation cover remained relatively high in areas with low animal load (Fig. 3a). This could indicate that the vegetation is able to recover after clear-cut if animals are kept off. However, areas that suffered past clear-cut had on average a higher number of dung pellets, indicating stronger grazing intensity. Greater availability and quality of fodder of herbaceous strata and higher accessibility may stimulate domestic animal movement into areas that were cleared because these animals preferentially forage on sites with palatable species (Skarpe et al., 2007). Moreover, grazing intensity was positively correlated with time since the last clear-cut, suggesting that once an area is clear-cut, animal activity may increase with time as goats also prefer to forage on sites with signs of previous browsing (Skarpe et al., 2007). Such a migration of animals into areas that were previously clear-cut could explain the negative correlation between time since the last clear-cut and basically all measures related to vegetation structure (Fig. A.3).

Our results show that in this dryland clear-cuts followed by higher grazing intensity in cleared areas may be responsible for

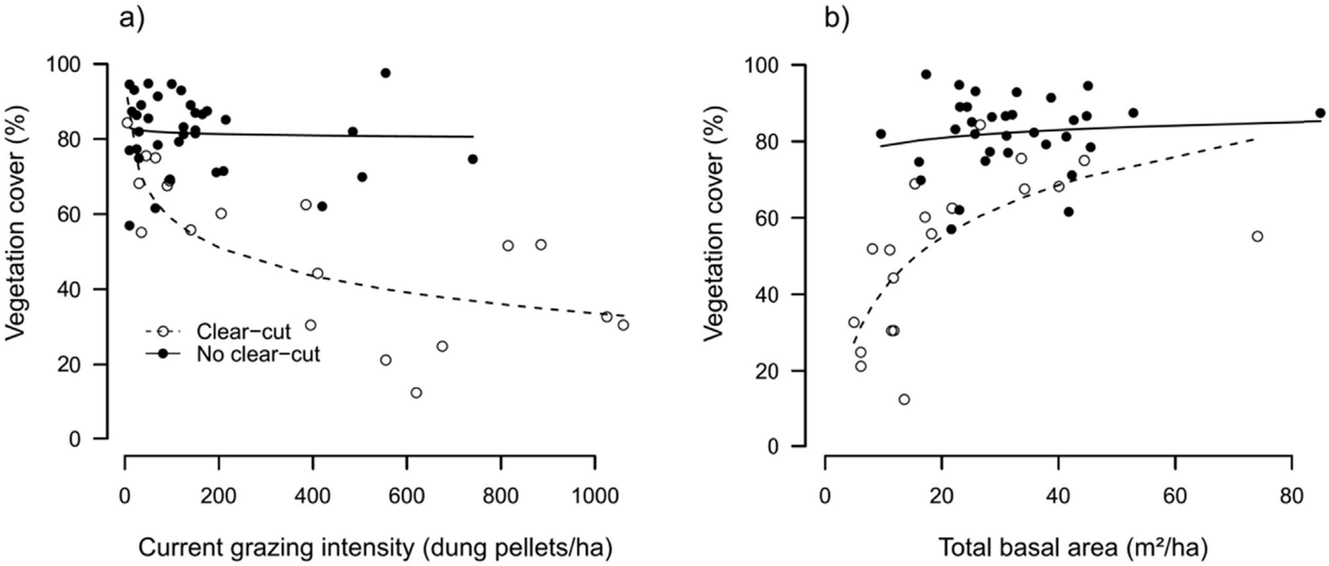

Fig. 3. Vegetation cover in 55 Caatinga plots. a) Effects of past clear-cut and current grazing intensity on vegetation cover. b) Relationship between total basal area and vegetation cover. The two lines represent the estimated effects of grazing in plots with past clear-cut (open circles and dashed line) and plots without past clear-cut (closed circles and solid lines).

contraction of vegetation patches (decreased vegetation cover), which is considered to be a primer signal for desertification (Cipriotti and Aguiar, 2005; Lopes et al., 2012). In drylands, recruitment and growth of woody plants is greatly improved under vegetation patches compared to areas outside the vegetation. This is due to milder environmental conditions (increased soil moisture and nutrient availability) and protection against seed predators and herbivores (Graff et al., 2007; Pugnaire et al., 2004; Vieira et al., 2013). Allowing animals to graze in natural areas for a long period might thus prevent plant regeneration and increase bare soil exposure over time. It could potentially start a desertification process especially in areas that suffered with previous clear-cut.

Although vegetation cover was not affected by increasing grazing intensity in areas that were not previously clear-cut, all other vegetation features were negatively affected by grazing intensity independent of clear-cut history, such as plant recruitment (Table 1). In the dry season, animals may increase their foraging area due to food shortage, using closed areas to feed on small stature seedlings and juveniles of woody species that retain leaves and twigs all year long (Kaufmann et al., 2013; Papachristou et al., 2005). In a study conducted in another dryland, grazing was more frequent on juvenile plants, which are more palatable due fewer defense mechanisms (Cipriotti and Aguiar, 2005). Additionally, seedlings are more prone to mortality due to trampling. The reduction of seedling density also observed in our study may impair natural regeneration causing long-term changes on the adult plant community if new individuals do not replace dead ones.

Grazing selectivity may shift plant community towards a more homogeneous composition causing the reduction of seedling richness in areas with high grazing intensity (Bagchi and Ritchie, 2010). Species possessing traits such as high investments in structural tissues, physical defenses and production of secondary compounds to avoid herbivory may thrive in communities with high grazing pressure (Díaz et al., 2007). In another study conducted at the Caatinga, grazers were able to exclude plant species that are less tolerant to trampling and more palatable (Severino and Albuquerque, 1999). Therefore, grazers could decrease palatable species abundance and consequently increase the success of unpalatable species as occurred in other drylands of Africa (Hanke et al., 2014), Israel (DeMalach et al., 2014) and Australia (Dorrough and Scroggie, 2008). Most plots with high animal load at the reserve investigated here are dominated by shrub species with low palatability such *Calliandra depauperata*, *Pavonia varians* and *Croton sonderianus*. These plant species have lower height and diameter which, combined with the smaller number of tree individuals, decrease average vegetation height and total basal area of the community.

5. Conclusions

Pervasive alterations of plant community structure and composition related to land use activities are occurring throughout the Brazilian semi-arid region. Dryland regions in Brazil and other areas of the planet are often densely occupied and exploited by human populations. Understanding how land use affects the plant community can help understanding whether sustainable land use is possible and how it can be achieved. Our study shows that plant community structure and the regeneration of the plant community are strongly influenced by past clear-cuts, even if these occurred more than 20 years ago. In fact, the negative correlations between time since the last clear-cut and current vegetation cover, basal area, average vegetation height and plant density highlights that the negative effect of past clear-cut on vegetation structure may increase over time. This correlation possibly reflects higher herbivore activity on older clearings which increase the negative effect of clear-cut over time. This is consistent with the negative effects of high current grazing intensities in previously clear-cut plots. We suggest that to allow succession to succeed in this drylands, land use must be planned avoiding the establishment of grazers in areas that suffered past clear-cut. This simple rule should help to prevent processes of land impoverishment and desertification in this dryland system.

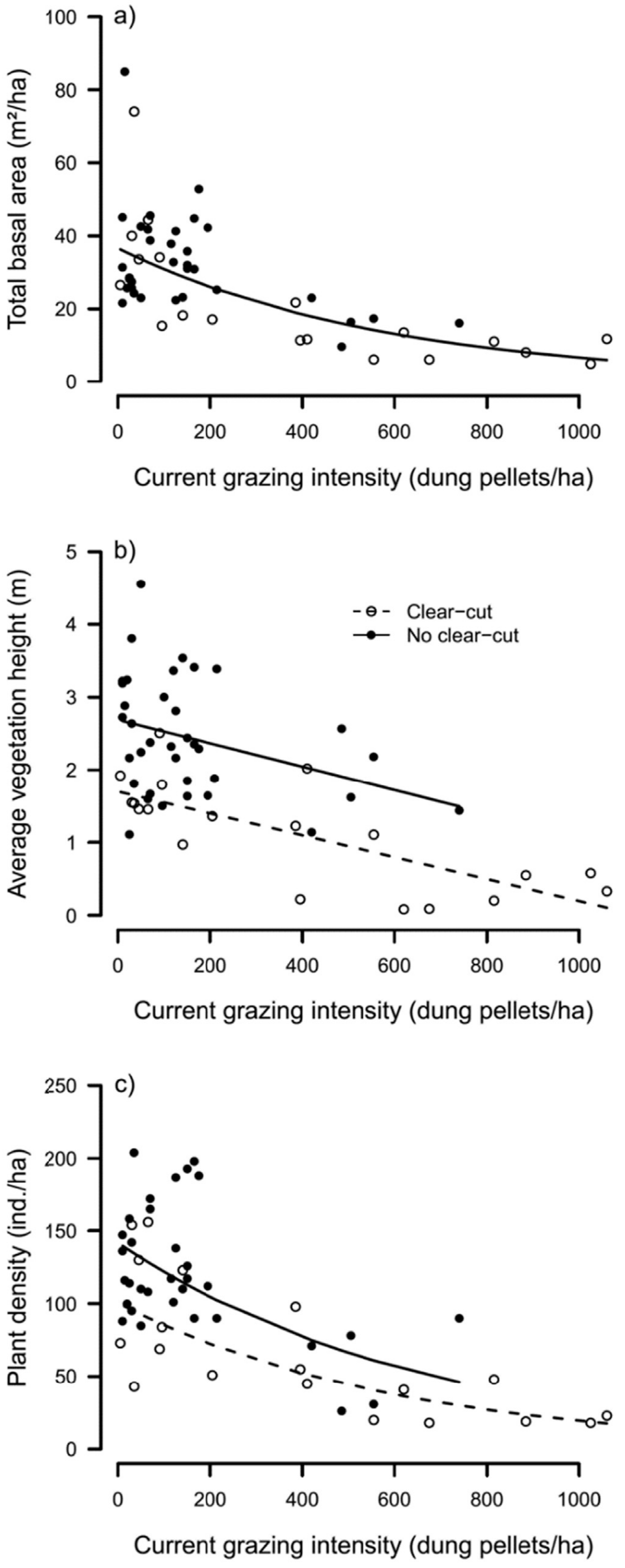

Fig. 4. Effects of current grazing intensity and past clear-cut on vegetation structure of the Caatinga: a) basal area, b) vegetation height, c) number of plants. The two lines represent the estimated effects of grazing in plots with past clear-cut (open circles, dashed line) and plots without past clear-cut (closed circles and solid lines).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jaridenv.2016.04.006.

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