Range Mgmt. & Agroforestry 40 (2) : 196-201, 2019
ISSN 0971-2070

Efficacy of landscape function analysis to assess differences between grazed and ungrazed rangelands in an arid landscape

Mohsen Sharafatmandrad* **and Azam Khosravi Mashizi**
Department of Natural Science, Faculty of Natural Resources, University of Jiroft, Jiroft, Iran
*Corresponding author e-mail: mohsen.sharafatmandrad@gmail.com
Received: 21st August, 2018 Accepted: 16th July, 2019

Abstract
This study was aimed to investigate the ability of landscape function analysis (LFA) procedure in distinguishing the functional differences between grazed and ungrazed rangelands. Ten transects were laid out in each rangeland. Different patch types were identified and their dimensions were measured to calculate landscape organization index. Soil surface indicators were also quantified within patches and inter-patches. LFA indices were extracted including: surface stability, infiltration, and nutrient cycling. There were significant differences between grazed and ungrazed areas and also between all grazing intensities. The difference between the infiltration of ungrazed and moderately grazed areas was not significant, but the difference was significant between severely grazed and moderately grazed areas. The results reflected the performance of the LFA procedures in evaluating and monitoring the status of rangelands.

Keywords: Ecosystem, Environment, Land degradation, Vegetation

Introduction

Biophysical resources of rangelands can be used to identify rangelands vulnerability for land degradation (Dharumarajan *et al.,* 2017). Assessing the health and function of patches such as shrubs in rangeland ecosystems over time in responses to environment and managerial interactions is important for the exploiters of these ecosystems *i.e.*, local pastoralists or residents (Minaseb *et al.,* 2018; Read *et al.,* 2016; Tongway and Hindley, 2004; Forouzeh and Sharafatmandrad, 2012). This assessment will lead to the adoption of managerial decisions that promotes the ecosystems qualitatively (Pyke *et al.,* 2002). The rangeland fertility limitations are varying with landform and soil properties (Lalitha *et al.,* 2018). The performance of arid and semi-arid rangeland ecosystems is widely influenced by ecological and hydrological processes and their feedbacks and interactions on different scales (Noy - Meir, 1973; Wilcox *et al.,* 2003; Ludwig *et al.,* 2005). So, new procedures for rangeland health assessment originated from a substantial shift in their underlying theories from ecological theories to eco-hydrological concepts. There is a strong relationship between hydrological processes and vegetation particularly in water-restricted environments, because vegetation patterns in these humidity regimes composed of patches with high biomass cover inter-sparsed within a low-cover or bare soil component (Saco *et al.,* 2006).

There are huge differences in the main processes of an ecosystem between the patches and inter-patches. The amount of water intercepted and run into soil by patches can reach upto 200% the net rainfall (Dankerley, 2002). The runoff-runon mechanism triggers a positive feedback, that is, increases soil moisture in vegetated patches reinforcing the pattern (Wilcox *et al.,* 2003; Turnbull *et al.,* 2008).

In patches analysis, it is possible to generalize information from smaller scales (patches) to larger scales (plant communities and landscapes) that can provide a proper perception of rangeland conditions (Ludwig *et al.,* 2005). The Landscape Functional Analysis (LFA), presented by Tongway and Hindley (2004), is a simple procedure for quantitative evaluation and monitoring of the potential and function of patches in the natural ecosystem of arid and semi-arid regions, which use quickly measurable indicators to determine the function of patches and landscape. Vegetation and soil indicators that are referred as ecological indicators in a natural ecosystem (Pyke *et al.,* 2002), are quantitative and measurable characteristics of plants and soil that indicate the dynamics of a habitat or natural system (Pellanet *et al.,* 2000). Rangeland changes shown by this procedure lead to better understanding of the environmental processes and have the greater potential to convert data into a set of useful information for direct application by land managers and supervisors. Speed and low and simple tools requirements for measuring soil surface indicators are two important points of this procedure, which ensure accurate and precise data collection and well correlation between measured indicators and environmental processes (Tongway and Hindley, 2004).

Hence, in this study, the efficiency of the LFA in an arid ecosystem was investigated. LFA was applied to evaluate the function of ecological patches of rangeland ecosystems. Therefore, in the present study, the following objectives were considered: (1) evaluation of rangeland function by LFA procedure in order to find out the effectiveness of this method in showing the differences in the functional characteristics of rangeland ecosystems, (2) evaluation of the effect of grazing on the functional characteristics of rangeland ecosystems, and (3) comparison of rangeland function indices between different grazing intensities.

Materials and Methods

***Study area*:** The field study was conducted in Mahonoiyeh rangeland located in Baft county, Kerman Province in South-East of Iran (28° 59' –28° 25' N and 56° 02' – 46° 39' E). The landscape is alluvial plains with a mean annual precipitation (MAP) of 340.8 mm, mean annual temperature (MAT) of 17.6°C and elevation between 2000-2200 m a.s.l. Geologically, sediments in this section are young alluvial terraces of the Cenozoic era with coarse-textured loam and sandy loam Entisol. The dominant plant species in this region are *Artemisia sieberi*, *Zygophyllum atriplicoides*, *Peganum harmala*, *Astragalus podolobus* and *Stipa barbata* with 10, 1.9, 1.8, 1.6 and 1.2% canopy covers, respectively.

***Data collection*:** Sampling was done separately for the grazed and ungrazed areas. It should be noted that the grazed and ungrazed areas were similar in terms of ecological characteristics, and their only distinguishing factor was their management (livestock grazing). The ungrazed areas were excluded from livestock grazing for about 20 years and separated from adjacent grazed areas by fences, ditches and a road. The area under grazing was also divided into two grazing intensities: moderately grazed and highly grazed based on Holechek and Galt (2000) procedure. Therefore, there were three grazing treatments namely ungrazed, moderately grazed and severely grazed areas. In each area, ten 50 m transects were parallelly laid out at random intervals.

Along each transect, different patch types were identified and their length and width and the distances between them (i.e. inter-patches) were measured. Soil surface indicators (Table 1) were also quantified within patches and inter-patches for five of them along each transect. Soil surface indicators definition and measurement were based on Tongway and Hindley (2004). Soil surface indicators were used to evaluate the condition of rangeland landscapes by producing three numerical indices namely: stability, infiltration and nutrient cycling that considered to reflect the status of landscape function. Scores obtained for soil surface indicators were grouped into 3 indices. If all indicators were present, scale ranged from 8 to 40, 6 to 57 and 4 to 43 for stability, infiltration and nutrient cycling, respectively. The final sum of scores obtained for each indices were then converted to a per cent value of the maximum.

Table 1. Soil surface indicators used to assess the rangeland landscape function and their relationship with landscape function indices

Indicators	Landscape function indices		
	Stability	Infiltration	Nutrient cycling
Rainsplash protection	*		
Perennial vegetation cover		*	*
Litter	*	*	*
Cryptogam cover	*		*
Crust broken-ness	*		
Erosion type and severity	*		
Deposited materials	*		
Soil surface roughness		*	*
Surface nature	*	*	
Slake test	*	*	
Texture		*	

***Data analysis*:** After field sampling, the data were entered into LFA spreadsheet and landscape functioning indices were calculated. Then Landscape function indices and landscape organization index (LOI) were accordingly compared between the grazed and ungrazed areas and also between different grazing intensities. LOI was the sum of all individual patch lengths measured along transect divided by the transect length (Tongway and Hindley, 2004). To do so, data were first tested for normality and Student's t-test was then used to compare the grazed and ungrazed areas.

Further analyses addressed one-way ANOVA followed by a Tukey HSD to compare different grazing intensities in terms of landscape function indices. All statistical analyses were performed using Minitab16 (Minitab Inc., State College, Pennsylvania).

Table 2. The mean of landscape function indices for patches without considering management practices

Landscape function indices (%)	Patches				
	Shrub	Grass	Forb	Shrub/grass	Shrub/forbs
Stability	40.8	37.7	35.9	43.5	41.8
Infiltration	24.2	21.6	17.7	26.8	23.9
Nutrient cycling	14.3	12.4	11.7	15.5	14.3

Results and Discussion

Patches structure: In the region, four patches were identified including shrubs, grasses, forbs, shrub/grass and shrub/forbs. Descriptive statistics of these patches were recorded (Table 2). For all indices, mix patches *i.e.* shrub/grasses and shrub/forbs had the highest scores. It means that these patches had the highest functionality in comparison to others. It can be related to the dense structure of these kinds of patches that effectively retain runoff and nutrient. In contrast, forb patches had the lowest indices.

LFA indices and grazing: The results of t-test indicated that there was a significant difference between grazed and ungrazed areas in terms of stability, infiltration, nutrient cycling and landscape organization index ($P<0.05$). The grazed areas had significantly lower soil stability, infiltration, nutrient cycling and landscape organization index in comparison to ungrazed areas (Table 3). Based on these results, the difference in the nutrient cycling index between the grazed and ungrazed areas was statistically significant. This index in grazed areas was higher than ungrazed areas, which was consistent with the results of Heshmati *et al.* (2006). Other study showed that grazing exclusion can substantially enhance soil respiration (Dongliang *et al.,* 2017). The difference in landscape organization index between the grazed and ungrazed areas was statistically significant. This indicator was higher in the ungrazed areas than the grazed areas, which was different from the results of Heshmati *et al.* (2006). They stated that the landscape organization index did not differ significantly between the exclosure and grazed areas. There was significant difference between the grazed and ungrazed areas in terms of infiltration, which was consistent with the results of Heshmati *et al.* (2006). Their results showed that the infiltration index in the grazed areas was significantly reduced compared to the ungrazed areas.

There are conflicting reports about the impact of grazing on the characteristics of a rangeland ecosystem which make us to evaluate rangeland function in different regions. High livestock density and extended exploitation beyond allowed grazing season were the factors that negatively affected the soil and vegetation of a region, as the high grazing intensity causes changes in the soil surface indicators and the landscape function indices of the rangelands (Habibian and Heshmati, 2015; Yari *et al.,* 2011; Heshmati *et al.,* 2006). Statistically, there was a significant difference between the grazed and ungrazed areas, regardless of the grazing intensity. So that the grazed areas had a much lower landscape function indices than the ungrazed areas, which was consistent with the results of some earlier studies (Safaei *et al.,* 2019; Molaeinasab *et al.,* 2018; Read *et al.,* 2016; Lotfi Anari and Heshmati, 2009; Heshmati *et al.,* 2006).

Table 3. Differences in landscape function indices between the grazed and ungrazed areas.

Landscape function indices (%)	Ungrazed	Grazed	P
Stability	18.51	11.21	<0.05
Infiltration	27.01	20.75	<0.05
Nutrient cycling	53.92	32.95	<0.05
Landscape organization index	0.38	0.19	<0.05

LFA indices and grazing intensity: The results of analysis of variance showed that stability, infiltration, nutrient cycling and landscape organization index were different in three grazing intensities ($P<0.05$). There was a significant difference in soil stability between the three grazing intensities ($P<0.05$) and the severely grazed areas had the lowest soil stability. In regard to infiltration, there was no significant difference between the moderately grazed and ungrazed areas, but the difference between moderately grazed and severely grazed areas was significant ($P<0.05$). Three grazing intensities were significantly different in terms of nutrient cycling ($P<0.05$) and the lowest nutrient cycling was related to the severely grazed areas. Finally, landscape organization index was significantly different between the three grazing intensities and the severely grazed areas had the lowest landscape organization index (Table 4).

Table 4. Differences in landscape function indices between different grazing intensities

Landscape function indices (%)	Grazing intensities			P
	Light grazing	Moderate grazing	Severe grazing	
Stability	18.51[a]	13.78[b]	8.64[c]	<0.05
Infiltration	27.01[a]	24.54[a]	16.97[b]	<0.05
Nutrient cycling	53.92[a]	39.93[a]	26.96[c]	<0.05
Landscape organization index	0.38[a]	0.25[b]	0.13[c]	<0.05

Means of three grazing intensity in each rows with the same letters had no significant differences

Based on the results of the effect of different grazing intensities on landscape function, it was found that there was a statistically significant difference between different grazing intensities and the grazing of the livestock caused changes in the soil surface indicators and functional characteristics of the rangeland soil, so that the mean values of the scores in the moderate to severe grazing areas decreased significantly in comparison to the light grazing area. The results were consistent with the results of other researchers (Habibian and Heshmati, 2015). In terms of soil stability, there was a significant difference between the three grazing intensities and the lowest soil stability index was related to severely grazed areas. In relation to infiltration, there was no significant difference between the moderately grazed and ungrazed areas, but the difference between the moderately and severely grazed areas was significant which was in line with the results of some earlier studies (Lotfi Anari and Heshmati, 2009) and inconsistent with other studies (Habibian and Heshmati, 2015). The reason for non-compliance results could be related to different grazing managements and vegetation composition of the regions, because different plant species are very effective in determining the infiltration index due to having different growth forms and basal areas (Lotfi Anari *et al.,* 2010). There was a significant difference between the three grazing intensities in nutrient cycling index, and the lowest nutrient cycling index was related to severely grazed areas. Finally, in relation to the landscape organization index, there was a significant difference between the three grazing intensities, and the lowest organization index was related to severely grazed areas.

In the ungrazed area, perennial vegetation and litter cover was higher than grazed area which contributed to higher stability, infiltration and nutrient cycling and better condition of soil (Gutierrez and Hernandez, 1996). Higher landscape function indices *i.e.*, stability, infiltration and nutrient cycling in the ungrazed area can be due to increased vegetation diversity and cover in this region (Sharafatmandrad *et al.,* 2014), while the grazed areas, especially in arid and semi-arid regions, had less coverage and diversity. Due to the direct relationship between the amount of erosion and grazing intensity, the soil surface micro-relieves decrease with the increase of grazing intensity, which reduces vegetation and litter cover (Ghoddousi *et al.,* 2005). Breaking the soil surface crusts and soil compaction in heavy grazing reduces the ability to stabilize nitrogen and consequently the ecosystem's function decreases in these conditions (Habibian and Heshmati, 2015; Ghelichnia *et al.,* 2008).

Conclusion

Landscape function indices *i.e.*, soil stability, infiltration, and nutrient cycling was improved with decreasing grazing intensity. Undoubtedly, exclosure or reduction of grazing intensity helps to improve the rangelands condition. As the results showed, there were significant differences between different grazing intensities in all landscape function indices. Therefore, grazing management practices change soil surface indicators and functional indices and the LFA procedure can identify these changes. Hence, our results confirmed the efficacy of landscape function analysis for assessing rangelands changes under different managements. As a suggestion, it can be recommended that it is possible to maintain rangeland health and exploit them at the same time by applying moderate grazing intensity in arid to semi-arid areas.

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