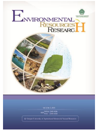

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Threshold of potential concern: an early way to identify the ecosystem structural thresholds in a grazing gradient

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Abstract

Identification of ecosystem thresholds is a way to predict future changes and taking the best management practices in restoration processes. Thresholds are an integral part of nonlinear responses of ecosystems to disturbances such as climate change or human activities. In this study, structural threshold of the total patch area and mean patch width in a grazing gradient were identified using the nonlinear function and the concept of threshold of potential concern. Other structural features including number of grass, shrub and forb patches were also measured. The result showed that three-parametric sigmoid functions had the highest ability to predict structural changes in ecosystem structure within a grazing gradient radiating out from the livestock stock night corral (camp). The result also showed that 1 to 2 Km radius from the livestock camp is the critical threshold in ecosystem structure based on total patch area, landscape organization index and mean patch width fitting to a sigmoid function. Generally, the area within 2 Km from the camp needed to receive emergency remedial management actions. The present study showed that the concept of threshold of potential concern is a useful and early way to predict the thresholds in the ecosystem for management actions. Also, the present study revealed that three-parameter sigmoid function provides a much better fit to structural data than other nonlinear functions.

***Keywords*: Ecosystem, Structure, threshold, concern, sigmoid**

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Introduction

Thresholds are integral part of ecosystem nonlinear responses to exotic disturbances such as climate change or human activities. A number of definitions on thresholds has been proposed in the literature. Friedel (1991) defines threshold as spatial and temporal boundaries between two states. Wiens *et al.*, (2002) specify threshold as points subjected to severe changes and disturbances. Thresholds occur in response to ecosystem changes in both soil and vegetation. In order to identify such thresholds, accurate measurements of soil and vegetation indicators are needed. Vegetation features respond to the external disturbances in different ways. For example, vegetation cover (both foliage and basal cover) tends to decrease as grazing intensity increases (Cesa and Paruelo, 2011).

Structural changes in ecosystem in response to the external disturbances can be applied in identifying the thresholds. For example, shifts in plant composition may occur in response to the disturbance (Brich, 2000) resulting in lower grass or occurrence of grass like patches in a heavily grazed site but not in a non-grazed one.Shrub patches may increase within grazed sites (Cesa and Paruelo, 2011) or even decrease under the influence of selective grazing (Cipriotti and Aguiar, 2005). Patch and interpatch pattern also can be useful metrics to measure to detect emerging trends during disturbances such as grazing pressure (Good *et al.*, 2013). Patch dimension, interpatch length or other related features of the patches also reflect the changes in the ecosystem (Tongway and Ludwig, 2002). Patch structural features such as patch dimension, number, average length and average width reduction are strongly affected by exotic disturbances (e.g. fire (Bastin, 2005)). Livestock grazing as a main disturbance in semi-arid rangelands also affects ecosystem's structure. The size and areal extent of herbaceous patches is strongly influenced by livestock grazing. They may be completely removed by heavy grazing regimes often after a phase where annual grasses and forb patches dominate (Perry, 1960).

Environmental impacts on ecosystem's structure is difficult to assess in arid and semi-arid rangelands due to short term changes in ecosystem with rainfall and the problems with sampling a very large area (Pickup and Chewings, 1994). Grazing gradient in arid and semi-arid rangelands has often been applied as a model system for understanding the ecological impacts of livestock (Wesuls *et al.*, 2013). So, to understand the effects of exotic disturbances on such ecosystems and the existence of thresholds, a grazing gradient approach is an applicable way (Lange, 1969; Andrew, 1988).Grazing gradient is a systematic change in vegetation cover with distance form water (Pickup and Chewings, 1994) or any other livestock concentration facility. After a period of livestock grazing, vegetation cover typically reduces as water is approached producing a spatial pattern known as a grazing gradient (Bastin *et al.*, 1993). Some structural changes in ecosystem components occur along agrazing gradient. For example, while studying a grazing gradient, Heshmati *et al.*, (1999) found that palatable patches were reduced close to the watering points (a place where animals congregate daily). Livestock concentration is usually high close to beginning of the grazing gradient that may be water point or a livestock camp site (Sasaki et al, 2008).This usually leads to catastrophic changes on ecosystem components, especially vegetative patches. A problem with these changes can be found when they are irreversible. So the identification of reversible thresholds in the ecosystem is of great importance. Thresholds occur in ecosystem provided that the response is nonlinear.Structural or functional variations in ecosystem in response to the disturbances can be explained by linear or nonlinear models. However, linear models (based on rangeland successional theory) are unable to predict multi pathways in arid and semiarid ecosystems (Briske *et al.*, 2005).

Nonlinear models are based on non-equilibrium context (Westoby *et al.*, 1989).

Many studies have tested the nonlinear models (including four-parameter sigmoid and piecewise) in the context of modeling the changes induced by exotic disturbances (environmental or manmade disturbances) on arid and semi-arid ecosystems. Noy-Meir (1981) stated that the structural and functional changes in the landscape follow a four-parameter sigmoid function. Bastin *et al.* (1993) reported that the relationship between grazing gradient and vegetation cover can be explained by a sigmoid function. Tom's and Lesperance (2003) introduced piecewise-regression models as a tool for identifying thresholds in semi-arid ecosystems. Tongway and Hindley (2004) reported a four parameter sigmoid function between soil surface indicators and distance from water in grazing gradient. Sasaki *et al.* (2008) reported that three nonlinear models include exponential, piecewise and sigmoid models provide a better fit to the vegetation data along grazing gradient than linear model. He stated that nonlinear models highlight the presence of a discontinuity in vegetation changes along the grazing gradient. Khosravi Mashizi and Heshmati (2010) examined several linear and nonlinear models for determining the structural changes in vegetation along a grazing gradient form water points. They stated that two nonlinear model (piecewise and exponential) are the best models for identification of the thresholds. According to the literature, most common responses reported in the literature are sigmoid and piecewise. Identification of the thresholds through the mathematical options may be a complex and time consuming process for restoration practitioners. So, an early and simple alternative method should be defined. The concept of threshold of potential concern as a quick way for identification of the thresholds provides this alternative option.

The concept of threshold of potential concern (Biggs and Rogers, 2003) as a useful basis for management can be derived from the sigmoid curve. The approach highlights changes over defined temporal and spatial scales, thereby defining the proper set of conditions within a system (Foxcroft, 2009). Thresholds of potential concern can be driven through Landscape Function Analysis field data about the ecosystem structural and functional condition (Tongway and Hindley, 2004). An early way for approximating the thresholds through the LFA field data was undertaken by Tongway (LFA Field Manual, 2011).

This study aims at identification of some structural thresholds using nonlinear functions and explores management implications of the concept of threshold of potential concern. Two nonlinear regression models (four-parameter sigmoid and three-segmented piecewise) and a three parameter sigmoid function (as an alternative for four-parameter sigmoid) was examined in the present work. Two questions are addressed: 1) which nonlinear model will perform better? and 2) at what distance from the livestock camps threshold occurs?

Materials and Methods

Study area

Our research was conducted near village Naviz, in Alborz mountains of Iran (36°44′N, 53°50′E) (Figure 1). Mean annual rainfall is 450 mm and peak rainfall occurs at January. About 70% of precipitation occurs in autumn and winter and 28% in spring from October to June. The lowest precipitation occurs in August. The study area is 8000 ha; average, min and max elevations are about 2646, 1793 and 3901 m respectively. Average maximum and minimum annual temperatures are 27.5 and -3.1 C respectively.

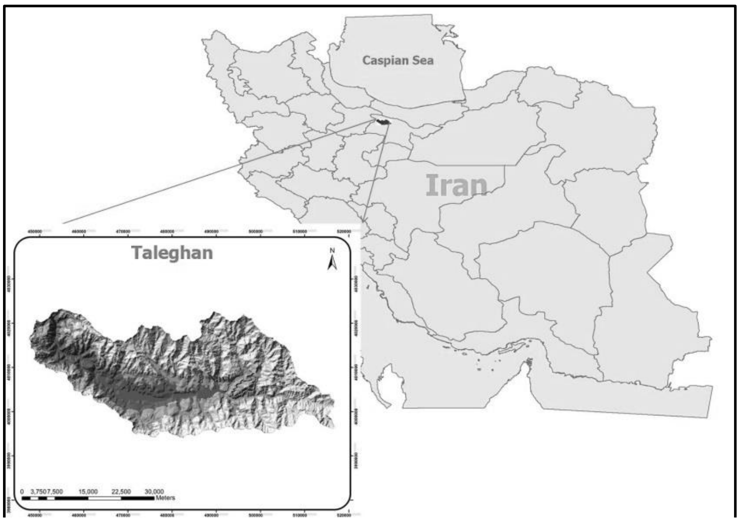

Figure 1. Location of study site

Data collection

Our study was based on field surveys of different vegetation variables along 4000 m transect from the livestock camp. Some structural features were measured at distances 0, 1000, 2000, 3000 and 4000 m from the livestock camp using landscape function analysis field manual (Tongway and Hindley, 2004). To this end, five transects (50 m) were laid out and measured in a down-slope direction in each point. LFA does not specify a transect length, but that enough assessment needs to be done to account for the local properties and heterogeneity (Tongway and Hindley, 2004). To identify site structural features, three following variables were measured along transects:

- Number of vegetation patches along transects regulating overland water flow (but in sandy landscapes, wind erosion can be important).
- Patches width along transect's length unit
- Patches mean distance along transect length unit

Three structural indices were calculated through LFA software: Landscape organization index, total patch area and mean patch width. Landscape organization index is calculated as: lengths of patches/length of transect; total patch area equals to the area of total patches were found on transect; mean patch width is the average patch width in each transect. The number of all kind of patches and fetch size also were measured along transect. Patches can be comprised of physical features, such as furrows or bays created by active land forming processes, or biological features such as plants or fallen logs (Tongway and Hindley, 2004). Here four kinds of patches were considered including: forb, shrub, grass and rock. Fetch size means the proportion of transect belonging to the specific patch or inter patch.

Data analysis

Primary evaluations of ecosystem's structural features were performed using the LFA software. According to the preliminary survey, linear models (simple linear and first order invers model), and cubic, quadratic and exponential regression models were not properly fit to the data (H. Siroosi, unpublished data). So, three remaining regression models were used to predict the variations of structural features along gradient distance from livestock camp. To plot and fit piecewise regression, Sigma Plot v.12 software was applied. Equations for data fitting are as follows:

Four-parameter sigmoid regression model:

(1)

$f = y0+a/ (1+\exp (-(x-x0)/b))$ (Noy-Meir, 1981; Tongway and Hindley, 2004)

Three- Parameter sigmoid regression model:

(2)

f =a/ (1+exp (-(x-x0)/b)) (recommended by authors)

Three-segmented piecewise regression model (Sasaki *et al.*, 2008; Toms and Lesparence, 2003):

(3)

t1 = min (t)
t3 = max (t)
region1 (t) = (y1*(T1-t) + y2*(t-t1)).(T1-t1)
region2 (t) = (y2*(T2-t) + y3*(t-T1)).(T2-T1)
region3 (t) = (y3*(t3-t) + y4*(t-T2)).(t3-T2)
f = if (t <= T1; region1 (t); if (t <= T2; region2 (t); region3 (t)))

Calculating the threshold of potential concern

Threshold of potential concern for each structural parameter was estimated through the equation (4) and best fit model.

(4)

TPC = (top value – lowest value)/2+lowest value (LFA Field Manual, 2011).

Through the equation (4) the threshold value for parameter was found. Then by replacing the threshold value in the best fit model, the location of the threshold along the grazing gradient was found.

Results

Landscape organization index

Landscape organization index (LOI) was not significantly different at the end of the grazing gradient. The highest LOI was found at the end of the gradient whilst the lowest was close to the livestock camp. Distances below 3 km from the camp were significantly different from each other in LOI index (Figure 2).

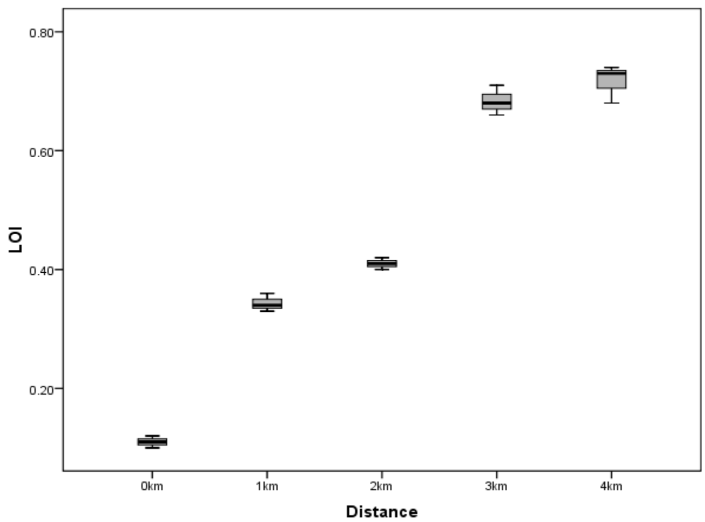

Figure 2. Box plot of landscape organization index along grazing gradient

The results of four parameter sigmoid function showed that, all of the parameters were not significant (Table 1). So, this regression function could not be used for prediction of the structural changes along grazing gradient.

Table 1. Result of four parameter sigmoid curve fitting to total patch data

	coefficient	Std. Error	P	Rsqr
a	1.3729	1.8787	0.4802	
b	1852.6574	2421.9052	0.4604	0.955
x0	690.8920	3113.6667	0.8285	
y0	-0.4403	1.4869	0.7726	

As per function (2), the model had a great ability for predicting the vegetation structural features along grazing gradient (Table 2).

Table 2. Result of three parameter sigmoid curve fitting to total patch data

coefficient		Std. Error	P	Rsqr
a	0.8076	0.0717	<0.0001	
b	1039.4191	191.6678	0.0002	0.9520
x0	1631.6930	263.5075	<0.0001	

Piecewise regression model had a good fit to the vegetation data but parameter y1 was not significant and could not be incorporated at the final model (Table 3). So, the model was not suitable to explain the vegetation trend along the grazing gradient.

Table 3. Result of piecewise regression fitting to landscape organization index

coefficient		Std. Error	P	Rsqr
y1	0.1378	0.0700	0.0806	
y2	0.4952	0.0608	<0.0001	
y3	0.6340	0.0536	<0.0001	0.9705
y4	0.7167	0.0648	<0.0001	
T1	2382.7649	7.3496E-008	<0.0001	
T2	2540.5031	3.3114E-006	<0.0001	

Landscape organization index increased as distance from the livestock camp increased (Fig. 3). Figure 3 also shows the three parameter sigmoid function goodness of fit to the vegetation data along the grazing gradient.

Threshold of potential concern (TPC) for landscape organization index can be calculated through the equation (4) as follows:

TPC = (top value – lowest value)/2+lowest value = (0.7167– 0.1100)/2 + 0.1100= 0.41335; this means threshold of potential concern (TPC) for landscape organization index occurs at 1680.867362m from the livestock camp.

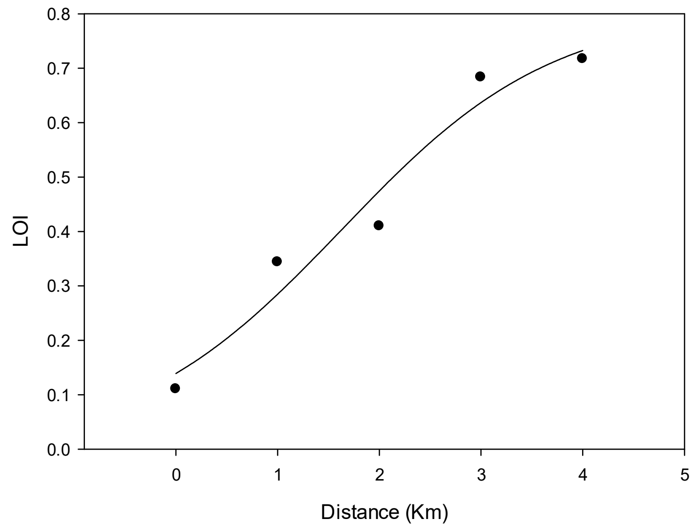

Figure 3. Change in landscape organization index along grazing gradient based on sigmoid function

Total patch area

Total patch area varied significantly in different distances from the livestock camp up to 3km but not beyond that radius (Figure 4).

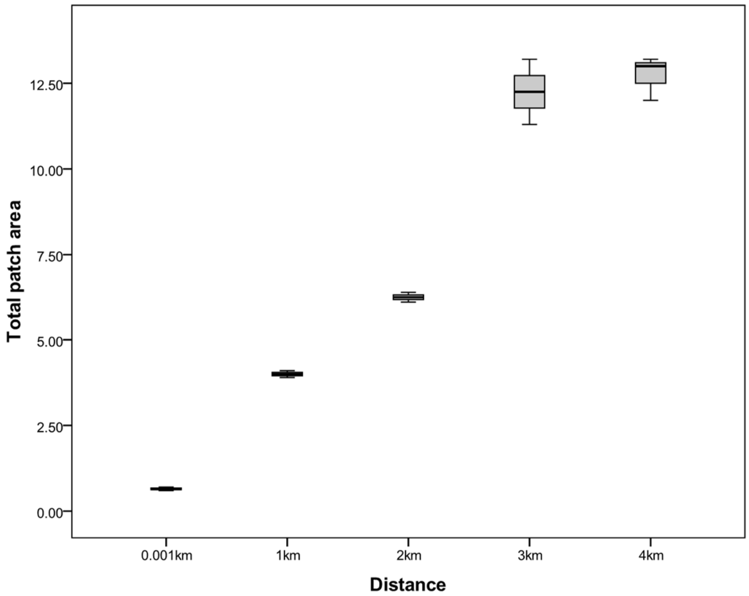

Figure 4. Box plot of landscape total patch area along a grazing gradient

Function 1 had a great potential to predict changes along a grazing gradient. However, Y0 was not significant so it could not be incorporated in the final ecosystem function (Table 4).

Table 4. Result of sigmoid curve fitting to total patch data

coefficient		Std. Error	P	Rsqr
a	14.9816	2.5572	0.0001	0.9708
b	799.1163	248.2271	0.0082	
x0	2051.4493	194.5299	<0.0001	
y0	-0.0389	1.3582	0.9777	

As per function 2, all three parameters were significant and R square also showed the high ability of the function to predict changes in total patch area along grazing gradient (Table 5).

Table 5. Result of sigmoid curve fitting to total patch data

coefficient		Std. Error	P	Rsqr
a	14.9195	1.0567	<0.0001	
b	793.1004	120.3683	<0.0001	0.9708
x0	2054.1226	175.0021	<0.0001	

The fitted sigmoid curve showed that total patch area increased with radial distance from the camp (Figure 5). TPC for landscape total patch area can be measured through the sigmoid function and equation (4) as follows: TPC = (top value – lowest value)/2+lowest value = (12.73 – 0.65)/2 + 0.65 = 6.69 this means threshold of potential concern (TPC) for total patch area occurs at 1889.86 m from the livestock camp.

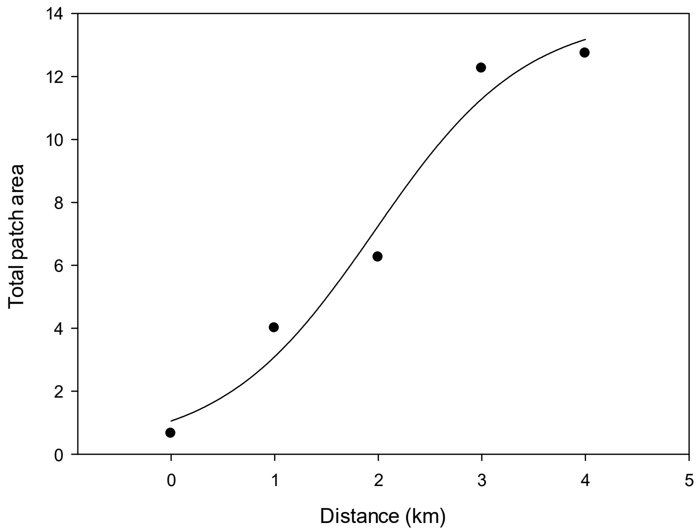

Figure 5. Change in total patch area along a grazing gradient based on sigmoid function

As per piecewise regression, the model had a maximum R square, but parameter Y1 was not significant so the function was not useful here (Table 6).

Table 6. Result of piecewise regression fitting to total patch data

	coefficient	Std. Error	P	Rsqr
y1	0.8333	0.8424	0.3484	0.9910
y2	7.0466	0.7729	<0.0001	
y3	11.5632	0.6229	<0.0001	
y4	13.4000	0.7872	<0.0001	
T1	2219.0245	0.0029	<0.0001	
T2	2402.76	0.0007	<0.0001	

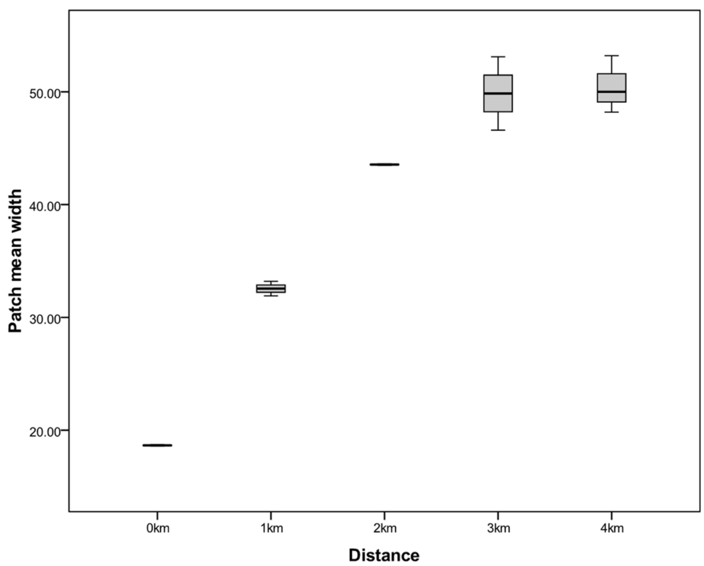

Figure 6. Box plot of mean patch width at different distances from the camp

Mean patch width

The results showed that mean patch width was greatly varied among the different distances from the camp (Fig. 6). At the end of grazing gradient no significantly difference has been observed.

An increase in mean patch width observed as distance from the livestock camp increased.

The result of sigmoid function showed that there was an R square of 0.9832 between distance and patch mean width. X0 and Y0 was not significant so they cannot be incorporated into landscape function. (Table7).

Table7. Result of sigmoid regression fitting on total patch data

coefficient		Std. Error	P	Rsqr
a	45.0939	10.9514	0.0017	
b	773.1139	217.8867	0.0046	0.9832
x0	763.2604	370.8997	0.0641	
y0	6.4381	9.8992	0.5288	

As per function (2), the function had great ability to predict changes in mean patch width along grazing gradient (Table 8).

Table 8. Result of sigmoid curve fitting to total patch data

coefficient		Std. Error	P	Rsqr
a	52.0714	1.1636	<0.0001	
b	888.3749	82.3820	<0.0001	0.9828
x0	530.7643	68.9513	<0.0001	

The sigmoid curve showed patch mean width increased along grazing gradient. The more distance away from the livestock camp, the greater the patch width is (Figure 7).

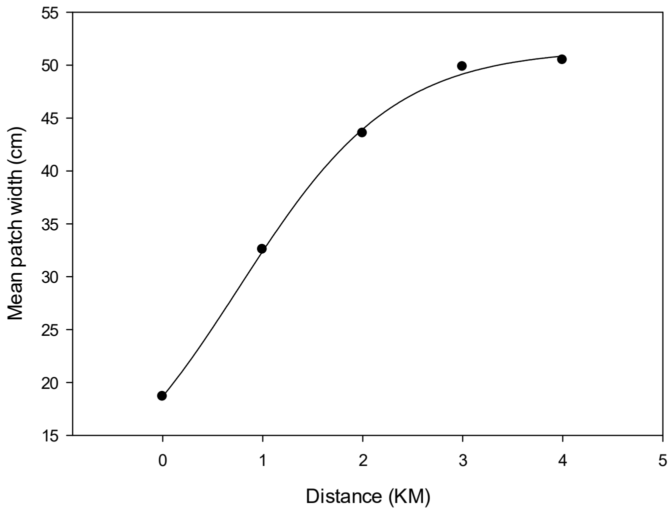

Figure 7. Change in patch mean width along grazing gradient based on sigmoid function

TPC for mean patch width estimated through equation (9) as follows:

TPC = (top value – lowest value)/2+lowest value = (50.46– 18.65)/2 + 18.65= 34.55 this means threshold of potential concern for mean patch width occurs at point 1133.95 m from the livestock camp.

As for piecewise model, most of the parameters were not significant so piecewise regression model was not useful to simulate the change of mean patch width along the gradient.

Number of patches and fetch size

Number of shrubs increased significantly as grazing pressure decreased (Figure 8).The point zero had the lowest number of shrubs, whilst 4 Km from the camp had the maximum number of shrub patches. The points zero and 1 Km from the livestock camp did not vary significantly in shrub number. This was the case for those in points 3 and 4 km from the camp.

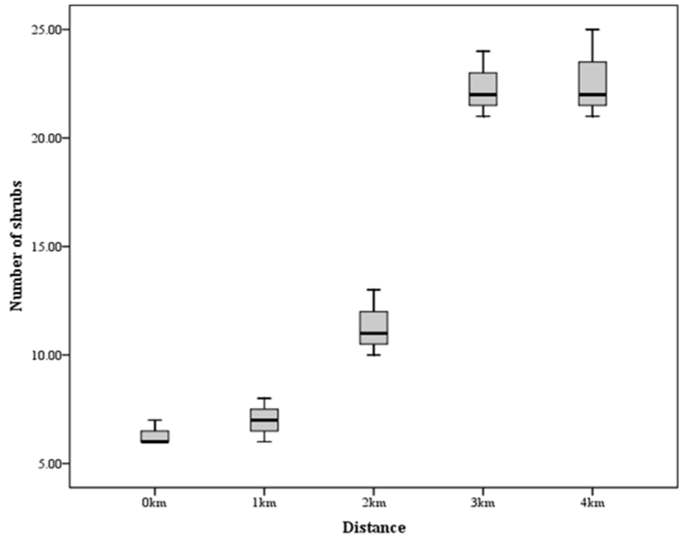

Figure 8. Box plot of number of shrubs in different distances from the camp

At zero Km from the livestock camp herbaceous patches were absent, whilst the point 4 Km from the camp had the maximum number of patches (Figure 9). The points 2, 3 and 4 Km from the livestock camp do not differ from each other in a statistically significant way. There was significant differences between 1 Km from the camps and the 3 next points (2, 3 and 4 Km from the camp) in the grazing gradient (Figure 9).

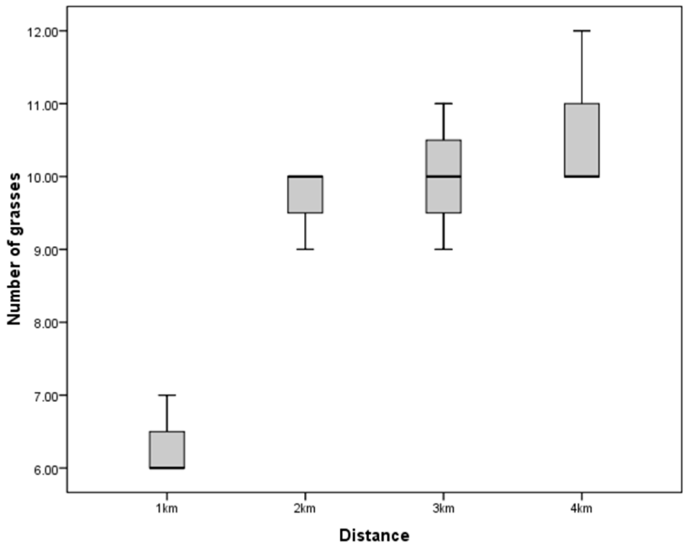

Figure 9. Box plot of number of grassat different distances from the camp

Number of forb patches decreased as distance increased from point zero to 2 Km from the camp. The point 2 Km from the camp had the lowest number of forb patches whilst zero Km from the camp had the maximum number of forb patches: there was no significant differences between 3 and 4 km (Figure 10). So, as grazing pressure decreased the number of forbs decreased to point 2 Km from the camp, and again increased to 4 Km from the livestock camp.

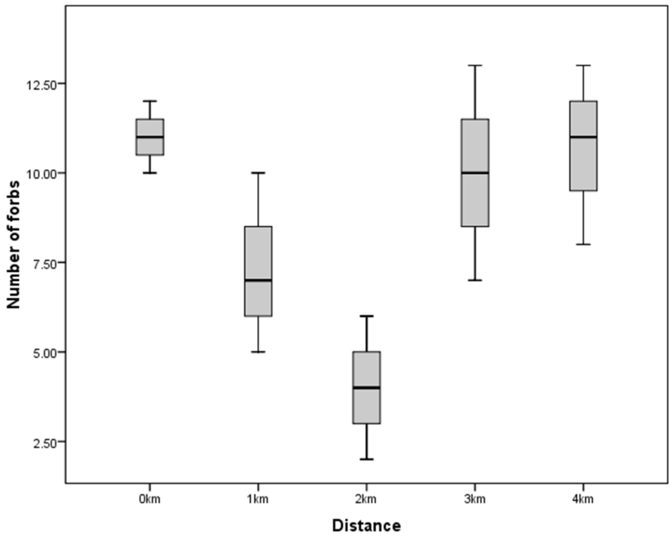

Figure 10. Box plot of number of forbs in different distances from the camp

Fetch size (proportion of transect belonging to specific patch or inter patch) in grass and shrub patches increased with distance from the livestock camp (Figure 11). Forb patch fetch decreased as distance from the camp increased up to 2 Km and increased again at a distance 4 km from the livestock camp. Bare soil (inter patch) decreased greatly as distance from the camp increased (Figure 11).

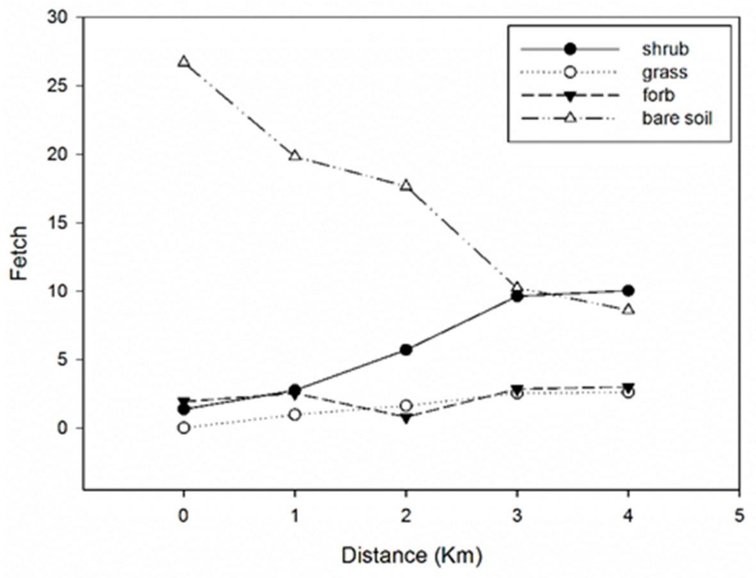

Figure 11. Fetch size of different patch and inter patch in different distance from the camp

Discussion

Some structural changes were observed along the grazing gradient as grazing pressure increased. The presence of livestock grazing and human activity near the livestock camp (as the main disturbances in the study site) is the main cause of changes in the ecosystem structure. Structural changes occur in the ecosystem in several ways such as changes in patch and inter-patch length, patch area and etc. Livestock grazing and human activity has catastrophic effects on vegetation structure. This usually occurs at the beginning of the grazing gradient due to livestock concentration (Sasaki *et al.*, 2008).

The present study showed that nonlinear models have high ability to predict the structural variations along grazing gradient. As it can be seen from the literature (e.g. Noy-Meir, 1981; Tongway and Hindley, 2004 and Bastin *et al.*, 1993) sigmoid or sigmoid logistic function has been widely used for predicting the ecosystem structure and function under different disturbances. Here, three-parameter sigmoid function was the best model to predict changes along grazing gradient for both total patch area and mean patch width. Given findings by Tongway and Hindley (2004) and Noy-Meir (1981) that expected ecosystem changes along grazing gradient follow four-parameter sigmoid function, the present study showed that three-parametric sigmoid function may be more suitable to predict structural changes along the grazing gradient. Toms and Lesparence (2003) reported that piecewise regression model predicted the changes in ecosystem; however, the present study showed that piecewise model had no potential to predict the changes in total patch area and mean patch width along grazing gradient as structural changes.

Here the concept of threshold of potential concern in total patch area warns the occurrence of some catastrophic changes in the ecosystem structure. The concept showed that ecosystem is in a bad situation below 2 Km from the camps and needed restoration plans. Graetz and Ludwig (1998) and Noble *et al.* (1998) also reported the negative consequences of overgrazing on the vegetation patches 2 to 3 Km from the watering point (as livestock resting point). Total patch area close to the beginning of the grazing gradient accounted for the lowest value. Presence of livestock and human activity reduced the total patch area close to the camps. Some major changes such as reduction in palatable patches density denotes an overgrazing regime on rangeland ecosystem (Laycock, 1994), in turn resulting in lower total patch area in the case of extreme degradation. Mean patch width as another structural feature was also reduced as grazing pressure increased. In the present study, 1km from the livestock camp in grazing gradient is the critical point of the mean patch width. Based on the mean patch width sigmoid function, threshold of potential concern occurs close to 1 Km from the camp. Mean patch width from 2 Km to 1Km greatly reduced, which indicates the worst condition of vegetation patches close to the livestock camp. What can be concluded from this study is that livestock overgrazing can lead to low vegetation patch size close to the camp. Van der Walt *et al.* (2012) also concluded that overgrazing may lower vegetation patch size and larger fetch length. Generally, the overgrazed sites were characterized by lower patch dimension than the area far from the livestock camps. Management actions and restoration plans should be focused on the degraded areas rather than those found in fair situation. The threshold of potential concern gives us critical points in the ecosystem which need restorative actions. However, it must be known that some areas are subject to trampling, heavy grazing and transfer of nutrients in great abundance and are not likely to be rehabilitated. This gives rise to the notion of 'sacrifice areas' around the camps, water points or other foci where livestock congregate.

Livestock prefer herbaceous and green leafed plants in the study area and this leads to removal of grass and grass like patches close to livestock camps (Scanlan *et al.*, 1996; Walker *et al.*, 1997). While studying Wyoming rangelands, Klott *et al.* (1993) found that these areas with high livestock concentrations had little grass cover and fewer herbaceous species. In the present study, more forb patches were found close to the livestock camps than 1 and 2 km from the camp. Field observations showed that species near the camp were unpalatable poisonous forbs such as *Verbascum sp.*, *Marubium sp.* and other unpalatable forbs (many of them nitrophyllus). In addition Klott *et al.* (1993) reported that where there were more livestock, the forb species would be dominant. From a study of chenopod shrublands in Southern Australia, Heshmati *et al.* (2002) reported a correlation of unpalatable species within the sampling sites near the watering points with the higher livestock concentration

Many forbs are unpalatable, toxic or have a low profile (rosette form) that is more resistant to grazing. So we might conclude that where the stocking rate of livestock increased, the density of unpalatable species also increased. The number of shrub patches decreased in the present study site as grazing and human presence increased. This may not be wholly attributed to the grazing effects, because herders and indigenous people remove shrub patches as fuel for cooking, resulting in lower number of shrub patches close to the livestock camp.

This study showed that fetch size properly reflect the impact of disturbances on the ecosystem. Close to the livestock camp inter-patch fetch was maximized, while minimum inter-patch fetch was found at the end of grazing gradient. Shrub and grass fetch was also found to be maximized as distance from the livestock camp increased (but for different reasons). Forb fetch (more a measure of species diversity) increased at distances beyond 2 Km from the camp. However, there were higher densities of forbs close to the resting site compared to distances 1 and 2 Km away, but these forbs were unpalatable, hence not removed by the livestock.

Conclusion

The results presented here add to the body of literature from a wide range of ecological biomes that will assist in refining ways to analyze structural and floristic change in grazed ecosystems. The predictive value of the various indices and the guidance as to where management interventions need to prioritize still requires further work. Most of the studies reported so far are a post hoc analysis of events that have already occurred. What ecosystem managers require is an early warning of when the critical thresholds are being approached and an indication of which management interventions are most appropriate given the ecological, biophysical and socio-cultural conditions at each site.

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