

# Does Stocking Rate Manipulation Promote Pasture Sustainability in the Humid Tropics?

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## Abstract

Stocking rate manipulation was examined as a means of improving plant diversity (as a measure of pasture sustainability and forage value) in a native grass pasture used for dairy production in the humid tropics of Veracruz, Mexico. Given that environmental impact reduces biotic diversity, plant phylogenetic and functional diversity should decline with increased stocking rate. Stocking rates of 2, 3, and 4 cows · ha<sup>-1</sup> and a rotational grazing plan of 3 d of occupation and 27 d of rest per pasture were applied continuously over 5 yr. Across 200 quadrats in each of two replicate paddocks per treatment, observed species richness, phylogenetic diversity (average taxonomic distinctness based on species presence/absence), and functional diversity (life-cycle duration and growth habit) were assessed. Most species were forb/herbs and forb/herb-subshrubs. Perennial species declined with increased stocking rate ( $F=16.36$ ,  $0.05 > P > 0.02$ ) while annual-perennial species increased ( $F=76.88$ ,  $0.01 > P > 0.005$ ); the proportion of annual species was least prominent and did not differ significantly. Observed species richness and phylogenetic diversity did not differ significantly with stocking rate. The correlation between functional diversity for life-cycle duration and phylogenetic diversity was significant and positive, suggesting that plant communities were predominantly assembled randomly from the surrounding species pool rather than through interspecies interactions acting to naturally filter immigrant species, thus leading to more opportunistic and undesired species. Although grazing pressure was not sufficient to alter indices or production measures, they did reveal shifts that may precede further pasture decline, indicating pasture sustainability was not being achieved. These rapid assessment methods permit monitoring for early warnings of reductions in pasture sustainability and forage quality for cattle.

**Key Words:** grazing, growth habit, life-cycle duration, observed species richness, plant diversity, rapid survey assessment

## INTRODUCTION

Rising demands for agricultural productivity will raise pressures on pastures in many regions of the world, increasing the difficulty for improving pasture sustainability. The general objective of land managers or ranchers in such systems is to increase forage yield so that higher stocking rates can be applied to improve animal production. Such goals, however, must be balanced by practices that avoid loss of biodiversity, freshwaters contaminated by agricultural runoff, degraded land, and invasions by undesired or introduced species (e.g., Harper et al. 1990; Archer 1995, 1996; Edwards et al. 2000; Smith et al. 2000; Campbell et al. 2010; see also Shachak et al. 2008), changes that lead to declines in production goals and financial returns (e.g., Friedel 1991; Laycock 1991; Holechek

1996). This is a difficult balance to achieve (Briske and Heitschmidt 1991; Stafford Smith 1996; Kauffman and Pyke 2001), especially in developing and underdeveloped regions of the world where poverty and near-subsistence rural living conditions are common. Such situations promote increased land use to meet subsistence needs and to supplement those needs with some market income from sales of dairy products and meat.

In the humid tropics of Mexico, more than 60% of livestock pastures are largely composed of native grasses in the genera *Paspalum*, *Axonopus*, *Cynodon*, and *Setaria* (Enríquez 1996; Améndola et al. 2005; Castillo et al. 2005). Such native grass pastures are the main source of forage for meat and dairy cattle in the state of Veracruz (Aluja and McDowell 1984; Menocal et al. 1992) and are important because they rapidly produce forage biomass and are adapted to tropical environments (Améndola et al. 2005). Yet animal production systems in the tropics are characterized by forage that is available only for short growing periods (Argel 2006), and native grass species in Veracruz generally have lower forage quality than introduced grasses (Enríquez 1996) because native grasses are more adapted to an adverse tropical environment (prolonged dry conditions and low soil fertility), resulting in low production, rapid maturity, and a subsequently rapid loss of nutritional quality (a rapid increase in fiber content and reduction in crude protein and leaf:stem ratio with rapid maturity) (Dabo et al. 1987). As such, more species-rich native grass pastures are often converted to less rich exotic grass pastures for intensive

Research funding was provided to J.J.R. by the Programa de Apoyo a Proyectos de Investigación e Innovación Tecnológica (PAPIIT) of the Universidad Nacional Autónoma de México, through grant IN205805, "Efecto de la carga animal bovina sobre la morfogénesis de gramas nativas y su calidad nutritiva en el trópico húmedo mexicano."

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Manuscript received 1 July 2011; manuscript accepted 29 January 2013.

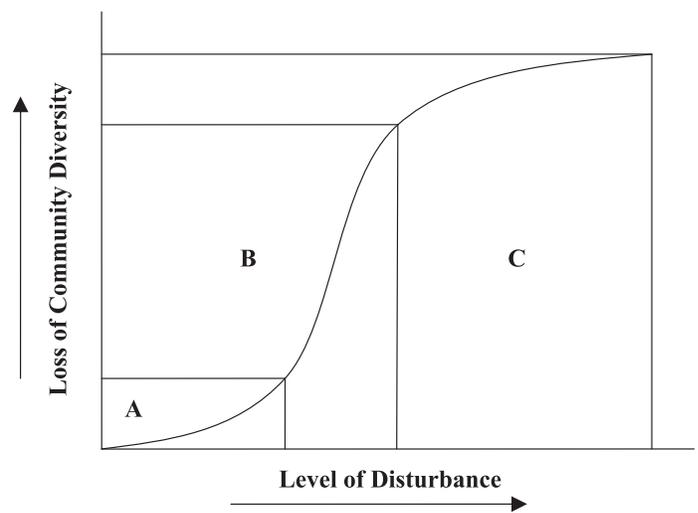
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grazing by livestock (Asner et al. 2004). Alternatively, since older native grass forage has lower nutritional quality (Dabo et al. 1987), stocking rates are manipulated to prolong the time for active grass growth (i.e., increasing forage value) to improve animal performance (Aluja and McDowell 1984; Dabo et al. 1988; Ungar and Noy-Meir 1988; Enriquez 1996; Ackerman et al. 2001; Fike et al. 2003; Améndola et al. 2005; see also McNaughton 1979). Yet increased stocking rates or prolonged grazing periods negatively affect dry matter yield by reducing plant regrowth, altering pasture botanical composition, and influencing plant utilization and the expression of grazing resistance/tolerance among plant species (Briske 1996). At high enough levels, pasture structural modifications occur that alter livestock foraging behavior (e.g., Gibb 2006), resulting in decreased forage intake and animal performance—a contradiction to pasture and livestock sustainability objectives.

Just as important as extended forage productivity is the maintenance of plant diversity to help offset the shorter growing period for grasses. Retaining diverse plant species having different growth habits and phenologies provides a healthy forage mix for livestock and for the maintenance of ecosystem equilibrium and function (Johnson et al. 1996; Fonseca and Ganade 2001; Lyons et al. 2005; Provenza et al. 2007, 2009; Shachak et al. 2008; see also Villa-Herrera et al. 2009; Manríquez 2010).

The relation between the loss of community diversity (plant or animal) and the degree of disturbance imparted by environmental impact is not linear (Fig. 1), and different indicators of impact generally perform better in different regions along the conceptual curve. At low levels of disturbance, communities are generally resilient/tolerant, displaying few early signs of change and without significantly altering community composition (Fig. 1, region A), suggesting measures of functional traits may provide better insight under such conditions. As the degree of disturbance increases beyond thresholds of resilience/tolerance (Fig. 1, region B), its effects are more rapidly propagated throughout a community, resulting in more detectable changes in community structure and composition with smaller degrees of added impact. In this region, biomonitoring indices and measures of production are generally most effective. At higher levels of disturbance (Fig. 1, region C), communities are profoundly disrupted as is physical habitat, and effects are often better assessed by focusing on the physical environment rather than biomonitoring indices or production measures. However, points defining the boundaries of each curve region and, thus, when a chosen measure is no longer informative are not exact; imagining such diagrams as having regions that blend, or grade, one into another is helpful in this regard. Using a range of indices and measures is, therefore, a practical approach when assessing disturbance.

To assess change in the phylogenetic diversity of plant communities resulting from impacts such as grazing, quantitative measurements are required for comparison (Magurran 2004), with species being the most natural and commonly accepted unit for such analyses. Phylogenetic variation is implicit in the perception of diversity, a property not encompassed by species richness alone (which treats all species equally). The greater the taxonomic difference among species, the greater the phylogenetic diversity (Clarke and Warwick



**Figure 1.** Conceptual model showing increased loss of community diversity with increasing disturbance. Region A: Low level of disturbance, the community is still relatively resilient/tolerant and likely to display a few early signs of change without significant alterations to community diversity. In this region of the curve, measures of functional traits may work best. Region B: Smaller levels of added disturbance result in larger changes to diversity because the influence has passed the community's tolerance/resilience thresholds. In this region, biomonitoring indices and production measures are generally more useful because the effects from disturbance are propagated throughout the community. Region C: High level of disturbance, biomonitoring indices and production measures are less likely to be useful. In this region, the community is strongly disrupted as is physical habitat; disturbance may be better assessed by measuring the physical environment.

2001; Magurran 2004), such that more closely related species (i.e., lower diversity) characterize disturbed assemblages, while species spread across a wider array of taxonomic levels (i.e., higher diversity) reflect assemblages experiencing less disturbance (Warwick and Clarke 1995).

Groupings of plant species based on functional traits in a community complement measures of phylogenetic diversity when assessing change because they reflect functional categories that influence the performance of a species group in its environment (e.g., Barkman 1988; Bullock et al. 2001; Lavorel and Garnier 2002). Functional diversity refers to the variety of functional traits (e.g., growth habit) and their trait states (e.g., grass, forb/herb) that describe an assemblage of organisms (e.g., Mayfield et al. 2005; Fontaine et al. 2006) and is better linked to sustained ecosystem performance than is species richness (e.g., Tilman et al. 1997; Diaz and Cabido 2001; Hooper et al. 2005; Diaz et al. 2007). Because most functional traits are conserved within major phylogenetic lineages, less disturbed communities are composed of many lineages having more trait states (i.e., higher diversity) than more disturbed communities having fewer major lineages (i.e., lower diversity) (Warwick and Clark 1995; Prinzing et al. 2008). In terms of life-cycle duration (e.g., annual, perennial), plants with shorter versus longer life cycles may experience less grazing pressure (e.g., Feeny 1976). Alternatively, plants intensively grazed throughout their growing season can be at a competitive disadvantage with plants that are dormant or quiescent during this period. Both grazing scenarios lead to more species having

shorter life-cycle durations (e.g., Archer and Smeins 1996; Briske 1996; Lavorel et al. 1997; Diaz et al. 2007).

Given that environmental impact is negatively related with diversity (e.g., Warwick and Clarke 1995, 1998; Campbell et al. 2010), we evaluated the effect of stocking rate manipulation (used to promote pasture sustainability) on plant phylogenetic and functional diversity in a tropical native pasture used for dairy production. Our hypothesis was that indices of phylogenetic and functional diversity would decline with increased stocking rate.

## METHODS

### Site Description

The study was carried out at the Centro de Enseñanza, Investigación y Extensión en Ganadería Tropical (CEIEGT), Facultad de Medicina Veterinaria y Zootecnia (FMVZ), Universidad Nacional Autónoma de México (UNAM), located in the municipality of Tlapacoyan, in the state of Veracruz, Mexico (lat 20°02'N, long 97°06'W; 112 m a.s.l.). The climate classification is Af(m)w''(e), tropical hot and humid with rains occurring throughout the year (with most deposition occurring from June through September/October), and the average annual temperature and precipitation are 23.5°C ± 0.5°C and 1991 ± 392 mm, respectively (García 1981). The soil in the region is characterized as acid Ultisol (pH 4.5–5.2), with K (8.5 ppm), low nitrogen (0.032%) and phosphorous (2.32 ppm) and is shallow in depth (8–30 cm) (Toledo 1986). The arable layer is somewhat shallow (≤25 cm) and limited by a hard bottom layer (*tepetate*) which contains acid silicates and results in limited root penetration and impaired drainage.

### Animals and Experimental Design

Holstein × Brahman (also called Zebu, or Cebú; *Bos taurus* L.) multiparous F1 cows with an average weight of 489.9 ± 67.5 kg were used for the study, and stocking rates of 2, 3, and 4 cows · ha<sup>-1</sup> were applied and were achieved by placing 10 cows per treatment in 5-, 3.3-, and 2.5-ha paddocks, with each treatment having 10 replicates (Jarillo-Rodríguez 2009; Jarillo-Rodríguez et al. 2011); disease control measures for the cows were applied as needed. The paddocks were established in February 2002, and a rotational grazing plan was applied with 3 d of occupation and 27 d of rest per paddock throughout each year over the course of the study. Control paddocks were not established because such areas are not normally present; ranchers put all pastureland to use for economic and subsistence needs. Thus, our objective was to evaluate the effects of different stocking rates used for pasture management; an absence of cows in such systems is not a useful management method for ranchers and was, therefore, not available.

### Data Collection

Quadrat sampling for plant community composition was performed from August to September 2007. Within each of two replicate paddocks chosen randomly from each stocking rate treatment, two linear transects (oriented along the longest pasture axis) consisting of 100 0.25 m<sup>2</sup> rectangular quadrats (equidistantly spaced to cover each transect length) were

randomly laid out (but not closer than 1.5 m from the fence line), yielding a total of 1 200 quadrats distributed over all six paddocks. Data from both transects in each replicate paddock were combined for analysis. Given that plant subspecies determination is highly impractical in the field, species was used as the ultimate level of taxonomic identification. Within each quadrat, the presence of all plant species was recorded (observed species richness). Plant taxonomic nomenclature and authority were obtained from the United States Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS 2011), the Integrated Taxonomic Information System (ITIS 2011), the International Plant Names Index (IPNI 2011), and associated official URL links (i.e., federal, scientific society, etc.), as was information on growth habit (grass, forb/herb, subshrub, shrub, tree, and intergrades such as subshrub-shrub that reflect a species' flexibility in growth form), phylogenetic group (grass, nongrass), and life-cycle duration (annual, perennial, and annual-perennial; the latter refers to species whose life-cycle duration is flexible).

### Data Analysis

Sampling effort was assessed using sample-based rarefaction curves (Gotelli and Colwell 2001) and their 95% confidence intervals, which were calculated for each paddock (transects combined) using EstimateS, version 8.0.0 (Colwell 2007), with each curve based on 50 randomized iterations. Recorded species were organized into hierarchical taxonomic classifications (i.e., taxonomic relatedness) consisting of species, genus, family, order, and class, with all species united through the division Magnoliophyta (Table S1; available online at <http://dx.doi.org/10.2111/REM-D-11-00110.s1>). Phylogenetic diversity was estimated per paddock using average taxonomic distinctness (ATD; PRIMER v5, PRIMER-E Ltd., Plymouth, UK; Clarke and Gorley 2002). The index uses presence/absence data to integrate observed species richness and taxonomic relatedness to yield an average path length connecting species pairs chosen at random from all species collected (Clarke and Warwick 1998). Examinations of statistical properties, index performance, and the differential weighting of step lengths between hierarchical taxonomic levels have shown average taxonomic distinctness is a robust index for the assessment of effects from environmental impact (Clarke and Warwick 1998, 1999; Warwick and Clarke 1998; Schweiger et al. 2008), even with variations in sampling effort (Price et al. 1999), and the data do not suffer from the variance-related problems associated with abundance-based sampling (e.g., Gotelli and Rohde 2002). Thus, sampling effort can be applied expediently to provide a rapid survey assessment of community structure and composition.

Functional diversity was calculated using the Shannon Index (e.g., Girão et al. 2007) on the proportion of species among trait states within the functional traits of growth habit and life-cycle duration. Spearman rank correlation coefficients (Zar 1984) were calculated between observed species richness, average taxonomic distinctness, and the functional diversity for growth habit and life-cycle duration across stocking rates to see whether stocking rate influenced the importance of species interactions in plant community assembly (e.g., Prinzing et al. 2008); significance was set at  $\alpha=0.1$ . Kruskal-Wallis tests

( $\alpha=0.1$ ) with two replications per treatment were conducted across stocking rates on observed species richness, average taxonomic distinctness, and functional diversity based on growth habit and life-cycle duration. Single-factor analyses of variance ( $\alpha=0.1$ ) were used to analyze the proportions of species in each phylogenetic group and life-cycle duration (for which both variables were arcsine square-root transformed prior to analysis) (Zar 1984). When response means differed significantly, a Tukey multiple comparison test was applied ( $\alpha=0.1$ ) (Zar 1984).

## RESULTS

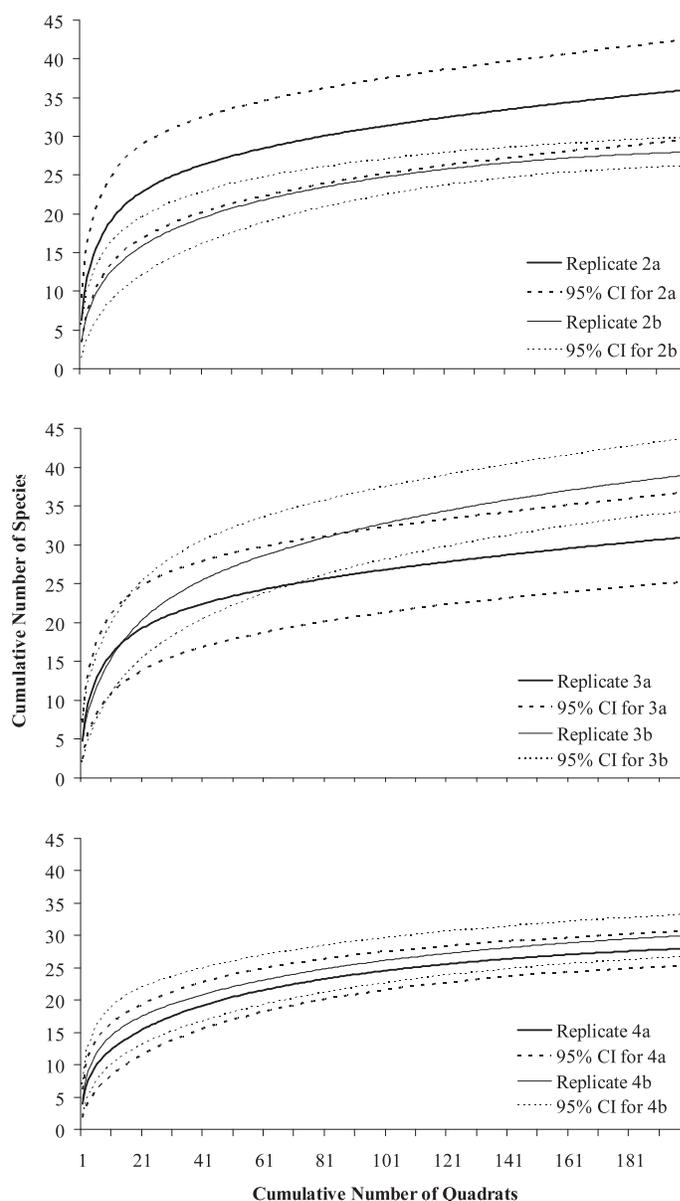
Sampling efforts provided a total of 56 plant species distributed across 37 genera, 18 families, 13 orders, and 2 classes (Table S1). Examination of the sample-based rarefaction curves revealed sampling efforts were adequate, and that sampling adequacy improved as stocking rate increased (Fig. 2). At the highest stocking rate, curves from the randomly chosen replicate paddocks for a stocking rate treatment were more similar to each other, and observed species richness in the two paddocks also was more similar.

Observed species richness, average taxonomic distinctness, and functional diversity based on growth habit and life-cycle duration did not differ significantly across stocking rates ( $H=2.279$ ,  $H=3.215$ ,  $H=3.714$ ,  $H=3.714$ , respectively,  $P > 0.1$  in all cases; Figs. 3 and 4). Most species were perennial, and their proportion declined significantly with increased stocking rate ( $F=16.36$ ,  $0.05 > P > 0.02$ ), while the proportion of annual-perennial species increased significantly with stocking rate ( $F=76.88$ ,  $0.01 > P > 0.005$ ; Fig. 5). The proportion of annual species was least prominent and did not differ significantly across stocking rates ( $F=2.4$ ,  $0.5 > P > 0.2$ ). Although the proportion of nongrass species was greater than for grasses, the values within each phylogenetic group did not differ significantly across stocking rates ( $F=0.956$  and  $F=0.976$ , respectively;  $P > 0.5$  in both cases; Fig. 5). A breakout of the nongrasses by growth habit showed the majority were forb/herbs and forb/herb-subshrubs (Fig. 6).

Spearman rank correlation coefficients between the different pairs of variables revealed two highly significant positive correlations, one between the functional diversity for life-cycle duration and average taxonomic distinctness, and the other between observed species richness and functional diversity based on growth habit (Table 1).

## DISCUSSION

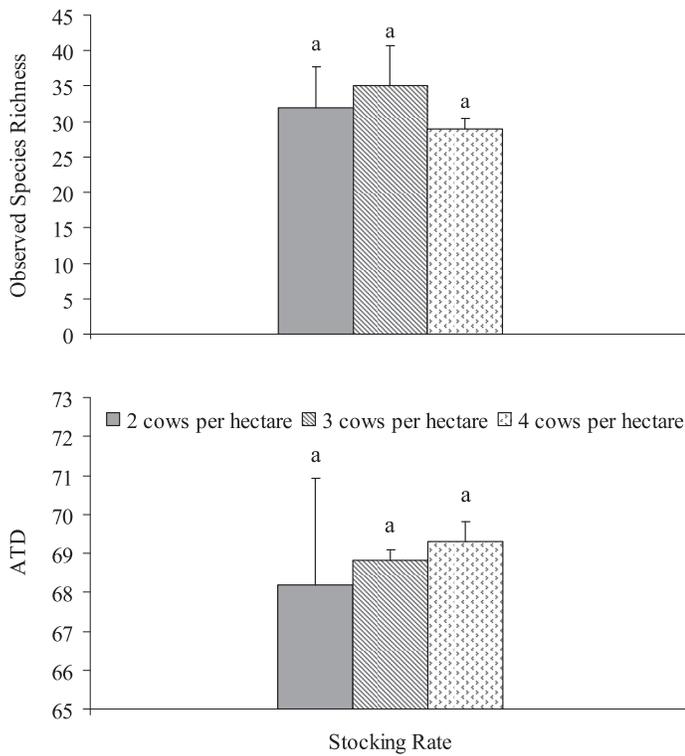
A relatively rapid and significant increase in the proportion of annual-perennial species was observed with increased stocking rate, as was a significant decrease in the proportion of perennial species. These changes do not indicate improved sustainability of the pasture plant community. Increased grazing pressure promoted more short-lived plants or good dispersers that colonized disturbed areas produced by grazers. Longer-lived plants are more damaged by grazing and cannot exploit openings (bare zones or areas with reduced competition) (Feeny 1976; Briske 1996; Archer and Smeins 1996; Lavorel



**Figure 2.** Sample-based rarefaction curves and their 95% confidence intervals (CI) for two randomly chosen replicate paddocks in each of the three stocking rates (replicate letters, a and b, are for graphic reference).

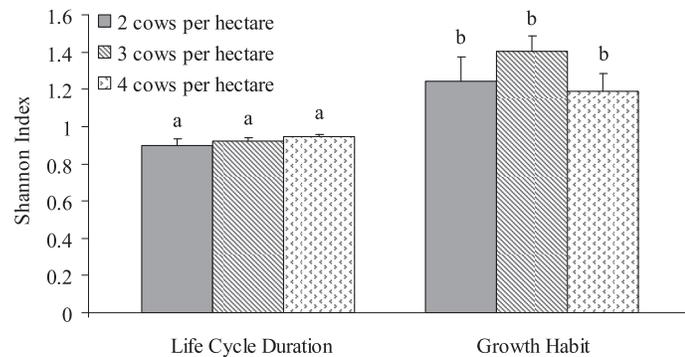
et al. 1997; Bullock et al. 2001). Although there was no species survey prior to paddock establishment, Jarillo-Rodríguez (2009) reports that the vegetation at the beginning of the experiment was relatively homogeneous in distribution and was composed of 86.9% native grasses, 2.9% introduced grasses, 1.7% native leguminous species, and 8.5% wide- and narrow-leaved weeds, thus supporting the assertion that the results were grazing-induced.

In the principal investigation preceding this report, Jarillo-Rodríguez (2009; see also Jarillo-Rodríguez et al. 2011) revealed no significant effects from stocking rate on standard measures of yield, nutritive quality, or pasture utilization for the dominant and abundant forage grasses *Axonopus compressus* (Sw.) P. Beauv. and *Paspalum notatum* Alain ex Flügge in the study site (i.e., tillers  $\cdot m^{-2}$ , leaf area, foliar growth rate, level of tiller use, tiller length and height, number of

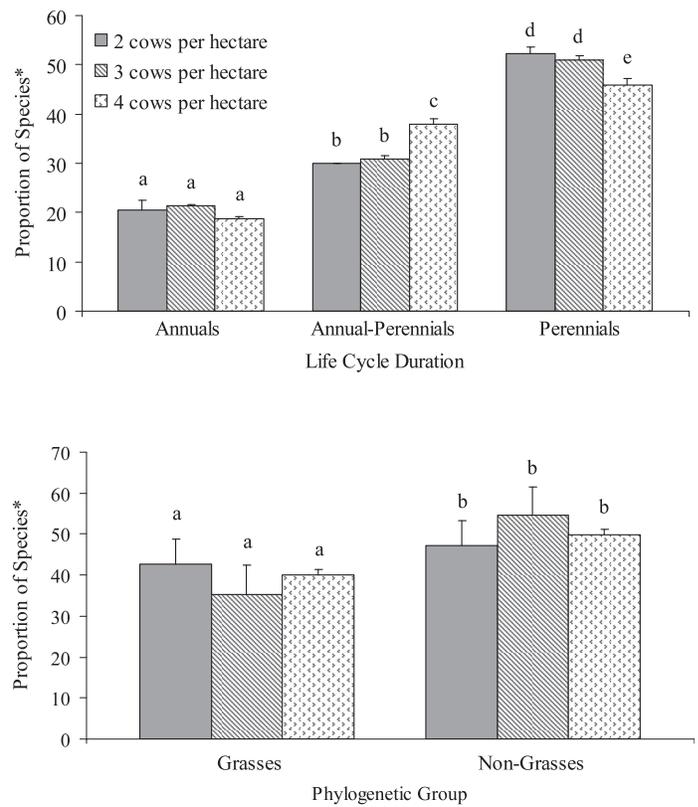


**Figure 3.** Observed species richness and average taxonomic distinctness (ATD) by stocking rate (SD whisker above each bar). The same letters above each bar indicate no significant difference ( $\alpha=0.1$ ).

leaves  $\cdot$  tiller<sup>-1</sup>, dry matter, root length, leaf and stem crude protein, neutral detergent fiber, and rumen digestion of leaf dry matter), although the amount of bare ground increased significantly with stocking rate. Further, stocking rates in Veracruz pastures are reported to range from 1.4 (Menocal et al. 1992) to 2.9 cows  $\cdot$  ha<sup>-1</sup> (Aluja and McDowell 1984; Hernández et al. 1998; Alarcón et al. 1999) without apparent negative effects on pregnancy rates of cows, weaning weight of calves, or calf weight gain. Without considering the proportional contributions of the different plant functional trait states, these production measures might suggest that pasture sustainability management methods were working. However, contri-

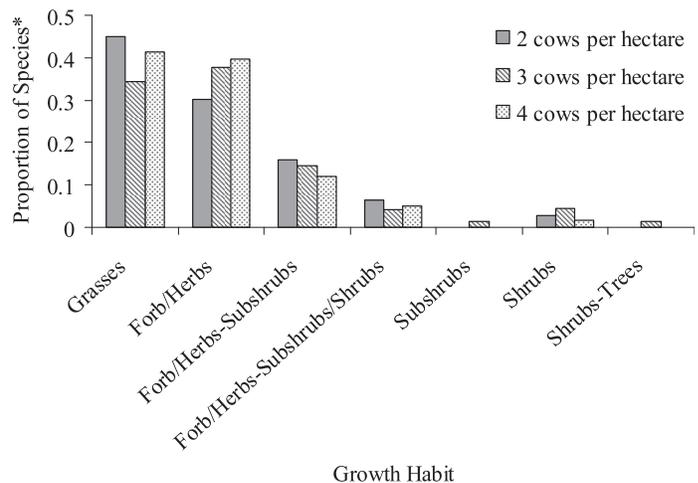


**Figure 4.** Functional diversity (Shannon Index) across stocking rates for life-cycle duration and growth habit. The similar letters above the bars within each functional trait indicate no significant difference ( $\alpha=0.1$ ; SD whisker above each bar).



**Figure 5.** Proportion of species (\*=arcsine square-root transformed) by stocking rate for life-cycle duration and phylogenetic group. Different letters above the bars indicate significant differences within each functional trait state ( $\alpha=0.1$ ; SD whisker above each bar).

butions from the functional trait states instead suggest that plant communities were responding, but had not yet responded sufficiently so that effects involving diversity indices and measures of forage quality were not realized. The significant and positive correlation between observed species richness and functional diversity based on growth habit (Table 1) suggests that if longer or higher grazing pressure did result in the decline



**Figure 6.** Proportion of species in each of the different growth habits across stocking rates (\*=values are averages of the two transects per grazing treatment).

**Table 1.** Spearman rank correlation coefficients among pairs of biological indices across the three stocking rates ( $\alpha=0.1$ ; \*=significant; SR=observed species richness, ATD=average taxonomic distinctness, H(LCD)=functional diversity based on life-cycle duration, H(GH)=functional diversity based on growth habit.

	SR	ATD	H(LCD)	H(GH)
SR	1			
ATD	-0.5	1		
H(LCD)	-0.5	1*	1	
H(GH)	1*	-0.5	-0.5	1

of species richness or growth habit diversity, then the other would also likely decline. As such, responses to grazing were most likely closer to the upper end of region A in Figure 1.

Positive correlations between indices of phylogenetic diversity and functional diversity may reflect a random community assembly process that draws from the surrounding species pool (Prinzing et al. 2008; see also Foster et al. 2004; Dickson and Foster 2008). This type of assembly process very often leads to the establishment of opportunistic species in the community (e.g., Fleischner 1994; DiTomaso 2000; Milchunas 2006; Vavra et al. 2007). Although the degree of change depends on the ecosystem, plant community, environmental conditions, and intensity and timing of grazing, changes have generally been more evident in ecosystems where grazing ungulates have been historically scarce or absent (Milchunas 2006) (e.g., the Mexican tropics). In contrast, in undisturbed communities with a more stable composition, interspecies interactions dominate the filtering of immigrant species. The strong positive correlation between phylogenetic and functional diversity and lack of significant change in either of these diversity indices across the grazing treatments suggests that community assembly is random in all the imposed levels of grazing pressure. In this case the colonization success of immigrant species is based on their rapidity of establishment and growth. Habitats open to colonization, such as those in the higher stocking rates and bare ground in this study, present opportunities and challenges to land managers. Open habitats may be good for restoration by seed or manual plantings, but such communities also are more unstable and susceptible to the entrance and establishment of less competitive, opportunistic, and toxic species. Indeed, both *Heliotropium indicum* L. (India Heliotrope) and *Solanum americanum* Mill. (American Black Nightshade), species known to be toxic to livestock and to establish better in disturbed sites, were observed in the two higher stocking rates.

Reductions in the proportion of perennial species and increases in the proportion of annual-perennial species prior to and during the study may also occur because of climate change. Global warming is altering precipitation and temperature patterns throughout many regions of the world. In the state of Veracruz, between 1969 and 1998, rainfall declined by 40 mm per year, and temperature decreased by 0.02°C per year (Gay et al. 2006). Annual precipitation in the state is predicted to decline further between 5% and 20% (IPCC 2007), and one form of adaptation by plant communities to reduced precipitation is to increase the number of species with shorter or more flexible life-cycle durations. Such flexibility allows new populations to explore novel habitats having variable quantity

and quality of resources, and to improve the survivability of others in existing habitats exposed to variable or prolonged change in resource availability (Archer and Smeins 1996; Barbour et al. 1998). Although climate change may have already shifted these plant communities to have shorter or more flexible life cycles, similar shifts caused by grazing pressure were still detected. The fact that these two stresses are expected to have similar effects on the plant communities suggests greater danger of increased grazing pressure in the future than seen in the results of this study.

The greater similarity in the rarefaction curves and generally reduced 95% confidence intervals for individual curves at the highest stocking rate suggest greater uniformity of species' spatial distributions within and between replicate paddocks. Reduced grazer selectivity and therefore more uniform impacts on all plants as stocking rate increased may be the cause of this similarity. Regardless of the cause, the patterns in rarefaction curves among the stocking rate treatments imply that these curves could be useful for detecting early community responses (i.e., region A in Fig. 1).

In summary, plant responses occurring in region A of Figure 1 were better assessed using direct measures of functional traits or sample-based rarefaction curves than by using measures of animal and pasture production or diversity indices that are more suited to detecting stronger effects propagated throughout the community. However, correlations involving said indices did provide supporting complementary information to further suggest that plant community composition was likely closer to the upper end of region A in Figure 1. Thus, future research and management efforts should use measurement methods with varying sensitivities to facilitate the detection of grazing impacts so that effects are not overlooked. Reducing stocking rates may ease pressures on plant communities but may be difficult considering the poverty faced by most ranchers in the region and their resultant need to improve subsistence conditions. Progress toward pasture sustainability will require that lasting economical, educational, and ecological bridges be built with ranchers to improve pasture management practices. Implicit in this effort is that political and socioeconomic conditions promote access, practicality, and adaptivity in investigations and tangible economic returns from the application of solutions.

## IMPLICATIONS

Increased stocking rates often implemented to increase animal production by improving forage value may have counterproductive effects on pasture sustainability. Such increases were associated with a decline in the proportion of perennial species, an increased presence of undesired species, and possibly decreased spatial variability among and within paddocks. Changes such as these in a pasture plant community provide an early warning to ranchers and land managers that further grazing pressure may have adverse effects on pasture sustainability; monitoring for such warning signs is prudent. The choice of measures to use for pasture monitoring should span detection sensitivities in order to provide evidence of changes in the pasture plant community before they are translated into costly or potentially irreversible shifts in forage quantity and

quality. Compared to abundance-based assessments for monitoring plant diversity, methods employing the use of species presence-absence in this and other studies are more easily and rapidly applied in the field and provide increased cost-effectiveness for sampling effort. This rapid assessment approach not only lends itself well to providing academic research and training experiences, but also can more effectively promote the integration of local ranchers and land managers (e.g., in extension, outreach, and citizen science) in field efforts, thus helping to build bridges for the improvement of pasture and economic sustainability.

## ACKNOWLEDGMENTS

We thank A. Symstad and the anonymous referees for helping to improve the manuscript. We also thank Ramiro Escobar-Hernández and Horacio Díaz-Esteban for their tireless assistance in the field.

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