Global Ecology and Conservation 23 (2020) e01088

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: http://www.elsevier.com/locate/gecco

Original Research Article

Floristic diversity and stocking rate in tropical dry forest secondary vegetation used for grazing

Osmar Espinosa-Palomeque MSc (OEP) [a], Gonzalo Castillo-Campos [b], Lucrecia Arellano [b], Ponciano Pérez-Hernández [a], Silvia López-Ortíz [a], *

[a] Colegio de Postgraduados, Campus Veracruz, Km. 88.5 de la Carretera Federal Xalapa -Veracruz (vía Paso de Ovejas), Predio Tepetates, Municipio de Manlio Fabio Altamirano, C.P. 91690, Veracruz, Mexico
[b] Instituto de Ecología, A.C., km 2.5 Carretera Antigua a Coatepec # 351, Congregación El Haya, C.P. 91070, Xalapa, Veracruz, Mexico

ARTICLE INFO

Article history:
Received 7 August 2019
Received in revised form 29 April 2020
Accepted 29 April 2020

Keywords:
Voisin grazing
Yield
Stock density
Forage plants
Plant recovery

ABSTRACT

The natural process of ecological regeneration in tropical regions in conjunction with local livestock management practices creates grazing environments with high floristic diversity and structural complexity. Yet, these environments are being neglected despite the opportunities and benefits for domestic herbivores. Voisin grazing (VG) is better in such highly biodiverse environments, as this management system seeks to improve forage utilization by coupling forage allowance with livestock needs for forage, using small paddocks, high stock densities over short occupation periods, and allowing plants to fully recover after grazing. Floristic diversity, biomass and stocking rate were assessed in sites having tropical dry forest secondary vegetation undergoing grazing. Six sites having extensive seasonal grazing were studied by placing 10 × 10 m^2 quadrats across sites to list woody species and nested 2 × 2 m^2 frames for listing herbaceous vegetation. The response of vegetation to Voisin grazing (VG) was evaluated in one of the six sites (split into 15 paddocks having 400-m^2 each). A total of 191 species (from all sites) including 50 potential forage species were listed. Quadrats were classified into two groups, one contained more preserved vegetation dominated by woody species, and the other a less preserved group dominated by herbaceous and shrub species. Available forage biomass across sites ranged from 1000 to 1200 kg DM ha^{-1} (30–70% woody biomass), supporting low stocking rates (0.2–0.3 AU ha^{-1}). In the site where VG was implemented, most of the identified species were forage (56/58). After one year of VG, the most productive paddocks (2500–3800 kg DM ha^{-1}) were dominated by forbs and the least productive ones (800–2000 kg DM ha^{-1}) were dominated by woody species, yielding an overall stocking rate of 1.2 AU ha^{-1}. Based on forage botanical composition, three groups of paddocks were identified: 1) dominated by grasses, 2) heterogeneous forage diversity, and 3) dominated by forbs and shrubs. Pastures recovered in 47–89 d during the 2017 rainy season, 50–123 d during the transition to the dry season, and 210–290 d during the 2018 dry season. Secondary vegetation provides high floristic diversity and a large number of forage plant species, but low forage yield and stocking rates. Yet, implementation of a proper grazing system such as VG gradually enhances yield and stocking rates.

* Corresponding author.
E-mail addresses: espinosa.omar@colpos.mx, osmar.palomeque9@gmail.com (O. Espinosa-Palomeque), gonzalo.castillo@inecol.mx (G. Castillo-Campos), lucrecia.arellano@inecol.mx (L. Arellano), pperez@colpos.mx (P. Pérez-Hernández), silvialopez@colpos.mx (S. López-Ortíz).

https://doi.org/10.1016/j.gecco.2020.e01088
2351-9894/

1. Introduction

Grazing lands in Mexico and in many parts of the world occur after a process of modification and replacement of natural ecosystems with grazing areas (Guevara and Lira-Noriega, 2004). Over time, rancher tendencies have been to maintain pastures dominated by grasses and forage plants selected for their high forage yield (Humphreys, 1994). However, in forest ecosystems, the natural process of ecological regeneration in conjunction with local livestock practices creates grazing environments where diverse herbaceous vegetation is mixed with the diversity of shrubs and arboreal plants of secondary vegetation and that of the original forest (Lira-Noriega et al., 2007; Schoenbaum et al., 2018), creating sites with high floristic diversity and structural complexity. These environments, far from being idle and unproductive spaces, offer a series of opportunities and benefits for domestic herbivores (Provenza and Villalba, 2010). The high floristic diversity generates opportunities to select diverse diets combined from all the strata the cattle can reach (Hickman et al., 2004; Feng et al., 2016). The combinations of selected plants guarantee the acquisition of nutrients and secondary compounds that the cattle need for their nutritional and health maintenance. As well, the complex structure of these environments plays an important role in animal welfare because it protects them from adverse weather conditions (intense solar radiation, rain, wind), helping to reduce stress. Moreover, these environments contribute to maintaining ecological processes and environmental services that prevent the deterioration and loss of resources such as soil, water and biodiversity (Maharning et al., 2009; Wang et al., 2011).

Interactions between livestock and vegetation in such environments have been little studied, possibly because these environments are considered marginal for livestock production and greater importance is given to simplified pastures in terms of richness and floristic structure.

Such sites can follow the natural process of succession to take the form of secondary vegetation, a process which can be accelerated by extensive livestock grazing because it promotes selective consumption of the most palatable plants, while less palatable ones increase their dominance, causing the paddocks to lose forage value, thus furthering succession (Oñatibia and Aguilar, 2019). This is one reason why this type of paddock is considered marginal and is often tilled. It is imperative to understand the benefits of the flora that exist in these grazing lands in different ecosystems, the most appropriate way to manage that floristic richness, and the changes such pastures undergo using sustainable grazing schemes. Voisin grazing (VG) could be a better option for using the diverse vegetation in these environments regardless of their successional progress. Voisin grazing (theory of Rational Grazing, also known as Voisinism, Voisin Grazing or Rational Intensive Grazing) is a method of operating ranches, and was developed by André Marcel Voisin (Voisin, 1988; Pinheiro, 2015). The method is based on four principles of managing forage and livestock, while expecting positive system performance. The first two principles apply to forage base management in pasturelands: 1) after grazing, plants must have a recovery time to reach their maximum productivity in the vegetative phase, also known as the optimal resting time of the pastures, so they can be grazed again; 2) grazing time in a paddock should be short enough to prevent recovering plants from being eaten during regrowth. Observing these principles promotes high quality forage with more leaves and tender stems, and productive and sustainable pastures over time (Murphy et al., 1986; Voisin, 1988; Pinheiro, 2015).

The objectives of this investigation were: a) to assess the floristic diversity, botanical composition of the forage biomass and stocking rate in sites with diverse vegetation subject to extensive grazing, and b) to study the response of one of these sites to Voisin grazing, describing changes in productivity, botanical composition of biomass, stock density and stocking rate when proper grazing management is implemented.

This research highlights a better fate for abandoned sites or pastures having associated vegetation undergoing early plant succession. Historically, such areas were not considered as suitable land for grazing, but were seen as idle and unproductive, until they could be converted into new pastures. Plant diversity has a stabilizing effect on ecosystems and plant community primary production through different mechanisms (Hector et al., 2010), and the same biological complexity inherent in natural ecosystems recreates complementarities in time and space among diverse plant species that favor herbivore forage intake and performance (Provenza et al., 2007). Thus, proper grazing over time might establish a floristic composition and structure suitable for foraging, with an acceptable carrying capacity, at low ecological costs.

2. Materials and methods

2.1. Study area location and description

The investigation was carried out on the coastal plain of central Veracruz State, Mexico (Fig. 1), in a landscape of low plains and hills of moderate relief (Chiappy-Jhones et al., 2002). In this landscape, the dominant vegetation type was deciduous tropical dry forest, yet land use shifts have left fragments of secondary forest in an agricultural matrix. Those remnants of secondary forest are at risk of being replaced by grass pastures, compromising the existence of the associated plant species. The chosen sites are examples where grazing lands are undergoing secondary regeneration at different stages, and where extensive grazing is performed seasonally after pastures are depleted. Such conditions made these sites suitable for this study. The climate in the area is sub-humid warm, where average annual rainfall is < 1000 mm, and rain falls mostly during summer (García, 2004). The seasonality of the precipitation and winter winds differentiate three periods: rainy (June to September), transition to dry (October to December) and dry (January to early June).

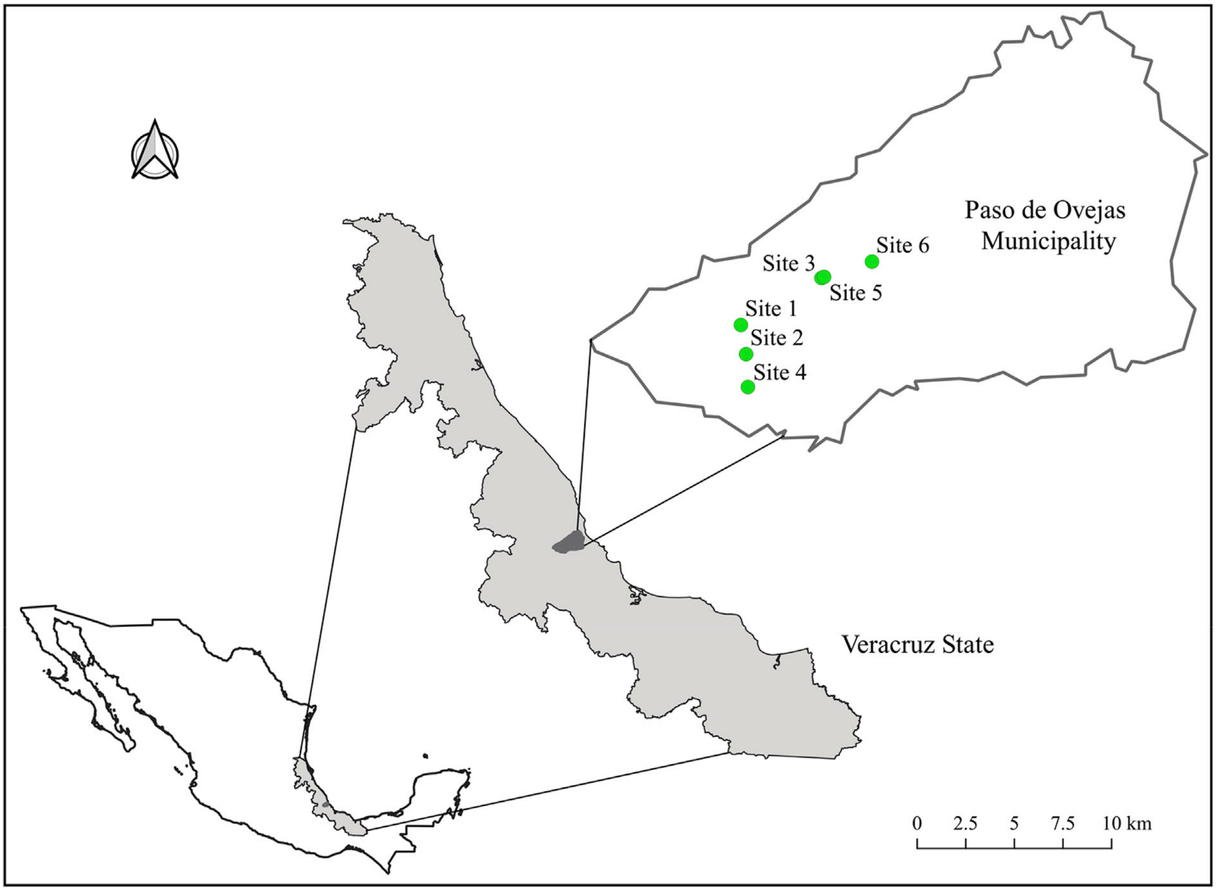

Fig. 1. Study area and sites in central Veracruz, Mexico.

2.2. *Study stages*

The investigation was conducted from June 2017 to September 2018 in two stages. The first described the floristic and botanical composition, potential forage biomass and stocking for sites with secondary vegetation. The second stage evaluated the forage yield, the stocking and the dynamics of vegetation recovery throughout the year in response to Voisin grazing.

2.3. *Stage 1. floristic composition, forage biomass and stocking in sites with secondary vegetation*

2.3.1. *Site descriptions*

Six sites were chosen that supported secondary vegetation in different degrees of succession and that were used as grazing land. These sites had from 3 to 40 years of ecological succession and surface area between 1 and 5 ha.

2.3.2. *Site floristic assessment*

Floristic diversity was inventoried during the rainy season (July to August 2017 and 2018). At each site, 100-m^2 quadrats (10×10 m) were drawn every 25 m along transects, and three nested 4 m^2 (2×2 m) frames were randomly placed (Castillo-Campos et al., 2008); a total of 43 large quadrats were sampled (site 1 = 7, site 2 = 6, site 3 = 5, site 4 = 14, site 5 = 6, site 6 = 5) and 129 nested frames. In the large quadrats, all woody species and lianas and their attributes (life form, cover, height) were assessed, and in the nested frames all herbaceous species (including vines) and their attributes (life form, cover, height) were listed.

2.3.3. *Biomass availability and stocking*

The potential forage biomass available at all sites during the rainy season was quantified. To do this, one of the 4 m^2 nested frames in each of the 10×10 m quadrats, was randomly chosen and the biomass (green foliage, flowers and fruits) of all the plants and parts of plants within the frame was harvested up to 1.7 m in height (above ground and available to cattle). The harvested biomass was separated into fodder groups: woody (trees, shrubs and lianas), broad-leaved herbaceous (forbs and vines), and grasses (native and introduced), to assess botanical composition. The biomass samples were dried at 60 °C in a forced air oven for 48 h and then the biomass yield (kg DM ha^{-1}) was calculated.

A list of the species available as forage was drawn up over all sites, which included all the herbaceous, lianas, shrubs and tree species that were less than 4 m high, because those plants have branches inserted at a lower height that could be reached by cattle. Thus, a list of potential forage species (PFS) was obtained, which was complemented with the coverage and frequency of each species, to obtain a list of the most important PFS.

The stock density and stocking rate were calculated using the harvested biomass data (kg DM ha^{-1}) at each site and the concept of animal unit (AU), being the equivalent to a 500 kg animal that consumes 3% of its live weight daily (15 kg DM day^{-1}; Pinheiro, 2015). The harvested forage biomass from each paddock at each utilization time was divided by 15, the result being the stock density defined as the AU grazing on an area of a pasture for a specific period of time. Stocking rate was also calculated, defined as the number of animals that a site can sustain in the period of one year (Pinheiro, 2015). After dividing the total annual biomass by 15 kg, the quotient was divided by 365 days of the year, resulting in the animal units ha^{-1} $year^{-1}$.

2.4. Stage 2. forage availability and stocking in a site using Voisin grazing

2.4.1. Site description and management

The previously mentioned site 6 was used, with 1 ha of surface area, and approximately 5 years of regeneration. This site had heterogeneous vegetation: patches of arboreal vegetation with open canopy, closed canopy patches with low internal cover and patches of open spaces with shrubs and herbaceous vegetation (including grasses). At the beginning, branches were pruned in areas with greater canopy cover to increase the incidence of sunlight in the lower strata, and in other areas, plants of *Senna pallida* (Vahl) H.S. Irwin & Barneby were cut to ground level because they are non-forage species.

Fifteen 400-m^2 paddocks (22.5 × 22.5 m) were delimited with electric fencing. The size of the paddocks was calculated to support roughly 15 AU for one day of occupation, taking as reference the available forage biomass obtained by Gómez-Fuentes-Galindo et al. (2017) in tropical dry forest secondary vegetation.

2.4.2. Forage availability and stocking

The availability of forage biomass was evaluated in all paddocks before each grazing period, when the vegetation available as forage had fully regrown to complete optimum plant growth (Murphy et al., 1986; Pinheiro, 2015), a time between vegetative growth ending and before flowering (Undersander et al., 2002). At that time, five sampling points were randomly chosen and the biomass (foliage, fruits, flowers and tender stems) was manually harvested within 1-m^2 frames to 1.7 m in height (Bonham, 1989). The biomass harvested in each frame was separated by species, and dried following AOAC (1990). The stocking rate and stock density that each paddock would support was calculated as described in section 2.3.3 of this investigation.

2.5. Implementation of Voisin grazing

Immediately after evaluating biomass, the cattle were introduced to the paddock in turn, meaning that each paddock was used on different dates because they achieved their recovery at different times. During the rainy season, optimum plant growth was defined beginning flowering and the first senescent leaves appeared at the base of herbaceous plants. During the transitional period, the point was defined when: a) plants started flowering in paddocks dominated by grasses and forbs, or b) the moment when the leaves began to senesce due to water stress in paddocks dominated by shrubs and trees. These Voisin grazing criteria were applied to the vegetation that dominated a paddock and that made up the largest forage mass; the interaction between the plants and the microsite conditions generated different recovery times in the paddocks (Azuara-Morales et al., 2020). Following these criteria, three moments of forage use were identified for each pasture during a 14-month period (July 23 - September 3, 2017, October 21 - November 30, 2017 and June 3 - September 3, 2018) (Fig. 2). Cattle were introduced to forage and the time they remained in each pasture ranged from 8 to 24 h, depending on the availability of forage biomass. The time it took the plants to recover from grazing and reach the optimum plant growth was recorded.

2.6. Statistical analysis

2.6.1. Stage 1

The final slope of a species accumulation curve was used to determine survey completeness (Hortal and Lobo, 2005). A predetermined slope (0.01) was used as a cut-off value to assess when communities are relatively well sampled. That cut-off value means a new species appears each 100 individuals, a value set by the rate of finding new species in additional samples, which suggests a comparative measure of survey completeness. The Michaelis—Menten (MM) equation was used as a reliable estimator for vegetation richness, since MM has been a frequently used indicator in diversity inventory assessments (Colwell and Coddington, 1994; Colwell, 2005). Calculations were performed with the program Estimate*S* 9.1.0 (Colwell, 1997).

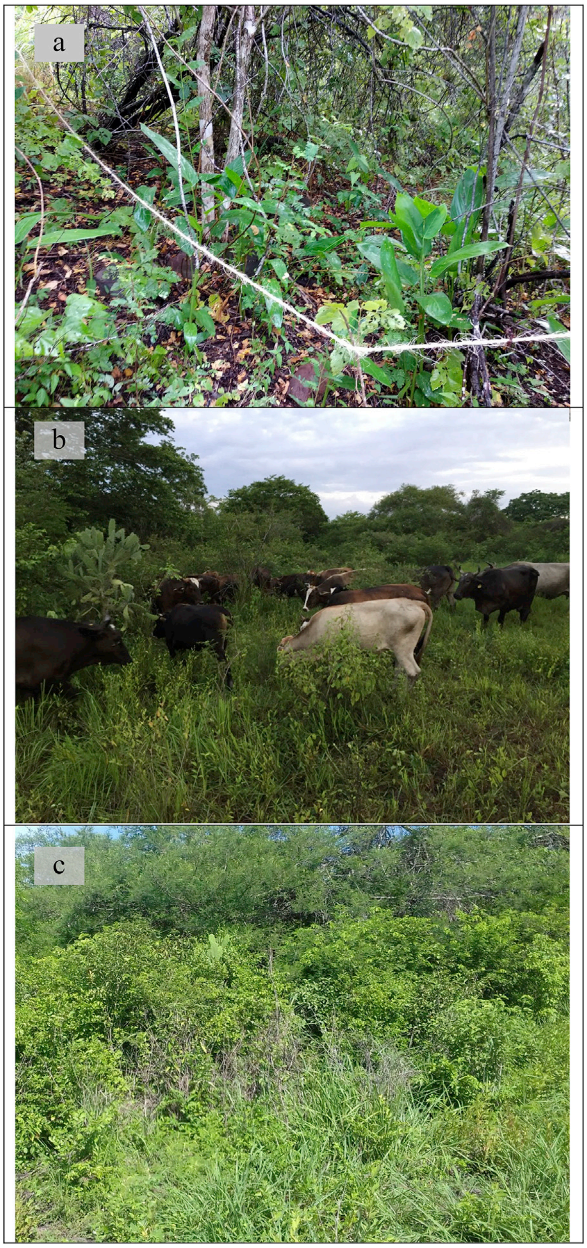

Fig. 2. Paddocks in a site having high plant diversity under Voisin grazing: a) preparing for vegetation sampling before grazing in a tree-dominated paddock, b) grazing in a shrub-herb dominated paddock, c) a shrub-herb dominated paddock nearing grazing initiation.

A cluster analysis (using species presence/absence) was performed using Jaccard's index and the unweighted arithmetic mean to approximate the similarity among quadrats (Sneath and Sokal, 1973). This index takes values from 0 to 1, where 0 = 100% dissimilarity and 1 = 100% similarity. Subsequently, the presence/absence of species and their coverage were used in a principal component analysis (PCA) to differentiate the conservation status of the squares (and sites) and sort them along a conservation gradient. Both analyses were performed using the Multi-Variate Statistical Package v 3.22 (Kovach, 1999). Totals of available biomass, stock density and stocking rate at each site were calculated, but not statistically analyzed.

2.6.2. Stage 2

Cluster analyses were performed using the forage biomass data of all species in each of the 15 paddocks in the site to detect the similarity among them using the Bray-Curtis coefficient for untransformed data (Bray and Curtis, 1957). This coefficient acquires values from 0 to 1, where 0 = 100% different and 1 = 100% similar. This analysis was made with the data from the initial and final samples using R Studio Version 3.4.3.3 (R Development Core Team, 2018).

Total biomass available from each pasture was measured, and with that data the botanical composition, stock density and stocking rate of the site were calculated; the recovery time of each paddock also was recorded (time between two grazing periods). These results are presented descriptively as a case study.

3. Results

3.1. Floristic composition, forage biomass and stocking in sites with secondary vegetation

The final slope of the observed species accumulation curve was 0.0011, which suggests an addition of a new species every 217 individuals (Fig. 3). According to the Michaelis-Menten estimator, at least 88% of the potential species richness for the entire region was recorded; this percentage is expected in heterogeneous plant communities such as grazing lands. Thus, sampling effort was representative of the floristic diversity in the study area and in order to obtain a complete inventory it would have been necessary to account for an additional 26 species.

3.1.1. Species richness and potential forage species

Throughout all six sites, 51 families of plants were listed, containing 148 genera and 191 species. The families with the most genera and species were Fabaceae, Malvaceae and Asteraceae, and 25 genera contained only one species (Table 1).

Species richness varied among sites (site 1 = 97, 2 = 70, 3 = 91, 4 = 125, 5 = 71, 6 = 59), but all life forms were represented in all sites: 59 species were trees, 56 were herbaceous and forbs, 48 were shrubs and <28 were lianas and vines combined.

The sampled quadrats over all sites (n = 43) were clustered into two groups: G1 and G2 (Jaccard coefficient = 0.144; Fig. 4). Group 1 contained 21 squares, 14 of which corresponded to site 4 having more preserved forest vegetation, while the other seven squares corresponded to site 1 which had patches of more preserved vegetation in its spatial matrix. In G2, squares were mostly aligned with sites being in early regeneration (sites 2, 3, 5 and 6), most likely due to abandonment time.

In the PCA ordination (Fig. 5), the quadrats were distributed along a conservation gradient (based on plant cover), those having the most preserved vegetation were placed on the right (all quadrats from site 4 and one from site 1), while to the left the quadrats were more aligned with less preserved sites (1, 2, 3, 5 and 6). Thus, site 4 is identified as G1, which has a longer period of ecological succession where canopy dominant species belong to more advanced successional stages, and G2 is made up of all the other sites.

The species listed in Table 2 show a greater number of shrubs and herbaceous species in G2, where the vertical structure of the vegetation is less complex and the abundance of herbaceous plants (including grasses) and shrubs indicates that these sites are in an earlier stage of ecological succession.

Over all species identified, 127 (66.5%) across all life forms were considered as potential forage species (PFS) that were found at heights within reach by livestock. However, only 50 species (26.3%) were listed as the most important PFS (Table 3), because they were more abundant and had greater cover in the sites.

The groups formed by cluster analysis (Fig. 4) and corroborated with ordination (Fig. 5) shared only 12 of the most important PFS and differed mainly in the numbers of tree and shrub species because in some sites fewer woody species were within reach of the cattle. In G1, 23 more important PFS were distinguished and in G2 up to 41; in both, there was a greater richness of herbaceous and shrub species.

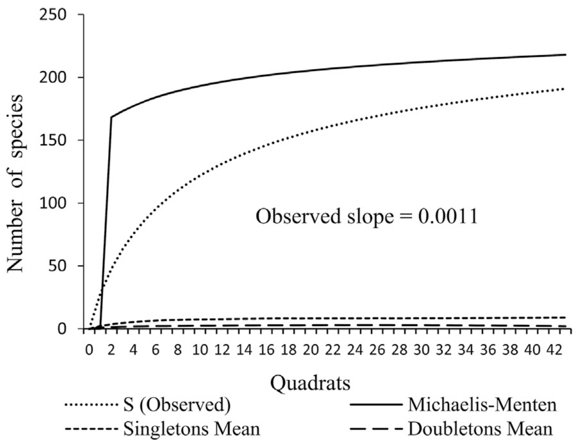

Fig. 3. Sampling effort curve for species listed in sites with secondary vegetation in tropical dry deciduous forest, subject to seasonal grazing.

Table 1
Floristic diversity in sites with secondary vegetation subject to seasonal grazing by cattle.

Family	Genera	Species	Family	Genera	Species
Fabaceae	22	33	Annonaceae	1	1
Malvaceae	12	15	Asparagaceae	1	1
Asteraceae	10	11	Bixaceae	1	1
Euphorbiaceae	6	10	Bromeliaceae	1	1
Poaceae	8	9	Cannabaceae	1	1
Rubiaceae	6	8	Combretaceae	1	1
Boraginaceae	1	7	Commelinaceae	1	1
Verbenaceae	5	7	Dioscoreaceae	1	1
Malpighiaceae	5	6	Ebenaceae	1	1
Celastraceae	5	6	Erythroxylaceae	1	1
Apocynaceae	5	5	Lamiaceae	1	1
Bignoniaceae	4	5	Loasaceae	1	1
Acanthaceae	4	4	Loranthaceae	1	1
Cactaceae	4	4	Lygodiaceae	1	1
Convolvulaceae	4	4	Lythraceae	1	1
Myrtaceae	3	4	Marantaceae	1	1
Anacardiaceae	3	4	Nyctaginaceae	1	1
Solanaceae	3	4	Orchidaceae	1	1
Rutaceae	3	3	Petiveriaceae	1	1
Sapindaceae	2	3	Polygalaceae	1	1
Burseraceae	1	3	Polygonaceae	1	1
Passifloraceae	1	3	Salicaceae	1	1
Moraceae	2	2	Sapotaceae	1	1
Phyllanthaceae	2	2	Smilacaceae	1	1
Amaranthaceae	1	2	Vitaceae	1	1
Meliaceae	1	2	–	–	–

- Indicates no data.

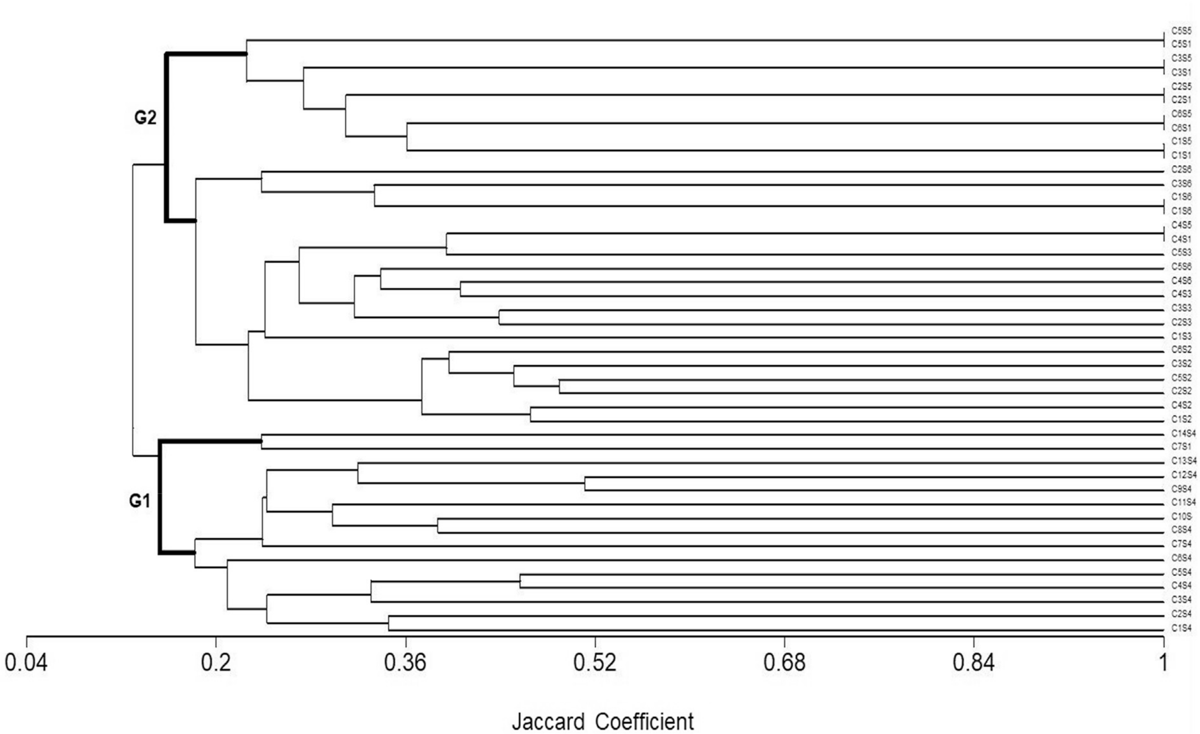

Fig. 4. Similarity dendrogram for sites having secondary vegetation, and based on species presence-absence. Quadrats from each site were labeled with a "c" for site, followed by a progressive number for sites 1 through 6, and a progressive number for quadrats 1 through 43.

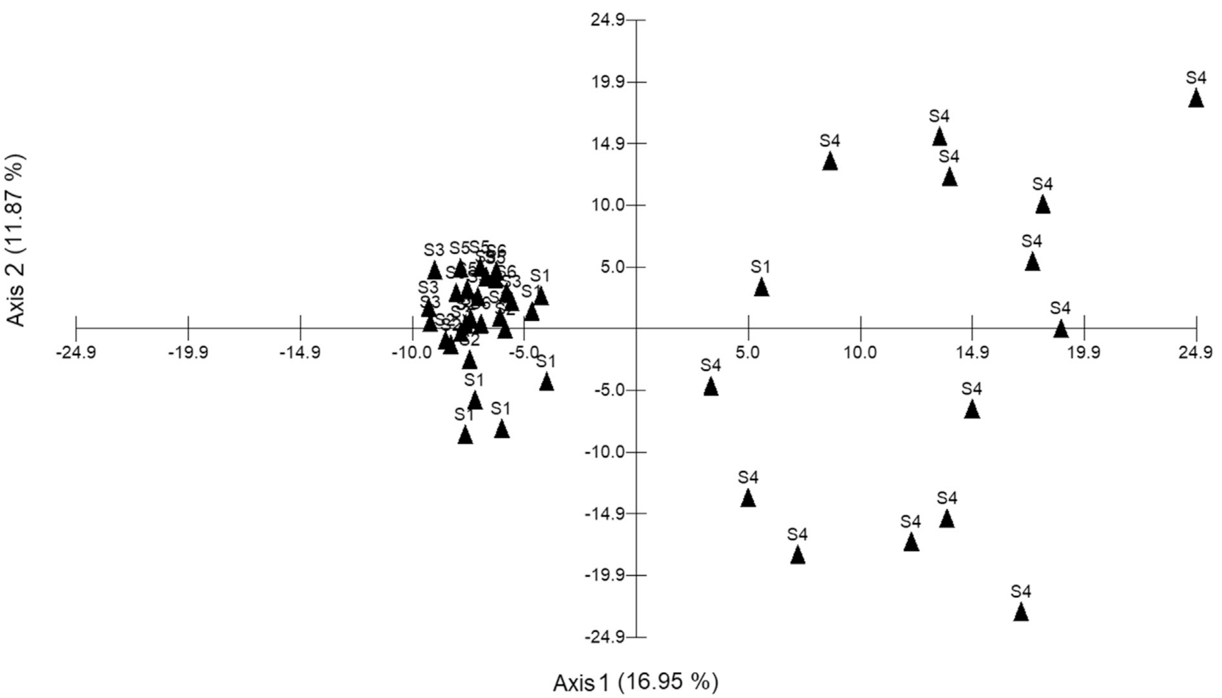

Fig. 5. Conservation gradient of vegetation in sites within a tropical dry forest, subject to seasonal grazing. Quadrats from each site were labeled with an "s" for site and progressive numbers from site 1 through 6.

3.1.2. *Available biomass and stocking*

Available biomass was 1176, 1291, 1207, 1000, 1055 and 1024 kg DM ha^{-1} in sites 1 to 6, respectively. Consequently, the stock density that these sites support (78, 86, 80, 67, 70 and 68 AU ha^{-1} in sites 1 to 6, respectively) is also low, less than 100 AU, which is equivalent to a stocking rate from 0.2 to 0.3 AU ha^{-1}.

All strata contributed to the forage biomass in all sites (Fig. 6). However, woody species were the botanical group that contributed most to potential forage biomass (16–70%), and the grasses contributed the least (2–38%). Forbs and grasses together made up about 50% of potential forage biomass in most sites. Site 1 had greater tree-shrub cover, thus there was more available biomass from this stratum, compared to site 6 which had patches containing more herbaceous vegetation including grasses.

3.2. *Forage available and stocking in a site using Voisin grazing*

3.2.1. *Site floristic composition before implementing Voisin grazing*

Site 6 was chosen to implement Voisin grazing (contained in G2; Figs. 4 and 5) where 58 species were recorded, within 26 families, of which the Fabaceae was dominant (14 species). It had a greater herb richness (18 species), followed by trees (14 species), shrubs (11 species), vines (9) and lianas (6). The dominant herbaceous species were *Bouteloua repens* (Kunth) Scribn., *Desmodium infractum* DC., *Nopalea dejecta* (Salm-Dyck) Salm-Dyck, *Hyparrhenia rufa* (Nees) Stapf, *Commelina rufipes* Seub., *Blechum pyramidatum* (Lam.) Urb., *Sida rhombifolia* L. and *Lagascea mollis* Cav. The arboreal stratum was dominated by *Guazuma ulmifolia* Lam., *Leucaena lanceolata* S. Watson, *Maclura tinctoria* (L.) D. Don ex Steud., *Handroanthus chrysanthus* (Jacq.) S.O. Grose, *Ipomea wolcottiana* Rose, *Esenbeckia berlandieri* Baill. ex Hemsl., *Wimmeria pubescens* Raldk., and *Sapindus saponaria* L. The shrub layer was dominated by *Randia aculeata* L., *Cordia pringlei* B.L. Rob., *S. pallida*, *Croton miradorensis* Müll. Arg., *C. glabellus* L., *Randia laetevirens* Standl. and *Acaciella angustissima* (Mill.) Britton & Rose. The liana species were *Pisonia aculeata* L., *Tetrapterys schiedeana* Schltdl. & Cham., *Fosteronia spicata* G. Mey., *Serjania racemosa* Seem., and *Pithecoctenium crucigerum* (L.) A.H. Gentry. This site had patches with greater coverage of grasses and forb species.

3.2.2. *Available biomass and stocking*

The biomass available in the 15 paddocks was not homogeneous, there were more productive paddocks (2500–3800 kg DM ha^{-1}) where grasses dominated, and less productive ones with greater woody cover (800–2000 kg DM ha^{-1}). There was more biomass available during the rainy season and the transition period was less productive (Fig. 7). During the dry season,

Table 2
List of the most abundant species by life form in sites with more (G1) and less preserved vegetation (G2) subject to seasonal grazing by cattle.

G1	G2
Trees	**Trees**
Bursera simaruba (L.) Sarg.	*Guazuma ulmifolia* Lam.
Citharexylum berlandieri B.L. Rob.	*Leucaena lanceolata* S. Watson
Trichilia trifolia L.	*Trichilia trifolia* L.
Handroanthus ochraceus ssp. neochrysanthus (A.H. Gentry & S.O. Grose)	*Diphysa minutifolia* Rose
Luehea candida (Moç. & Sessé ex DC.) Mart.	*Esenbeckia berlandieri* Baill. ex Hemsl.
Leucaena lanceolata S. Watson	*Vachellia pennatula* (Schltdl. & Cham.) Seigler & Ebinger
Maclura tinctoria (L.) D. Don ex Steud.	*Ipomoea wolcottiana* Rose
Guazuma ulmifolia Lam.	*Senna atomaria* (L.) H.S. Irwin & Barneby
Erythroxylum havanense Jacq.	*Handroanthus ochraceus* ssp. neochrysanthus
Heliocarpus pallidus Rose	*Wimmeria pubescens* Raldk.
Diphysa minutifolia Rose	**Shrubs**
	Calea ternifolia Kunth
Shrubs	*Calliandra rubescens* (M. Martens & Galeotti) Standl.
Bunchosia biocellata Schlecht.	*Cordia pilosa* M. Stapf & Taroda
Cracca ochroleuca (Jacq.) Benth. & Oerst.	*Acaciella angustissima* (Mill.) Britton & Rose
Randia aculeata L.	*Mimosa tricephala* Cham. & Schltdl.
Randia monantha (Benth.)	*Randia aculeata* L.
Desmopsis trunciflora (Schltdl. & Cham.) G.E. Schatz	*Senna pallida* (Vahl) H.S. Irwin & Barneby
Croton miradorensis Müll. Arg.	*Croton miradorensis* Müll. Arg.
Malvaviscus arboreus Cav.	*Chamaecrista nictitans* Moench
Mimosa tricephala Cham. & Schltdl.	*Croton glabellus* L.
Physalis melanocystis Bitter	*Lantana camara* L.
Croton glabellus L.	*Lantana hirta* Graham
Senna pallida (Vahl) H.S. Irwin & Barneby	*Randia laetevirens* Standl.
Psidium sartorianum Nied.	*Aeschynomene purpusii* Brandegee
Lianas	*Cordia pringlei* B.L. Rob.
Pisonia aculeata L.	*Vachellia cornigera* (L.) Seigler & Ebinger
Fridericia pubescens (L.) L.G. Lohmann	*Amyris purpusii* P. Wilson
Serjania racemosa Seem.	**Lianas**
Fosteronia spicata G. Mey.	*Pisonia aculeata* L.
Combretum fruticosum (Loefl.) Stuntz	*Tetrapterys schiedeana* Schltdl. & Cham.
Herbs	*Serjania cardiospermoides* Schltdl. & Cham.
Lasiacis rugelii Hitchcock	*Byttneria aculeata* Jacq.
Blechum pyramidatum (Lam.) Urb.	*Serjania racemosa* Seem.
Ayenia pusilla L.	**Herbs**
Ruellia inundata Kunth	*Blechum pyramidatum* (Lam.) Urb.
Aldama dentata La Llave	*Bouteloua repens* (Kunth) Scribn.
Bromelia pinguin L.	*Ayenia pusilla* L.
Aeschynomene fascicularis Cham. & Schltdl.	*Commelina rufipes* Seub.
Vines	*Maranta arundinacea* L.
Gonolobus sp. Michx.	*Desmodium infractum* DC.
Baltimora recta L.	*Nopalea dejecta* (Salm-Dyck) Salm-Dyck
Passiflora yucatanensis Killip	*Hyparrhenia rufa* (Nees) Stapf
-	*Euphorbia hyssopifolia* L.
-	*Amphilophium paniculatum* (L.) Kunth
-	*Bidens pilosa* L.
-	**Vines**
-	*Mucuna pruriens* (L.) DC.
—	*Dioscorea floribunda* M. Martens & Galeotti
—	*Operculina pinnatifida* (Kunth) O'Donell

The table lists only the most abundant species, truncating the list between 60 and 78% of coverage; only in the vines of G1 was the truncation made at 90%.

no paddocks were sampled because there was little growth and the study included very few paddocks which were not enough to supply forage each day of the dry season to measure biomass.

The stock density that the paddocks could sustain at the beginning was variable (52–264 AU ha^{-1}), consistent with the available biomass that they supported, and as more grazing periods were performed, the stock density was more homogenized among paddocks up to the range of 170–230 AU in the last evaluation (2018, Fig. 8).

3.2.3. Botanical composition of the forage biomass

Although the site was considered as a paddock with secondary vegetation, the 15 paddocks were heterogeneous in their botanical composition and were separated into three groups (approximate value of the Bray-Curtis index = 0.75). At the beginning of the study, half of the paddocks were combined into G1, which was identified as having the highest total biomass, and dominated by forbs and grass species (Table 4). Group 2, had intermediate amounts of biomass, and contained higher forb

Table 3
Species defined as more important potential forage species based on their abundance and accessibility to cattle, located in sites with secondary vegetation from tropical dry forest and subject to seasonal grazing by cattle. The species were found in sites with more (G1) and less preserved vegetation (G2).

Species	G1	G2	Species	G1	G2
Trees			*Blechum pyramidatum*	x	x
Citharexylum berlandieri	x	–	*Bromelia pinguin*	x	–
Diphysa minutifolia	–	x	*Commelina rufipes*	–	x
Guazuma ulmifolia	x	x	*Desmodium infractum*	–	x
Leucaena lanceolata	x	–	*Dorstenia contrajerva* L.	x	–
Shrubs			*Elytraria imbricata* (Vahl) Pers.	–	x
Acaciella angustissima	–	x	*Euphorbia hyssopifolia*	–	x
Aeschynomene purpusii	–	x	*Hyparrhenia rufa*	–	x
Amyris purpusii	–	x	*Lagascea mollis* Cav.	–	x
Bunchosia biocellata	x	–	*Maranta arundinacea*	x	x
Calea ternifolia	–	x	*Megathyrsus maximus*	x	x
Calliandra rubescens	–	x	*Melampodium divaricatum* (Rich.) DC.	x	–
Cordia pilosa	–	x	*Ruellia inundata*	x	–
Cordia pringlei	–	x	*Ruellia tweedii* (Nees) T. Anderson ex Morong & Britton	x	x
Cracca ochroleuca	x	–	**Vines**		
Croton glabellus	x	x	*Baltimora recta*	x	–
Croton miradorensis	x	x	*Desmodium incanum* DC.	–	x
Lantana camara	–	x	*Dioscorea floribunda*	–	x
Lantana hirta	–	x	*Gonolobus* sp.	x	–
Mimosa tricephala	x	x	*Mucuna pruriens*	–	x
Randia aculeata	x	x	*Operculina pinnatifida*	–	x
Randia laetevirens	–	x	**Lianas**		
Vachellia cornigera	x	x	*Byttneria aculeata*	–	x
Herbaceous			*Pisonia aculeata*	x	x
Aeschynomene fascicularis	–	x	*Serjania cardiospermoides*	–	x
Ayenia pusilla	x	x	*Serjania racemosa*	x	x
Amphilophium paniculatum	–	x	*Tetrapterys schiedeana*	–	x
Bidens pilosa	–	x	Total number of species	23	40

x indicates that the species is potential forage in that group; - indicates that the species was not present.

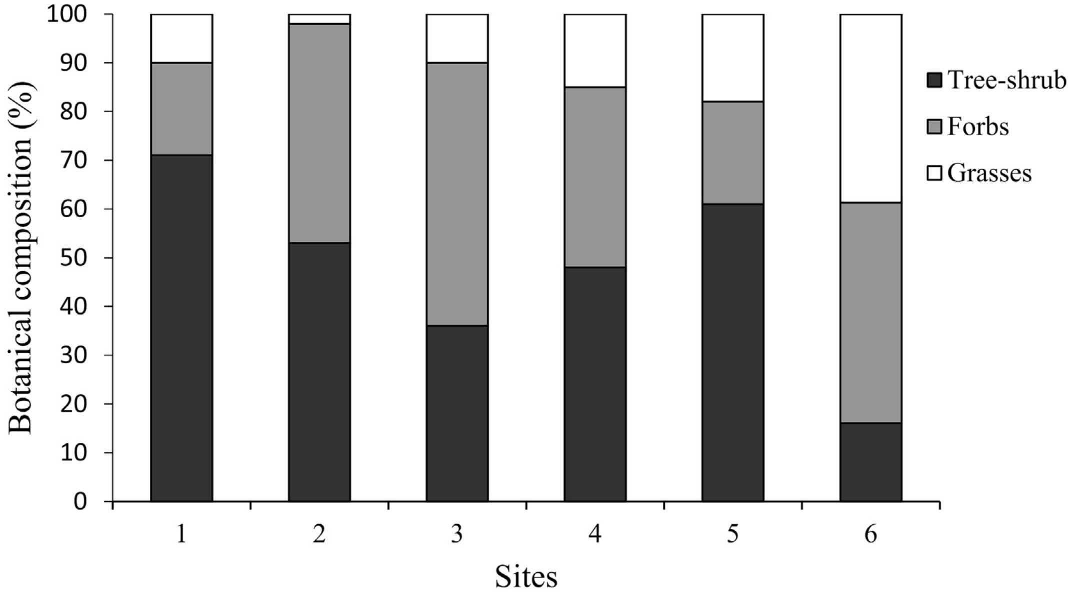

Fig. 6. Botanical composition (%) of the potential forage biomass in the sites, evaluated during the rainy season (July to August 2017 and 2018).

biomass. The third group (G3) had the lowest biomass yield and included paddocks also dominated by forbs, and little presence of grasses (unlike G2).

During the final stage, the paddocks continued to distinguish themselves into the three groups, with a slight increase in the similarity index (approximate value of the Bray-Curtis index = 0.81) and shifts of some paddocks due to changes in their biomass composition (Table 4). More paddocks increased woody species biomass and decreased their forb biomass, and the number of paddocks that lost or gained grass biomass was more balanced (6 *vs.* 8). Here, paddocks having intermediate

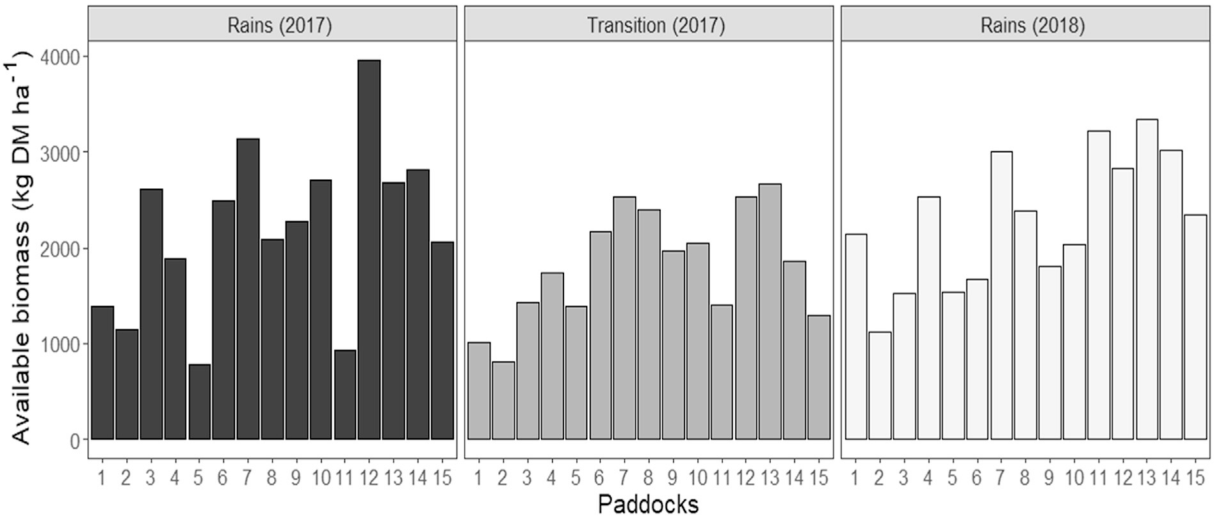

Fig. 7. Available biomass in paddocks with secondary vegetation subject to Voisin grazing, during the rainy season (July to September 2017 and 2018) and transition to the dry season (October to December 2017).

biomass and heterogeneous yet balanced composition of the three plant groups composed G1. Group 2 was the least productive with dominance of woody biomass and almost no presence of grasses (similar to G3 at the beginning). Group 3 was formed by the most productive pastures with dominance of grasses.

The diversity of species present in the paddocks was used by cattle as forage, except for *S. pallida* and *S. rhombifolia* which were not consumed. Even though, a great diversity existed in the paddocks; *H. rufa*, *R. aculeata*, *Desmodium incanum* DC., *F. spicata*, *C. rufipes*, *G. ulmifolia*, *B. pyramidatum*, *B. repens*, *C. miradorensis*, *L. mollis* and *Byttneria aculeata* Jacq. contributed most forage biomass across all paddocks. Utilization was not measured in this research, although green foliage from all plants (except the two aforementioned species) was consumed.

3.3. Recovery time over seasons

Pasture recovery happened at different times depending on season. During the 2017 rainy season, they recovered in 47–89 days after the first grazing, and in 50–123 days during the transition period. After that, the paddocks spent the dry season at rest until their recovery during the following 2018 rainy season, between 210 and 290 days after grazing (Fig. 9).

4. Discussion

4.1. Floristic composition, forage biomass and stocking in sites with secondary vegetation

Species richness observed in this study is considered high, but within the range of known species (59–390) in tropical dry forests in different stages of succession (Medina-Abreo and Castillo-Campos, 1993; Álvarez-Yépiz et al., 2008; Castillo-Campos et al., 2008; Gutiérrez-Báez and Zamora-Crescencio, 2012). The dominance of the Fabaceae is consistent with other reports on similar environments in other regions of Mexico and Latin America (Flores and Bautista, 2012; Alayón-Gamboa and Alvarez-Florez, 2017; Silva-Aparicio et al., 2018). A high richness and a relatively high number of potential forage species represent a great opportunity for livestock to select diverse diets, and benefit from nutrients and secondary compounds contained in the plants (Provenza et al., 2007). Furthermore, the dominance of legume species increases the consumption of nitrogen-rich forages such as *A. angustissima*, *L. lanceolata*, and *Diphysa minutifolia* Rose, as long as the foliage is within reach by the livestock.

All life forms were represented in all sites according to the species diversity and complex structure that secondary vegetation can maintain (Pykälä, 2005; Castillo-Campos et al., 2008). Such a composition creates vegetation structures favorable for herbivore comfort, although cattle might perform better where the structure of the vegetation is less complex and herbaceous plants (including grasses) and shrubs are more abundant given their feeding strategy as roughage consumers (Hofmann, 1989), as in sites within G2. These sites are in an earlier stage of ecological succession and have greater open spaces that favor the growth of herbaceous vegetation (Begon et al., 2006), which might be a combined result of the succession process and grazing management.

Sixty-seven percent of the species identified across all life forms were considered as PFS that were found at heights within reach by livestock. However, only 51 species were forage species because they were more abundant and had greater cover in the sites. This number of PFS (51) is similar to that reported by other authors regarding potential forage that is being used by

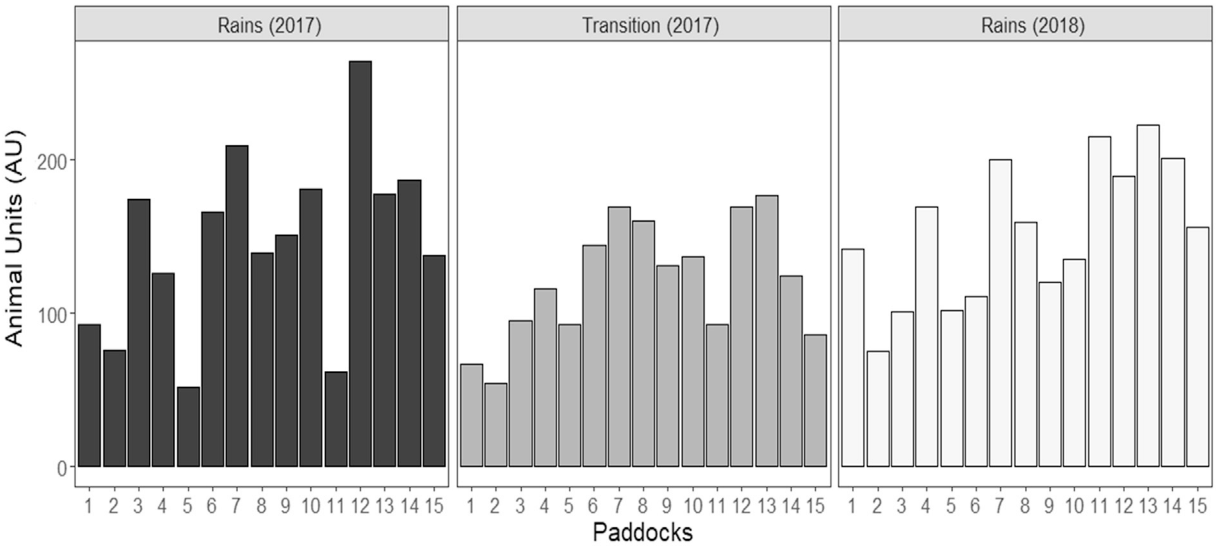

Fig. 8. Stock density in paddocks with secondary vegetation subject to Voisin grazing, during the rainy season (July to September 2017 and 2018) and transition to dry season (October to December 2017).

Table 4
Botanical composition (by life forms) of the forage biomass (kg DM ha^{-1}) in paddocks subject to Voisin grazing by cattle, at the beginning and end of a 14-month period.

Paddock	Beginning			Paddock	End		
	Woody	Forbs	Grasses		Woody	Forbs	Grasses
	.... *Group 1*				... . *Group 1*		
12	241	709	1027	1	390	235	442
7	185	716	977	9	307	278	315
13	118	379	840	15	464	292	415
3	892	892	63	6	429	259	145
9	207	419	509	10	390	235	442
15	173	292	567	Means	396(26)	260(11)	352(56)
8	60	551	431		... . *Group 2*		
Means	268(92)	565(82)	631(129)	4	812	418	34
	.... *Group 2*			5	415	348	3
10	268	1072	16	2	376	173	11
6	367	606	275	3	513	234	12
14	85	1000	320	Means	529(98)	293(55)	15(6)
11	95	209	161		... ... *Group 3*		
Means	204(68)	722(199)	193(67)	7	740	186	576
	.... *Group 3*			12	322	364	728
2	100	453	41	8	333	143	715
5	138	238	0	11	641	199	771
4	98	840	.76	13	302	235	1134
1	242	431	24	14	197	302	1008
Means	145(33)	491(126)	16(9)	Means	423(87)	238(33)	822(84)

* Paddocks ordered on the basis of groups formed by similarity; the Woody group includes trees, shrubs and lianas. Numbers within parentheses are standard errors.

livestock in biodiverse environments (range: 19 to 54 species) (Sosa et al., 2000; Carranza-Montaño et al., 2002; Isselstein et al., 2007; de la O-Toris et al., 2012; Gómez-Fuentes-Galindo et al., 2017). Only 12 species were the most important PFS and differed mainly in tree and shrub species because in some sites fewer woody species were within reach by the cattle.

In sites with vegetation at more advanced successional stages, 22 more important PFS were distinguished and in sites where the structure of the vegetation is less complex up to 41 species. Thus, more forage species were available in areas having less preserved vegetation where there is greater species richness within reach by cattle in the most important PFS category (Cowles, 1899; Antoniadou et al., 2019). Corroborating that these species are a part of the diet of livestock, however, involves more detailed diet selection studies with grazing methods other than extensive or seasonal.

Some PFS are similar to species mentioned in other studies performed in sites with primary or secondary vegetation (Velázquez-Martínez et al., 2010; Gómez-Fuentes-Galindo et al., 2017; Soto, 2019). Woody species contribute to forage

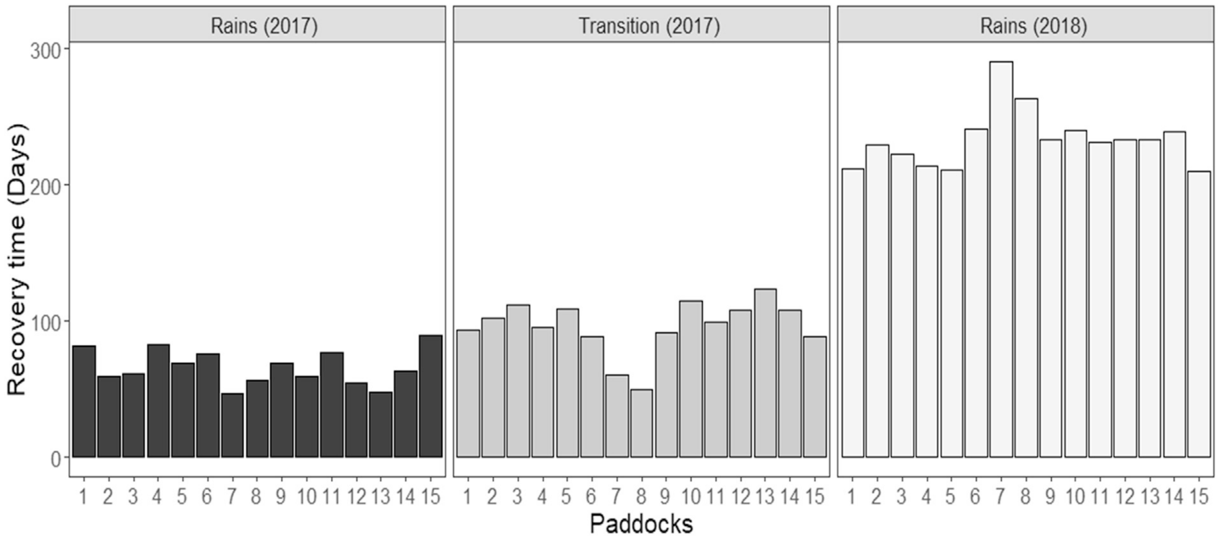

Fig. 9. Recovery time for the paddocks with secondary vegetation subject to Voisin grazing.

biomass during the dry season (Lombo et al., 2013; Franzel et al., 2014), and in the area where this research was conducted some available and abundant species are *R. aculeata*, *G. ulmifolia*, *A. angustissima*, *Mimosa tricephala* Cham. & Schltdl., *D. minutifolia* and *L. lanceolata*, which have previously been mentioned regarding their forage potential (Velázquez-Martínez et al., 2010; Gómez-Fuentes-Galindo et al., 2017; Soto, 2019).

Biomass yield was low across sites (1000–1291 kg DM ha^{-1}), and only sites 1 to 3 yielded slightly more biomass due to a greater abundance of shrubs and herbaceous plants that made up the potential fodder biomass. In these sites, the dominance of shrubs and trees limits the growth of herbaceous vegetation (including grasses that are not very tolerant to shade), which provides the greatest amount of forage biomass. To this limitation is added that species under a high canopy may not be within reach by cattle for browse.

These yields are low compared to that reported by Velázquez-Martínez et al. (2010) during the dry (1480 kg) and rainy season (1790 kg DM ha^{-1}) in tropical dry forest secondary vegetation, where rainfall is higher than in our study area. However, regardless of the type of vegetation, our results reinforce the fact that the forage biomass available in sites with high floristic diversity and complex structure is lower than that in other pasture types (Gómez-Fuentes-Galindo et al., 2017; Rodríguez-Medina et al., 2017; Vermeire et al., 2018).

Consequently, the stocking density that these sites support (67–86 AU ha^{-1}) is also low (less than 100 AU), which is equivalent to a stocking rate from 0.2 to 0.3 AU ha^{-1}, and lower than that estimated by SAGARPA and COTECOCA (2009) for similar sites (0.7 AU ha^{-1}) and for other grazing environments where the growth of forage swards is favored (Franzel et al., 2014; Cortiana-Tambara et al., 2017; Estrada et al., 2018; Loges et al., 2018). Thus, it is lower than the stocking rate threshold (200 AU) for a ranch to be profitable (Pinheiro, 2015).

4.2. Plant community response in a site subjected to Voisin grazing

The biomass available was not homogeneous across the 15 paddocks evaluated, higher yields (2500–3800 kg DM ha^{-1}) were assessed where grasses dominated, and lower yields (800–2000 kg DM ha^{-1}) where woody cover dominated. Small-scale vegetation patches could be induced by previous grazing practiced in the site (Marion et al., 2010) or other successional mechanisms of plant species (Ramirez-Pinero et al., 2019). The fencing of small paddocks can further split patches of vegetation in the site, leading to heterogeneous paddocks in plant composition and available biomass, as evidenced by the cluster analysis we performed.

There was more biomass available during the rainy season due to greater available precipitation and higher temperatures that favor plant growth. Biomass was lower during the transition period because precipitation declined and the plants experienced water stress that led them to lose their foliage, similar to most dry forest species. During the dry season, no paddocks were sampled because there was little growth and the study included few paddocks, which were not enough to supply forage to measure biomass each day of the dry season.

The stock density that the paddocks could sustain at the beginning was variable (52–264 AU ha^{-1}), consistent with the available biomass that they supported. Yet, as more grazing periods were performed, the stock density slightly homogenized among paddocks up to the range of 170–230 AU ha^{-1} in the last evaluation (2018). This may indicate that at the beginning, the botanical composition and forage available was still the result of the extensive and selective grazing practiced on the site, but over time, Voisin grazing promoted the more uniform use of plants and a possible decrease of less grazing-tolerant species, giving step to adjustments in the plant community that favored the availability of light for previously limited species (Vertés et al., 2019). The result was a change of species towards a community of plants with more fodder potential.

During the 2018 rainy season, the annual forage biomass was equivalent to 1.2 AU ha^{-1} stocking rate, higher than the initial rate during the 2017 rainy season, and also higher than the stocking rate (0.7 AU ha^{-1}) used by SAGARPA and COTECOCA (2009) for similar environments in Mexico. It is also comparable to the biomass from *H. rufa* and *M. maximus* measured in the same area where this research was performed, but managed with extensive grazing (Quiroz MS, personal communication), as well as in the association of grasses with native species in Voisin grazing (Guevara et al., 2003; Benítez et al., 2007).

The 15 paddocks built in the site were heterogeneous in their botanical composition. Even though, a great diversity existed among the paddocks, with *H. rufa*, *R. aculeata*, *D. incanum*, *F. spicata*, *C. rufipes*, *G. ulmifolia*, *B. pyramidatum*, *B. repens*, *C. miradorensis*, *L. mollis* and *B. aculeata* contributing most of the forage biomass in all paddocks. Utilization was not measured in this research because total forage utilization was assumed (as promoted by Voisin grazing), and as such, green foliage from all plants (except *S. pallida* and *S. rhombifolia* that were not palatable) was consumed. This behavior of livestock is elicited when high stock densities are exerted over short periods of grazing, because animals change the selective habit for a more voracious consumption due to competition for forage (Humphreys, 1994; Pinheiro, 2015).

Significant shifts in plant composition based on biomass happened within 14-month period in the paddocks, towards a higher equilibrium in biomass from all life forms. Implementing high stock densities as promoted by Voisin grazing exerts nearly the same grazing pressure over all species in a paddock, and this should lead to assemblages of species more adapted to periodical defoliation. It should also lead to yield increase and to homogenized yield among paddocks up to a point, although this could not be observed during this study. However, complete homogenization among paddocks might not happen because of the vegetation heterogeneity induced by patchiness and complex species assemblages in such biodiverse sites (Marion et al., 2010). Furthermore, homogenization among paddocks might not be the desirable end, but rather preserving all life forms and productivity in an acceptable range through management.

Recovery times during the wet season were relatively long (up to 89 d). While this could be influenced by the amount and distribution of precipitation (Azuara-Morales et al., 2020), we observed paddocks that recovered faster had more herbaceous vegetation and the optimal resting point was favored by that vegetation (beginning blooming). Yet, paddocks dominated by woody vegetation accomplished the optimal resting point later in the season, because those species have longer life cycles, and understory herb species must have slower growth rates under limited sunlight (Humphreys, 1994). Summed together, the optimal resting point was delayed compared to pure sward pastures that reach the optimal resting point earlier (Castro-Mendoza M., unpublished results). However, these issues were not addressed in this study.

The long resting periods during the dry season are directly related to the agroecological conditions of the area, mainly the absence of precipitation driving species phenology, because all species in the site belong to tropical dry forest and are sensitive to seasonal changes in rainfall, losing their foliage annually (Trejo, 1999). These results are important for decision-making when designing grazing systems and deciding how many paddocks to install on ranches according to the critical times of year for forage production.

Monitoring the ongoing dynamics of sites having high plant diversity under an alternative grazing system as done in this research, is important, and helps to discern patterns of vegetation and herbivore interactions, within the context and agroecological conditions under which this research was performed. While this might be a limitation of this research compared to performing controlled experiments, evidence of such interactions in similar or different ecosystems will contribute to revealing proper grazing management for such sites. Also, having few paddocks to assess, and limited measurement during the dry season when no data was taken was limiting for this study, but is normal when the majority of useable land is privately owned. Having yield data during the dry season, in such sites under Voisin grazing would be useful for decision-making by ranchers.

5. Conclusions

Floristic diversity in biodiverse foraging sites is high, regardless of their state of plant succession. The richness of forage species comes from all strata, but the participation of each stratum depends on the degree of succession in a site. In the most preserved sites, the greatest richness of forage plants arose from woody species, and in less preserved sites it arose from herbs and shrubs. Over all sites, plant richness was beneficial for livestock diets under current extensive grazing. Yet, the low forage biomass yield and stocking rate may be a deterrent for ranchers to keep such highly biodiverse sites within their land.

Using Voisin grazing, yield and stocking rate increased over time by two-fold compared to extensive grazing and most plant material within reach by cattle became forage in all seasons. Within a year, the forage vegetation changed with more grazing periods, and the available biomass of grasses, forbs, shrubs and trees became more balanced, and a tendency to homogenize yield among paddocks was also observed. However, the critical time for plant growth was long, leading to long recovery periods and few utilization times during a year.

Implementing better grazing systems such as Voisin grazing may be the key to improving productivity of grazing lands undergoing secondary succession. Increasing utilization efficiency of the forage available based on native plant communities, without using intrusive methods to replace that vegetation, is promising, because it is a subtle form of modifying the vegetation over time to shift to biodiverse grazing lands. Managing the correct stock density to meet forage allowance, limiting grazing time to avoid overgrazing, and allowing plants to regrow to achieve the optimal plant growth as promoted by Voisin grazing, are the basic rules to achieving sustainable grazing. As well, enhancing biodiversity through management such as regulating shade and cover of non-palatable invasive species should be considered. Such management is an alternative to the destruction and loss of secondary vegetation to grass monocultures. However, this management should be performed in sites undergoing early plant succession where more herbaceous and shrub vegetation dominate. Old-growth sites must be allowed to continue succession and serve as seed and propagule banks and provide connectivity in agricultural landscapes.

There is a great need to make grazing systems more efficient and ecologically sound, and in all senses, managing local and native vegetation seems a low cost way to do so. Thus, future research should focus on knowing the life cycles and responses of plant species from tropical forests to herbivory, understanding the effects of herbivory on the mechanisms driving biodiversity under more controlled and intensive grazing systems such as Voisin grazing, and the effects on physical-chemical and biological properties of soils in the long-term time. There is also a need to elucidate the influence of structural diversity and how physical and chemical plant properties in such biodiverse environments interact to influence intake and preference by livestock. Above all, research should focus on the benefits of plant diversity on herbivore nutrition, health and well-being in biodiverse grazing lands in the tropics.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank the owners of the ranches where this research was conducted, the undergraduate and graduate students who helped with vegetation sampling, and the staff of the GIS Laboratory from Campus Veracruz for their assistance in making the map.

References

Alayon-Gamboa, J.A., Alvarez-Florez, F., 2017. Diversidad e importancia de la vegetación secundaria en un sistema silvopastoril en Yucatán. México. Agroproductividad. 10, 60–64.

Álvarez-Yépiz, J.C., Martínez-Yrízar, A., Búrquez, A., Lindquist, C., 2008. Variation in vegetation structure and soil properties related to land use history of old-growth and secondary tropical dry forests in northwestern Mexico. For. Ecol. Manag. 256, 355–366. https://doi.org/10.1016/j.foreco.2008.04.049.

Antoniadou, C., Voultsiadou, E., Chintiroglou, C.C., 2019. Succession and colonization. Encyclopedia of Ecology. Elsevier, USA, pp. 369–378. https://doi.org/10.1016/B978-0-12-409548-9.10594-9.

AOAC, 1990. Official Methods of Analysis of the Association of Official Agricultural Chemists, twelfth ed. Published by the Association of Official Agricultural Chemists, Washington, D. C.

Azuara-Morales, I., López-Ortiz, S., Jarillo-Rodríguez, J., Pérez-Hernández, P., Ortega-Jiménez, E., Castillo-Gallegos, E., 2020. Forage availability in a silvopastoral system having different densities of *Leucaena leucocephala* under Voisin grazing management. Agrofor. Syst. https://doi.org/10.1007/s10457-020-00487-5.

Begon, M., Townsend, C.R., Harper, J.L., 2006. Ecology from Individuals to Ecosystems, fourth ed. Blackwell, Victoria, Australia, p. 714.

Benítez, D., Fernández, J.L., Ray, J., Ramírez, A., Torres, V., Tandrón, I., Díaz, M., Guerra, J., 2007. Factores determinantes en la producción de biomasa en tres especies de pastos en sistemas racionales de pastoreo en el Valle del Cauto, Cuba. Rev. Cubana Cienc. Agric. 41, 231–235.

Bonham, C.D., 1989. Measurements for Terrestrial Vegetation. Wiley & Sons, Inc., USA, p. 338.

Bray, J.R., Curtis, J.T., 1957. An ordination of the upland forest communities of southern Wisconsin, 27. Ecological Society of America, pp. 325–349. http://www.jstor.org/stable/1942268.

Carranza-Montaño, M.A., Sánchez-Velásquez, L.R., Pineda-López, M. del R., Cuevas-Guzmán, R., 2002. Calidad y potential forrajero de especies del bosque tropical caducifolio de la sierra de Manantlán, México. Agrociencia 37, 203–210.

Castillo-Campos, G., Halffter, G., Moreno, C.E., 2008. Primary and secondary vegetation patches as contributors to floristic diversity in a tropical deciduous forest landscape. Biodivers. Conserv. 17, 1701–1714. https://doi.org/10.1007/s10531-008-9375-7.

Chiappy-Jhones, C.J., Gama, L., Soto-Esparza, M., Geissert, D., Chávez, J., 2002. Regionalización paisajística del estado de Veracruz, México. Universidad y Ciencia 18, 87–113.

Colwell, R.K., 1997. Estimate*S*: Statistical Estimation of Species Richness and Shared Species from Samples (Software and User's Guide). Version 9.1.0. http://viceroy.eeb.uconn.edu/estimates. accessed: March 20 2019.

Colwell, R.K., 2005. ESTIMATES: statistical estimation of species richness and shared species from samples. Version 7.5. User's Guide and application. Available from: URL: http://oclc.org/estimates.

Colwell, R.K., Coddington, J.A., 1994. Estimating terrestrial biodiversity through extrapolation. Phil. Trans. Roy. Soc. Lond. B Biol. Sci. 345, 101–118.

Cortiana-Tambara, A.A., Regiani-Sippert, M., Cardoso-Jauris, G., Carvalho-Flores, J.L., Henz, E.L., Velho, J.P., 2017. Production and chemical composition of grasses and legumes cultivated in pure form, mixed or in consortium. Acta Sci. Anim. Sci. 39, 235–241. https://doi.org/10.4025/actascianimsci.v39i3.34661.

Cowles, H.C., 1899. The ecological relations of the vegetation on the sand dunes of Lake Michigan. Bot. Gaz. 27, 95–117. https://www.jstor.org/stable/2465177.

de la O-Toris, J., Maldonado, B., Martínez-Garza, C., 2012. Efecto de la perturbación en la comunidad de herbáceas nativas y ruderales de una selva estacional mexicana. Botanical Sciences 90, 469–480. https://doi.org/10.17129/botsci.475.

Estrada, L., Esparza J, I.S., Albarrán, P.B., Yong A, G., Rayas A, A.A., García M, A., 2018. Evaluación productiva y económica de un sistema silvopastoril intensivo en bovinos doble propósito en Michoacán. México. Ciencia *ergo-sum* 29, 1–13. https://doi.org/10.30878/ces.v25n3a7.

Feng, C., Ding, S., Zhang, T., Li, Z., Wang, D., Wang, L., Liu, C., Sun, J., Peng, F., 2016. High plant diversity stimulates foraging motivation in grazing herbivores. Basic Appl. Ecol. 17, 43–51. https://doi.org/10.1016/j.baae.2015.09.004.

Flores, S.J., Bautista, F., 2012. Knowledge of the Yucatec Maya in seasonal tropical forest management: the forage plants. Rev. Mex. Biodivers. 83, 503–518. https://doi.org/10.22201/ib.20078706e.2012.2.1243.

Franzel, S., Kiptot, E., Lukuyu, B., 2014. Agroforestry: fodder trees. Encyclopedia of Agriculture and Food Systems 1, 235–243. https://doi.org/10.1016/B978-0-444-52512-3.00023-1.

García, E., 2004. Modificaciones al sistema de clasificación climática de Köppen. 5a. Instituto de Geografía. Universidad Nacional Autónoma de México, p. 90.

Gómez-Fuentes-Galindo, T., González-Rebeles, C., López-Ortiz, S., Ku-Vera, J.C., Albor-Pinto, C.D.J., Sangines-García, J.R., 2017. Dominancia, composición química-nutritiva de especies forrajeras y fitomasa potential en una selva secundaria. Agricultura, Sociedad y Desarrollo. 14, 617–634. https://doi.org/10.22231/asyd.v14i4.699.
Guevara, R., Ruiz, R., Curbelo, L., Guevara, G., Gálvez, M., Martínez, S., Estévez, J., Pedraza, R.M., 2003. Asociación de Guinea (*Panicum maximum*) con leguminosas nativas explotadas en pastoreo racional en una vaquería comercial. Pastos Forrajes 26, 215–220.
Guevara, S., Lira-Noriega, A., 2004. De los pastos de la selva a la selva de los pastos: la introducción de la ganadería en México. Pastos 34, 109–150.
Gutiérrez-Báez, C., Zamora-Crescencio, P., 2012. Especies leñosas de la selva baja caducifolia de Xmatkuil, Yucatán, México. For. Veracruzana 14, 9–14.
Hector, A., Hautier, Y., Saner, P., Wacker, L., Bagchi, R., Joshi, J., Scherer-Lorenzen, M., Spehn, E.M., Bazeley-White, E., Weilenmann, M., Caldeira, M.C., Dimitrakopoulos, P.G., Finn, J.A., Huss-Danell, K., Jumpponen, A., Mulder, C.P.H., Palmborg, C., Pereira, J.S., Siamantziouras, A.S.D., Terry, A.C., Troumbis, A. Y., Schmid, B., Loreau, M., 2010. General stabilizing effects of plant diversity on grassland productivity through population asynchrony and overyielding. Ecology 91, 2213–2220. https://doi.org/10.1890/09-1162.1.
Hickman, K.R., Hartnett, D.C., Cochran, R.C., Owensby, C.E., 2004. Grazing management effects on plant species diversity in tallgrass prairie. J. Range Manag. 57, 58–65. https://doi.org/10.2458/azu_jrm_v57i1_hickman.
Hofmann, R.R., 1989. Evolutionary steps of ecophysiological adaptation and diversification of ruminants: a comparative view of their digestive systems. Oecologia 78, 443–457. https://doi.org/10.1007/BF00378733.
Hortal, J., Lobo, J.M., 2005. An ED-based protocol for the optimal sampling of biodiversity. Biodivers. Conserv. 14, 2913–2947. https://doi.org/10.1007/s10531-004-0224-z.
Humphreys, L.R., 1994. Tropical Forages, Their Role in Sustainable Agriculture. Longman, Scientific and Technical, Essex, England, p. 414.
Isselstein, J., Griffith, B.A., Pradel, P., Venerus, S., 2007. Effects of livestock breed and grazing intensity on biodiversity and production in grazing systems. 1. Nutritive value of herbage and livestock performance. Grass Forage Sci. 62, 145–158. https://doi.org/10.1111/j.1365-2494.2007.00571.x.
Kovach, W., 1999. MVSP-a Multivariate Statistical Package for Windows. Kovach Computing Services, Pentraeth, UK version 3.2. https://www.kovcomp.co.uk/mvsp/.
Lira-Noriega, A., Guevara, S., Laborde, J., Sánchez-Ríos, G., 2007. Composición florística en potreros de Los Tuxtlas, Veracruz, México. Acta Bot. Mex. 80, 59–87. https://doi.org/10.21829/abm80.2007.1047.
Loges, R., Bunne, I., Reinsch, T., Llub, C., Hermann, A., Taube, F., 2018. Forage production in rotational systems generates similar yields compared to maize monocultures but improves soil carbon stocks. Eur. J. Agron. 97, 11–19. https://doi.org/10.1016/j.eja.2018.04.010.
Lombo, D., Muhammad, I., Villanueva, C., Benjamin, T., Skarpe, C., 2013. Disponibilidad de biomasa y capacidad de rebrote de leñosas forrajeras en potreros del trópico seco de Nicaragua. Agroforestería en las Américas 50, 62–68.
Maharning, A.R., Mills, A.A.S., Adl, S.M., 2009. Soil community changes during secondary succession to naturalized grasslands. Appl. Soil Ecol. 41, 137–147. https://doi.org/10.1016/j.apsoil.2008.11.003.
Marion, B., Bonis, A., Bouzillé, J., 2010. How much does grazing-induced heterogeneity impact plant diversity in wet grasslands? Ecoscience 17, 229–239. https://doi.org/10.2980/17-3-3315.
Medina-Abreo, M.E., Castillo-Campos, G., 1993. Vegetación y listado florístico de la Barranca de Acazónica, Veracruz, México. Bol. Soc. Bot. México 53, 73–111. https://doi.org/10.17129/botsci.1417.
Murphy, W., Rice, J.R., Dugdale, D.T., 1986. Dairy farm feeding and income effects of using Voisin grazing management of permanent pastures. Am. J. Alternative Agric. 1, 147–152. https://www.jstor.org/stable/44506960.
Oñatibia, G.R., Aguilar, M.R., 2019. Grasses and grazers in arid rangelands: impact of sheep management on forage and non-forage grass populations. J. Environ. Manag. 235, 42–50. https://doi.org/10.1016/j.jenvman.2019.01.037.
Pinheiro, L.C., 2015. Pastoreo Racional Voisin: Tecnología Agroecológica para el Tercer Milenio. Editorial Hemisferio Sur S.A., Buenos Aires, Argentina, p. 253.
Provenza, F.D., Villalba, J.J., Haskell, J., MacAdam, J.W., Griggs, T.C., Wiedmeier, R.D., 2007. The value to herbivores of plant physical and chemical diversity in time and space. Crop Sci. 47, 382–398. https://doi:10.2135/cropsci2006.02.0083.
Provenza, F.D., Villalba, J.J., 2010. The role of natural plant products in modulating the immune system: an adaptable approach for combating disease in grazing animals. Small Rumin. Res. 89, 131–139. https://doi.org/10.1016/j.smallrumres.2009.12.035.
Pykälä, J., 2005. Plant species responses to cattle grazing in mesic semi-natural grassland. Agric. Ecosyst. Environ. 108, 109–117. https://doi.org/10.1016/j.agee.2005.01.012.
Ramírez-Pinero, M., Lira-Noriega, A., Guevara, S., 2019. Canopy asymmetry in solitary *Diphysa Americana* trees: wind and landscape on the Mexican coast. J. Coast Conserv. 23, 163–172. https://doi.org/10.1007/s11852-018-0648-3.
R Development Core Team, 2018. R. A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. Available. http://www.R-project.org/. Accessed 5 December 2018.
Rodríguez-Medina, K., Moreno-Casasola, P., Yañez-Arenas, C., 2017. Efecto de la ganadería y la variación estacional sobre la composición florística y la biomasa vegetal en los humedales de la costa centro oeste del Golfo de México. Acta Bot. Mex. 119, 79–99. https://doi.org/10.21829/abm119. 2017.1233.
Sagarpa, Cotecoca, 2009. Coeficientes de agostadero por tipo de vegetación. http://aplicaciones.semarnat.gob.mx/estadisticas/compendio2010/10.100.13.5_8080/ibi_apps/WFServletbe33.html. Accessed 20 April 2019.
Schoenbaum, I., Henkin, Z., Yehuda, Y., Voet, H., Kigel, J., 2018. Cattle foraging in Mediterranean oak woodlands – effects of management practices on the woody vegetation. For. Ecol. Manag. 419, 160–169. https://doi.org/10.1016/j.foreco.2018.03.017.
Silva-Aparicio, M., Castro-Ramírez, A.E., Castillo-Campos, G., Perales-Rivera, H., 2018. Estructura de la vegetación leñosa en tres áreas con Selva Baja Caducifolia en el Istmo-Costa de Oaxaca, México. Rev. Biol. Trop. 66, 863–879. https://doi.org/10.15517/rbt.v66i2.33419.
Sneath, P.H.A., Sokal, R.R., 1973. Numerical Taxonomy: the Principles and Practice of Numerical Classification. W. H. Freeman and Company, San Francisco, USA, p. 573.
Sosa, R.E.E., Sansores, L.L.I., Zapata, B.G.J., Ortega, R.L., 2000. Composición botánica y valor nutricional de la dieta de bovinos en un área de vegetación secundaria en Quintana Roo. Tec. Pecu. Mex. 38, 105–117.
Soto, C.N., 2019. Relación de la calidad de la dieta de bovinos con la remoción de excretas por escarabajos coprófagos, en distintos ambientes de pastoreo. Tesis de Maestría en Ciencias, Programa de Maestría en Agroecosistemas Tropicales. Colegio de Postgraduados, Campus Veracruz, p. 70.
Trejo, V.I., 1999. El clima de la selva baja caducifolia en México. Invest. Geográficas 39, 40–52.
Undersander, D., Albert, B., Cosgrove, D., Hohnson, D., Peterson, P., 2002. Pastures for Profit: A Guide to Rotational Grazing (A3529). Cooperative Extension Publishing. University of Wisconsin-Extension, Cooperative Extension-Minnesota Extension Service. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1097378.pdf. Accessed 10 April 2020.
Velázquez-Martínez, M., López-Ortiz, S., Hernández-Mendo, O., Díaz-Rivera, P., Pérez-Elizalde, S., Gallegos-Sánchez, J., 2010. Foraging behavior of heifers with or without social models in an unfamiliar site containing high plant diversity. Livest. Sci. 131, 73–82. https://doi.org/10.1016/j.livsci.2010.03.001.
Vermeire, L.T., Strong, D.J., Waterman, R.C., 2018. Grazing history effects on rangeland biomass, cover and diversity responses to fire and grazing utilization. Rangel. Ecol. Manag. 71, 770–775. https://doi.org/10.1016/j.rama.2018.05.001.
Vertés, F., Delaby, L., Klumpp, K., Bloor, J., 2019. C-N-P uncoupling in grazed grasslands and environmental implications of management intensification. In: Lemaire, G., C de Faccio, P.C., Kronberg, S. (Eds.), Agro-Ecosystem Diversity: Impact on Food Security and Environmental Quality. Academic Press, USA, pp. 15–34. https://doi.org/10.1016/B978-0-12-811050-8.00002-9.
Voisin, A., 1988. Grass Productivity. Island Press Edition, Washington, DC, p. 353.
Wang, L., Wang, D., Liu, J., Huang, Y., Hodgkinson, K.C., 2011. Diet selection variation of a large herbivore in a feeding experiment with increasing species numbers and different plant functional group combinations. Acta Oecol. 37, 263–268. https://doi.org/10.1016/j.actao.2011.02.010.