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Landscape Functionality Analysis of Soil Surface Conditions in an Arid Zone: A Case Study of Lajaneh Piosphere, Iran

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Abstract: Livestock grazing changes landscape functionality, nutrient availability and soil structure, and surface conditions in dryland rangelands. A piosphere is a zone of interaction among vegetation, watering point and livestock. This study uses landscape and soil indicators to evaluate the condition of the soil surface in Lajaneh piosphere, Shahrood, Iran. Lajaneh is in an arid region, with predominant land cover of *Zygophyllum eurypterum,* and grazed by camels, goats and sheep. We used landscape function analysis (LFA) and trigger-transfer-reserve-pulse (TTRP) to derive eleven soil surface indicators which were measured and combined to calculate the three indices of infiltration, stability and nutrient cycling. One-way ANOVA and Tukey's post hoc tests were used to find the differences in infiltration, stability and nutrient cycling indicators among three distances 10, 100 and 1000 m. Significant differences were found in infiltration, stability and nutrient cycling among at 10 m, 100 m and 1000 m from watering point. The three indices of nutrient cycling, infiltration and stability increased with increasing distance from watering point. Our study showed the importance of vegetation patches and runoff/runon processes in soil surface condition, and showed the results of grazing pressure on soil health centered on the "sacrifice zone" closest to the watering point and decreasing with distance. We show that the LFA method is an effective measure for monitoring soil surface health around watering points and piosphere, balancing the feedbacks and offtakes based on the condition of soil surface indices.

Key words: LFA, piosphere, arid zone, overgrazing, offtakes, feedbacks.

Water controls the growth and vitality of plant and animal species in arid zones. Where mineral (salt) licks and water are supplied in rangelands in arid zones, the distribution of livestock is changed and this makes the mineral block sites and watering holes foci of livestock congregation (Danckwerts *et al*., 1993). Osborn *et al.* (1932) in Australia and Valentine (1947) in the Chihuahuan Desert, USA were the first researchers who reported grazing intensity around watering point. Lange (1969) completed his research on sheep track and dung patterns on Lincoln Gap Station, west of Port Augusta, South Australia and introduced the term piosphere: a combination of livestock, watering point and grazing lands. *Pios* in Greek means "to drink" (Lange, 1969). Patterns of soil and vegetation disturbance around piospheres will show evidence of localized pressure on soil and plant species (Heshmati *et al*., 2002). Intensive grazing in arid lands kills plant species, erodes soil nutrients and increases the rate of soil erosion (Eze *et al*., 2018; Parsons *et al*., 2017). Piosphere-associated grazing changes the size of vegetation patches and density (Havstad *et al*., 2017; Jawuoro *et al*., 2017), height (Shahriary *et al*., 2012), tree-grass ratio (Thrash and Derry, 1999) and sex ratio of shrubs (Graetz, 1976, 1978).

Ludwig and Tongway (1997, 2000) introduced a Trigger-Transfer-Reserve-Pulse (TTRP) framework to show the landscape function of arid land soil and vegetation in response to water and erosion (Fig. 1). Rainfall and wind trigger the erosion and transfer resources such as litter, water and seed from the bare patch/interpatch to a vegetation patch (sink). Thus begins a pulse of growth in the vegetation patch, improving the function and structure of the landscape. Fire and grazing remove pulse production from landscape and vegetation patches are not able to capture the resources (Ludwig, 2005). Ludwig *et al*. (1999) and Ludwig and Tongway (2000) stated that when landscape losses and input are equivalent, it can be maintained in balance.

In the present work, we aim to study landscape functionality by using landscape function analysis (LFA) (Tongway and Hindley,

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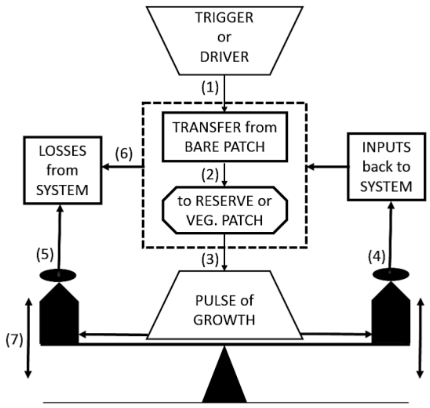

Fig. 1. Trigger-transfer-reserve-pulse (TTRP) framework (Ludwig and Tongway, 1997, 2000) (John A. Ludwig, Disturbances and landscapes: The little things count. In John A. Wiens, Michael R. Moss (Eds.), pp. 42-51. Issues and Perspectives in Landscape Ecology © Cambridge University Press 2005).

2004) at the Lajaneh piosphere in the arid climate zone of Shahrood, Semnan province, Iran (Shahriary *et al*., 2012). A companion study (Shahriary *et al*., 2018) has also been conducted at the Mojen piosphere in the steppe zone of Iran.

Landscape function analysis (LFA) methods combine eleven soil surface indicators (Tongway, 2010) and provide three indices of stability, nutrient cycling and infiltration (Tongway and Hindley, 2004). The index of stability indicates the soil resistance to erosion and its potential to recover after disturbance. The index of infiltration indicates the runoff lost and water availability for vegetation and the index of nutrient cycling indicates the decomposition of organic matter. We aim to assess the landscape functionality along transects radial to watering points using eleven soil surface indicators and calculation of three indices of stability, nutrient cycling and infiltration.

Materials and Methods

The location of the study was in Lajaneh, in an arid-climate zone of Semnan province, northeast Iran (55°01′30″E, 36°10′30″N) (Fig. 2). Lajaneh has a mean annual precipitation of 97.3 mm. The maximum temperature recorded in this region is 42°C in June and the minimum temperature is - 8.4°C in December. The primary plant cover is of the species *Zygophyllum eurypterum.* Other vegetation species in this region are *Salsola vermiculata, Tamarix aphylla, Peganum harmala, Alhaji camelorum* and *Atraphaxis spinose.* The vegetation in this arid region is under grazing by camel, goat and sheep.

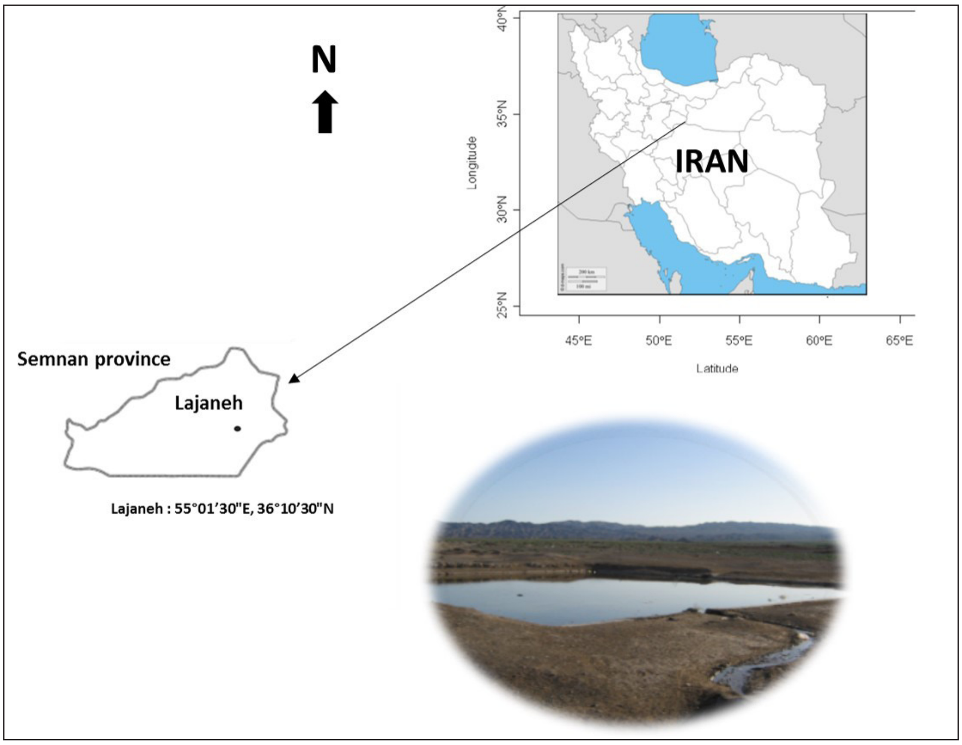

Fig. 2. Location of Lajaneh, Iran, where data collected around the watering point.

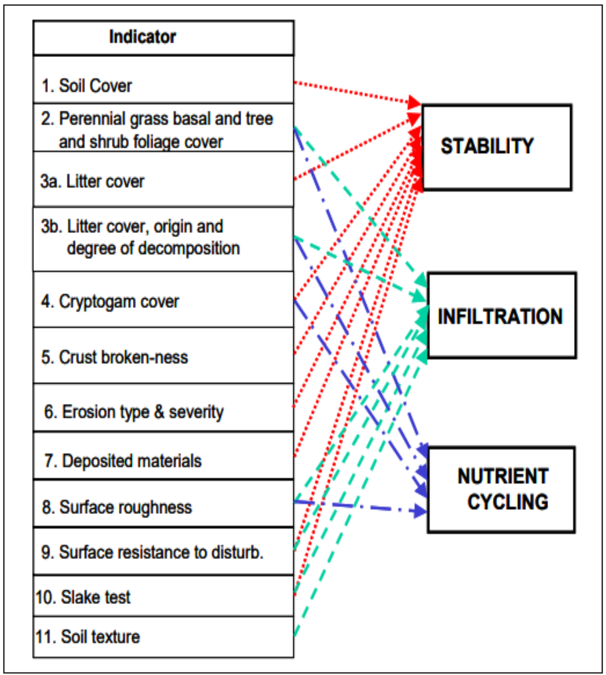

Fig. 3. Combination of the scores of 11 soil surface condition indicators to calculate stability, infiltration and nutrient cycling indices (Copyright © CSIRO Australia) (Tongway and Hindley, 2004).

The area around the Lajaneh watering point was classified into three different distances 10 m, 100 m and 1000 m. Eleven soil surface condition indicators (Fig. 3) for LFA were measured at five replicates of *Zygophyllum* patches and interpatches using 50 m transects (Fig. 4) according to the guidelines of soil surface assessment method (Tongway and Hindley, 2004). Each soil surface condition indicator shows the condition of processes at soil surface (Tongway and Hindley, 2004). Eleven soil surface condition indicators combined to derive three indices of stability, infiltration and nutrient cycling with a Microsoft Excel worksheet (Landscape Function data entry V3.0) developed by CSIRO Sustainable Ecosystems (2003). One-way ANOVA (P <0.05) and Tukey's post hoc tests (Quinn and Keough, 2002) were used to find the differences in infiltration, stability and nutrient cycling among three distances 10, 100 and 1000 m using AOV and HSD test functions and agricolae package [version 1.2-8 (de Mendiburu, 2012)] in the R software (R Core Team, 2018).

Results and Discussion

The stability, infiltration and nutrient cycling indices of *Zygophyllum* patches and interpatches improved with increase in distance from watering points (Table 1). We found statistically significant differences in each index; stability, infiltration and nutrient cycling, among the three distances 10, 100 and 1000 m (P<0.05) (Table 1). Grazing intensity caused the significant differences in infiltration indices, for example indices in *Zygophyllum* patches at 10, 100 and 1000 m from watering point were 22, 24 and 46 and in interpatches 16, 20 and 25, respectively.

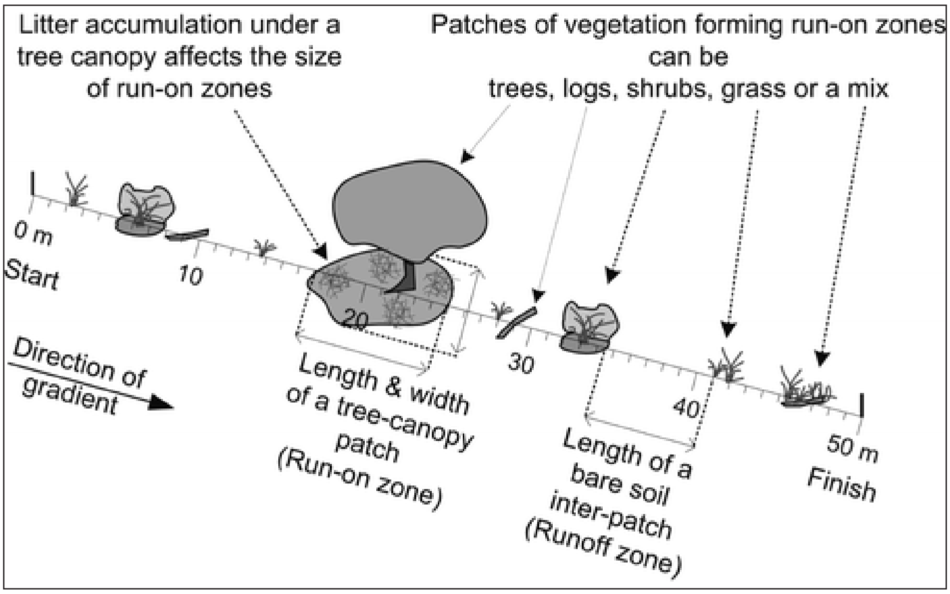

Fig. 4. Illustration of transect for LFA monitoring, showing patches and interpatches (from Restoring Disturbed Landscapes by David J. Tongway and John A. Ludwig. Copyright © 2011 by the authors. Reproduced by permission of Island Press, Washington, DC) (Tongway and Ludwig, 2011).

Grazing intensity has an inverse relationship with soil infiltration rate (Gross *et al.*, 2015; Kneller *et al.*, 2018). The "sacrifice area" immediately around the watering point is highly overgrazed, resulting in trampling, loss of vegetation and soil disturbance (Graetz and Ludwig, 1976, Travers *et al.*, 2018). Intensive grazing around watering points removes the protective cover of vegetation and compacts the soil surface (Evans, 1998). Intensive grazing decreases water infiltration and vegetation production pulses and increases water and wind erosion (Fynn *et al.*, 2017; Santos *et al.*, 2017; Erickson, 2017; Li *et al.*, 2017; Magliano *et al.*, 2017; Gaitán *et al.*, 2017). Cox and Amador (2018) and Concostrina-Zubiri *et al.* (2017) found a significant relationship between the grazing gradient along the watering point and soil infiltration.

Decrease in patch length, density and width reduces the resources capturing and intensifies the rate of erosion (Frank *et al.*, 2018; Peri *et al.*, 2017). Overgrazing in the sacrifice area adjacent to the watering point prevents production pulses. The indices of stability of *Zygophyllum* patches were 44 (10 m distance), 47 (100 m distance) and 50 (1000 m distance) and in interpatches were 33 (10 m distance), 41 (100 m distance) and 48 (1000 m distance) (Table 1). The *Zygophyllum* patches act as sinks, capturing water and nutrients and entrapping materials from sources resulting in areas with high grazing pressure depicted as Fig. 5a.

Table 1. Soil surface condition indices, stability, infiltration and nutrient cycling along watering point in arid zone Lajaneh (Mean ± SD)

Soil surface condition indices	Distance (m)	*Zygophyllum* patch	Interpatch
Stability	10	44 ± 0.15 c	33 ± 0.29 c
	100	47 ± 0.36 b	41 ± 0.18 b
	1000	50 ± 0.18 a	48 ± 0.30 a
Infiltration	10	22 ± 0.73 c	16 ± 0.39 c
	100	24 ± 0.41 b	20 ± 0.34 b
	1000	46 ± 0.14 a	25 ± 0.96 a
Nutrient cycling	10	8 ± 0.14 c	7 ± 0.38 c
	100	11 ± 0.29 b	10 ± 0.20 b
	1000	39 ± 0.11 a	14 ± 0.26 a

Means of Indices in each columns with different letters are statistically different according to a Tukey's means separation test (P<0.05).

Nutrient cycling condition index of *Zygophyllum* patches at 10 m from the watering point was 8, 11 at 100 m and 39 at 1000 m distance. In interpatches the nutrient cycling condition index was 7 (10 m distance), 10 (100 m distance) and 14 (1000 m distance). Intensive overgrazing in the area close to watering point (sacrifice area) reduces the litter decomposition, nutrient cycling and biological crusts (Whitney *et al.*, 2017). Areas under high intensity grazing lose their resources to areas under low intensity grazing, giving them low vegetation cover and lower soil surface condition indices. Ludwig and Tongway (2000)

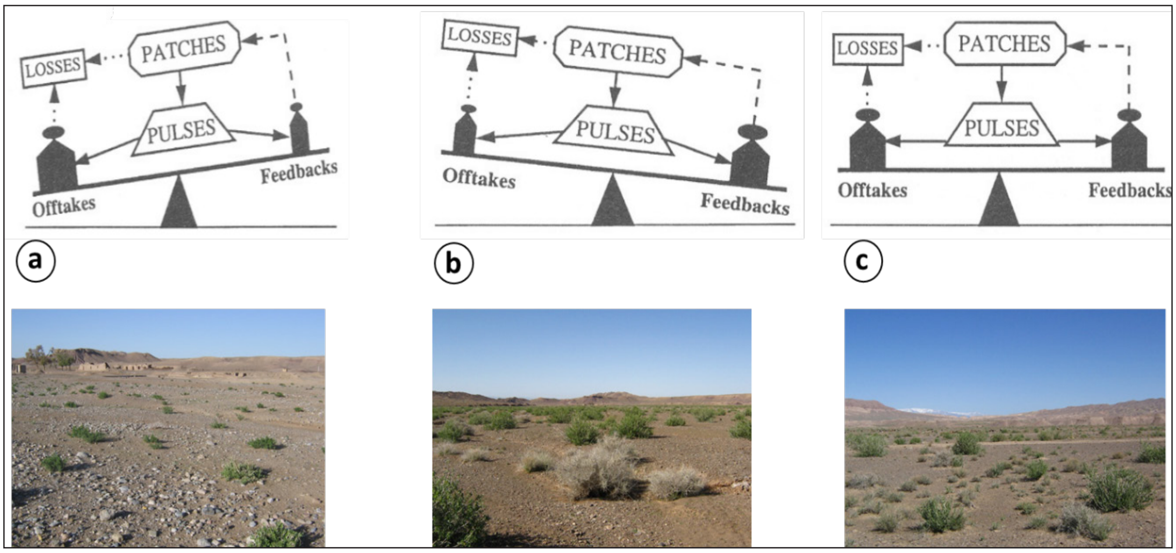

Fig. 5. The role of livestock grazing in the balance between feedbacks and off-takes in arid zone Lajaneh (a) high offtakes - low feedbacks, (b)low offtakes - high feedbacks and (c) balanced (Copyright © CSIRO Australia) (modified after Ludwig and Freudenberger, 1997).

termed this process as the reversed Robin Hood effect (takes from poor and gives to the rich). Decreases in length, density and width of vegetation patches and biological crusts shows the high grazing pressure and dysfunctional landscape (Fernandes *et al.*, 2018; Abdalla *et al.*, 2018) (Fig. 5a).

Heavy grazing can eradicate plant species (Shahriary *et al.*, 2012) and decreases the length, width and number of vegetation patches (Abedi *et al.*, 2007). A poorly functioning landscape loses its resources; water, nutrients and seeds (Ludwig and Tongway, 1997; Arzani *et al.*, 2007). The extreme soil disturbance "sacrifice area" around the watering point indicates that livestock spent more time in the vicinity of water, compacting soil and eventually affecting soil surface indices, so stability, infiltration and nutrient cycling are the lowest for the *Zygophyllum* patches and interpatches close to watering point (Table 1). Severe grazing removes plant species and litter, so that seeds and water cannot be trapped in vegetation patches consequently pulses of production and replacement do not occur. Subsequently, soil erosion occurs and the landscape will be in a degraded condition (Nadal-Romero *et al.*, 2018; Wilson *et al.*, 2018; Fig. 5a). An opposite condition is illustrated at the greater distance: vegetation patches trap resources from water and wind erosion (Hille *et al.*, 2018) and act as habitats if feedbacks enrich them (Fig. 5b). Higher vegetation cover protects the soil from the action of wind and water and increase the rate of infiltration: at the Lajaneh piosphere, this is indicated by the index of infiltration of 46 for the *Zygophyllum* patch at the distance of 1000 m from watering point.

Our results are in accordance with those of previous studies such as those of Hille *et al.* (2018) and Gaitán *et al.* (2017), demonstrating that LFA is an easily applied method to study landscape functionality in arid and semi-arid rangelands and demonstrate potential land degradation. Our LFA analysis of the Lajaneh piosphere system demonstrated the meaningful role of grazing in arid and semi-arid rangeland landscapes especially along watering points and also suggested the importance of vegetation patches and runoff/runon processes on the soil surface condition of piospheres.

Livestock grazing changes the cover of plant species and patch size around watering points, as shown worldwide in the examples of the Nama-Karoo shrublands of Africa (Todd, 2006), Victoria River District of northern Australia (Ludwig *et al.*, 1999) and semi-arid rangelands of Argentina (Peláez *et al.*, 2017). Our findings at the Lajaneh piosphere are in agreement with these other studies: differences in soil surface condition indices were shown at different distances from the piosphere and *Zygophyllum* patches and interpatches showed the role of livestock grazing. Severe grazing degraded the 'sacrifice area' and the part of the landscape closest to water. A companion study at the Mojen piosphere, Iran with a different vegetation community and slightly different grazing conditions reported similar (Shahiary *et al*., 2018).

Sustainable land management needs soil and water conservation (Hruska *et al.*, 2017) and it is difficult to replace these resources when severe erosion and resource leakage occur (Briske *et al.*, 2005; Chartier and Rostagno, 2006). Soil and water conservation is always preferred for restoring a degraded landscape. Improving landscape and ecosystem health in arid and semi-arid grazing lands through development of the vegetation patches and trapping of the resources is recommended (Wilson *et al.*, 2018; Favretto *et al.*, 2016). In piospheres, provision of new watering points and grazing practices will be important landscape restoration practices if land managers aim for the pulses of growth and regulated transfer and reserve processes to work effectively (Bean *et al*., 2017). We recommend land managers should monitor watering points using LFA methodology and balance the offtakes and feedbacks (Fig. 5c) based on the condition of soil surface indices to maintain the health and stability of piosphere systems.

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