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Impact of off-road vehicles on soil and vegetation in a desert rangeland in Saudi Arabia

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ABSTRACT

Off-road vehicle driving is considered as main contributor to land degradation in arid regions. This study examined the impact of off-road vehicles (ORV) on soil and vegetation in a natural recreational desert meadow of Raudhat Khuraim, Saudi Arabia. Vegetation canopy cover and plant height away from road tracks were assessed. Also, species density and canopy cover, bare ground cover and soil attributes were assessed in four microhabitats; tracks, inter-tracks, verges, and away from vehicle tracks (undisturbed natural areas). Results show that the cover of forbs and grasses was negatively associated with distance from road verges. It was observed that the height of woody species responded negatively to distance away from tracks. Cover of native species decreased under verge, inter-track and track microhabitats giving more opportunity for weeds to flourish. Bare ground was highest (60.7%) in tracks. ORV impact on soil bulk density was clear with an increase of 38% under tracks compared to soils of undisturbed natural vegetation and a similar decrease in porosity was observed. On the other hand, soil electrical conductivity was significantly higher (5.45 mS cm^{-1}) under disturbance compared to 1.32 mS cm^{-1} in undisturbed natural vegetation. Organic matter and nitrogen were not affected significantly by ORV disturbance. The results emphasize that managing off-road vehicle driving is essential for conserving native vegetation.

1. Introduction

Off-road vehicles (ORV) can directly affect desert ecosystems through the fragmentation and loss of natural habitats within their tracks and the surrounding environments (Brown and Schoknecht, 2001; Belnap, 2002). Such disturbances lead to changes in soil properties and vegetation composition, and consequently affect the ecological functions and services of desert landscape (Hammit and Cole, 1998; Kutiel et al., 2000; Brooks and Lair, 2005). Therefore, exploring the nature and extent of changes induced by off-road vehicles and the practices for mitigating their negative impacts are necessary for maintaining and conserving of native biodiversity and ecosystem processes in arid regions (Lovich and Bainbridge, 1999; Bolling and Walker; 2000).

One of the most important ecological impacts of vehicular routes involves changes in hydrological patterns by redirecting rainfall water along roadsides (Belnap, 1995), and lead to a significant redistribution of soil moisture which is the main limiting factor for plant growth in desert landscape (Forman and Alexander, 1998; Chamizo et al., 2012). Because of their large mass, off-road vehicles can cause compaction of soil pores (Webb, 2002; Sack and Da Luz, 2003; Webb et al., 2013). Therefore, the soils ability to absorb and retain water is reduced (Misak et al., 2002; Chamizo et al., 2012; Al-Awadhi, 2013; Khalaf et al., 2013). Microscopic organisms have no adaptability to mechanical disturbances such as ORD (Belnap and Gillette, 1998). Thus, ORV decreases soil fertility by indirectly harming the microscopic organisms that would have otherwise break down the plant litter and release nutrients for plant growth (Feng et al., 2012). Johnston and

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Johnston (2004) indicated that soils close to roadsides had lower electrical conductivity than soils away from the road tracks. Off-road vehicle traffic has been reported to alter soil texture (Belnap, 2002), increase soil bulk density (Garten et al., 2003; Lei, 2004), induce changes in soil EC and pH (Zeng et al., 2012) and reduce soil organic matter (Lei, 2004). Such modification in these edaphic factors can contribute to direct and indirect impacts on the structure and diversity of plant communities (Kutiel et al., 2000; Kinugasa and Oda, 2014).

The most obvious physical impacts of ORV on vegetation include plant crushing, shearing, and uprooting (Liddle, 1997; Newsome et al., 2002). Such destruction of vegetation in arid ecosystems can lead to land degradation and desertification (Belnap, 1995; Mouat et al., 1997; Lovich and Bainbridge, 1999). Desert plant species exhibit varying degrees of vulnerability to vehicle use intensity (Kutiel et al., 2000; Brown and Schoknecht, 2001), which results in changes in vegetation composition, height, biomass, reproductive structures, cover and seedbank (Kelly, 2014; Kinugasa and Oda, 2014). Besides the physical impacts on vegetation composition, ORV affects plant species diversity as different plant life forms respond differently to disturbance created by ORVs (Luckenbach and Bury, 1983; Kutiel et al., 2000). Luckenbach and Bury (1983) observed a decline in herbaceous and perennials under ORV use, while annuals were found to be more resistant to ORV damage than perennials (Hall and Kuss, 1989; Cole, 1995). Single passes by ORVs created tracks that became favorable microsites for annual species in deserts of Kuwait (Brown and Schoknecht, 2001).

Vehicular routes and their microhabitats are the primary pathway for plant invasions into arid and semi-arid ecosystems (Buckley, 2001; Rooney, 2005; Hochrein, 2008), and threaten the survival and growth of native species (Greenberg et al., 1997; Forman and Alexander, 1998; Johnston and Johnston, 2004; Mortensen et al., 2009). Greenberg et al. (1997) showed that disturbances within vehicular route corridors facilitated the establishment of weeds and inhibited the growth of native species along sides of roads. Johnston and Johnston (2004) found that road verges and its adjacent sides (0–2 m from the road verge) had higher frequency of non-native species compared to natural undisturbed areas (10 m away from the road verge). Moreover, vehicles serve as dispersal agents for alien plant propagules (Parendes and Jones, 2000; Von der Lippe and Kowarik, 2007; Mortensen et al., 2009).

Due to the negative impacts of off-road vehicles, much of the research and management policies have been directed towards controlling and restoring the affected areas, and maintaining ecosystem function in arid regions (Lovich and Bainbridge, 1999; Gelbard and Harrison, 2003; Khalaf et al., 2013). Gelbard and Harrison (2003) proposed reducing vehicle disturbances on roads to maintain local biodiversity in arid landscape. The potential of abandoned roads in United States desert was documented for the recovery and succession of native vegetation (Bolling and Walker, 2000; Holl et al., 2000).

During the last few years, off-road vehicles use is considered as one of the main recreation and leisure activities of the Arabian Gulf countries (Brown and Schoknecht, 2001; Al-Nafie, 2007; Khalaf et al., 2013). In Saudi Arabia, ORV driving is one of the leading contributors to land degradation in natural landscapes such as rangelands and nature reserves (Al-Rowaily, 1999; Al-Nafie, 2007), which is similar to other areas of the world (Outdoor World Directory, 2014). Desert meadows (locally known as Raudhats), owing to their high vegetation diversity, represent the main natural reserves and national parks in the central and eastern regions of Saudi Arabia (Alfarhan, 2001; Al-Rowaily et al., 2008). In order to reduce extensive ORV impacts in these desert meadows, several management practices have been introduced which include metal post fencing of the park main body. However, ORV prevails over a large area of the Raudhat outside the fence. To our knowledge, no detailed studies have been carried out for evaluating the impact of ORV on vegetation and soil of these attractive areas. We hypothesize that ORV will alter vegetation structure and physical and chemical soil properties leading to rangeland deterioration. Therefore, the main aim of current study was to quantify the effects of ORV on soil and vegetation in Raudhat Khuraim natural recreational park that is considered as one of the most extensively used ORV trails in Saudi Arabia (Al-Nafie, 2007). Our objectives were to assess (1) how ORV affects vegetation, (2) the changes in soil properties in the different microhabitats as affected by ORV.

2. Materials and methods

2.1. Study area

The study was conducted in Raudhat Khuraim natural park 100 km northeast of Riyadh (25.4 N, 47.26 E; Fig. 1). Like other desert meadows, Raudhat Khuraim is a land depression characterized by lush of vegetation due to collecting rainfall water and soil depositions from surrounding watershed systems (Chaudhary and Al-Jawaid, 1999). Although limited in size (nearly 25 $\times$ 3 km), it harbors a great wealth of biodiversity (Al-Farraj et al., 1997; Alfarhan, 2001). Public motor vehicle traffic is not allowed inside the protected area fenced by mounted metal posts. The climate is

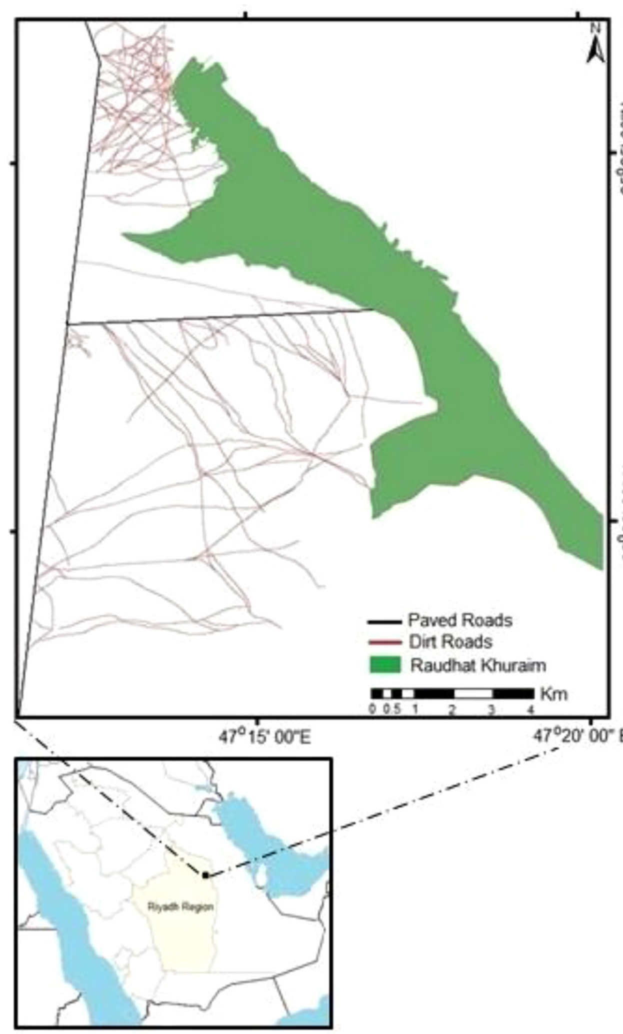

Fig. 1. Study site, Raudhat Khuraim in Riyadh region.

classified as hyper-arid with average annual rainfall of 70 mm and mean temperature of 13 °C in January and 36 °C in July and August.

2.2. Soil sampling and analysis

Five off-road vehicle tracks were randomly selected. To avoid overlapping, if two road tracks fell in close proximity (50 m), reselection was performed. Soil samples were collected to a depth of 50 cm from four microhabitats; tracks, inter-tracks, verge and undisturbed natural areas (10 m away from vehicle tracks) using six 0.5 m × 0.5 m quadrats in each microhabitat per road track (Fig. 2). Samples were air-dried and ground to pass a 2-mm (10-mesh) sieve for physical and chemical analysis. Soil texture was determined according to the method of Gee and Bauder (1986); soil pH was determined using pH meter (McLean, 1982). Soil electrical conductivity was determined according to the method of Rhoades (1996). Organic matter and carbon were analyzed according to the method of Nelson and Sommers (1996). Total phosphorus and nitrogen were determined according to Olsen and Sommers (1982) and Bremner and Mulvaney (1982), respectively.

Two additional soil samples in each quadrat from each microhabitat were collected to a depth of 15 cm to determine bulk density. The volume of excavated soil was measured, and soil samples were oven dried and weighed to determine bulk density (Blake and Hartge, 1986). The total porosity was calculated using the dry bulk density values and an assumed particle density of 2.65 g/cm^3 (Rowell, 1994).

2.3. Vegetation measurements

Ten lines (each 20 m long) were placed perpendicularly to each off-road track and directing outward from the edge of each track. Five quadrats (1 m × 1 m) of 2 m apart were distributed along each line. Vegetation density and height were measured within each quadrat (Curtis and McIntosh, 1950). Vegetation canopy cover was determined using line intercept method (Bonham, 1989).

Additionally, for each off-road track species, density and cover were determined in the same microhabitats used to assess soil properties. Plant species were identified and classified into three life form groups (grasses, forbs, and woody shrubs). Plant nomenclature followed Chaudhary (1999, 2000a,b,c, 2001) and Chaudhary and Akram (1987).

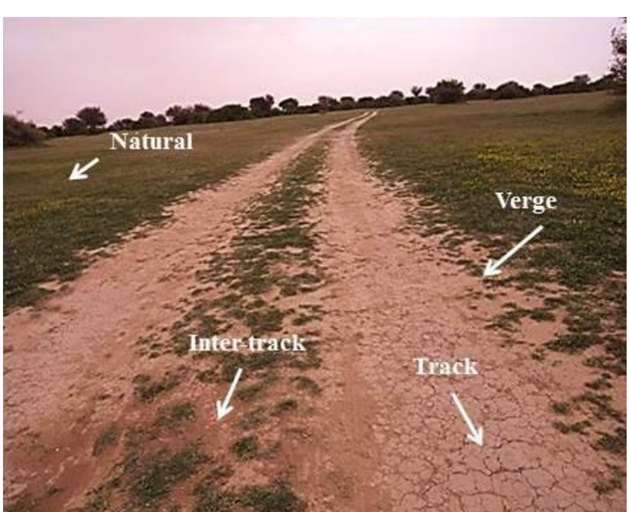

Fig. 2. Pictorial viewing of different microhabitats created by ORV in Raudhat Khuraim, Saudi Arabia.

2.4. Statistical analysis

Vegetation attributes (cover and height) were regressed against distance away from road tracks. Impact of ORV on vegetation and soil characteristics in microhabitats was analyzed in a randomized block design with the five lanes being the replicates. Data from transects and quadrats were averaged for each replicate. Analysis of variance was performed for soil and vegetation data (Steel and Torrie, 1980) using SPSS Version 16.0.

3. Results and discussion

3.1. Impact of ORV on soil properties

Off-road vehicle traffic altered soil texture in microhabitats with the immediate physical effect of passing traffic. Sand content increased in tracks and inter-tracks while soils of road verges had higher clay content (Table 1). Belnap (2002) found similar results when soils were subjected to ORV disturbance. Soil bulk density was 38% higher under tracks compared to soils of undisturbed vegetation. Early, Lei (2004) found that off-road vehicle traffic increases soil bulk density. Total porosity was 0.34 under track compared to 0.55 under natural undisturbed vegetation. These results are comparable those of Lei (2004) under frequent vehicle passes.

Soil electrical conductivity was significantly higher in disturbed areas (3.32 mS cm^{-1} and 5.45 mS cm^{-1} in inter-track and track microhabitats respectively) compared to 1.32 mS cm^{-1} under natural undisturbed vegetation. Although significant, slight differences in soil pH were observed among microhabitats. Differences in soil EC and pH could be attributed to differences in soil texture (high sand content, see Table 1) induced by ORV (Pérez, 1991). Organic matter and organic carbon were not affected significantly by ORV disturbance. Similarly, Lei (2004) did not observe significant differences among several sources of soil compaction varying in intensity on organic matter in southern Nevada. Total phosphorus significantly increased in road verges by 40% over that of undisturbed vegetation. An explanation to that might be because phosphorus associated with smaller soil particles created under tracks and inter-tracks are deposited in road verges (Li et al., 2007; Field et al., 2010).

Compared to verges and natural undisturbed vegetation, the other two habitats were lower in total phosphorus concentration. Total nitrogen was not significantly different among different habitats as a result of ORV. Similar results were reported by Belnap (1995) in a surface disturbed soil.

3.2. Effect of ORV on vegetation cover and height

Forb and grass cover was negatively associated with distance from off-road edges. Conversely, cover of woody species had a positive relation with distance from road verges (Fig. 3). This finding is in agreement with several findings in different environments (Lovich and Bainbridge, 1999; Kutiel et al., 2000; Milchunas et al., 2000).

The height of all growth forms (woody, forbs and grasses species) responded negatively to distance away from road tracks (Fig. 3, Table 2). Milchunas et al. (2000) reported that long-term heavy machinery maneuvers alter the vertical structure of the community. Several studies reported a reduction in plant heights near road tracks (e.g. Cole, 1987; Kutiel et al., 2000). However, in the present study, continuous heavy camel browsing away from road tracks could have offset the impact of ORV on the height of plant species.

Table 1
Soil physical and chemical properties in microhabitats created by off-road vehicle traffic in Raudhat Khuraim (Mean ± SD).

Soil variable	Road			Natural area	F-value	p-level
	Inter track	Track	Verge			
Sand (%)	73.97 ± 2.83	74.18 ± 4.25	30.70 ± 1.94	49.80 ± 7.22	8.12	0.015
Silt (%)	15.00 ± 2.34	12.50 ± 3.06	24.30 ± 4.32	22.50 ± 5.20	2.27	0.174
Clay (%)	11.03 ± 0.83	13.33 ± 2.58	45.00 ± 5.12	27.70 ± 2.50	14.54	0.003
Bulk density (gm/cm^3)	1.754 ± 0.063	1.752 ± 0.092	1.688 ± 0.082	1.197 ± 0.119	12.95	<0.0001
Porosity	0.34 ± 0.021	0.34 ± 0.031	0.36 ± 0.028	0.55 ± 0.018	13.21	<0.0001
EC (mS/cm)	3.32 ± 0.05	5.45 ± 0.80	2.447 ± 0.24	1.32 ± 0.11	13.21	0.004
pH	7.29 ± 0.04	7.21 ± 0.03	7.40 ± 0.05	7.44 ± 0.05	9.41	0.010
Organic matter (%)	1.21 ± 0.24	1.39 ± 0.13	1.59 ± 0.22	2.04 ± 0.32	2.84	0.125
Organic carbon (%)	0.70 ± 0.14	1.19 ± 0.19	0.92 ± 0.11	0.81 ± 0.07	2.84	0.125
Total phosphorus (ppm)	325.00 ± 46.25	412.19 ± 64.59	773.75 ± 53.54	550.42 ± 64.93	3.09	0.019
Total nitrogen (mg/kg)	509.81 ± 88.66	668.03 ± 119.46	873.33 ± 167.45	834.59 ± 179.71	1.23	0.349

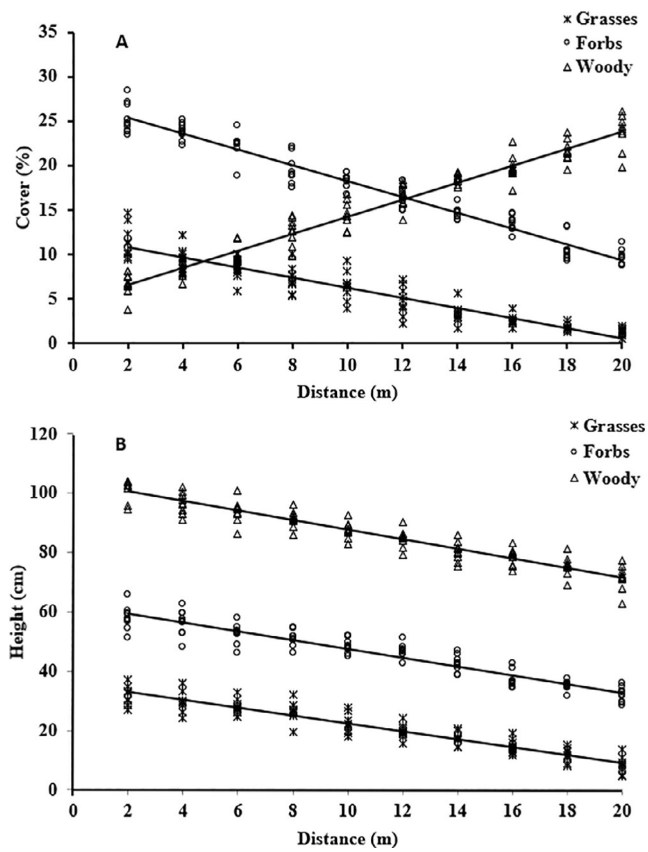

Fig. 3. Relationships between distance away from road verges and (A) Cover and (B) Height of grasses, forbs and woody species in Raudhat Khuraim as affected by off-road vehicle traffic.

Table 2
Summary of regression analysis of vegetation cover (%) and height (cm) along a gradient away from off-road tracks.

Plant life form	Regression equation	R^2	P
Vegetation cover			
Grasses	$y = -0.5685x + 11.89$	0.88	<0.0001
Forbs	$y = -0.8901x + 27.15$	0.95	<0.0001
Woody shrubs	$y = 0.9587x + 4.65$	0.95	<0.0001
Vegetation height			
Grasses	$y = -1.3215x + 35.49$	0.89	<0.0001
Forbs	$y = -1.4719x + 62.19$	0.89	<0.0001
Woody shrubs	$y = -1.6299x + 104.11$	0.89	<0.0001

3.3. Effect of ORV on vegetation composition

Off-road vehicle driving has created local microhabitats; road verges, inter-tracks, and tracks. Away from dirt road tracks where vegetation was not disturbed, the bare ground cover was limited (9.2%). The majority of vegetation cover under these undisturbed natural areas is comprised of native species (80%). Cover of native species decreased under verge, inter-track and track microhabitats (27.5%, 16.5%, and 5% respectively) giving more opportunity for weeds to nourish as the intensity of disturbance increased. Bare ground was highest (84%) in track microhabitat while the cover of weeds was highest (55.8%) along road verges (Fig. 4).

Numerous studies have revealed close positive relation between intensity of disturbance and weed invasibility (Von Holle and Simberloff, 2005; Hierro et al., 2006; Belote et al., 2008; Eschtruth and Battles, 2009; Renne and Tracy, 2013; Houseman et al., 2014), while negative relations were observed between abundance of native species and weed invasibility (van Ruijven et al., 2003; Von Holle and Simberloff, 2005; Maron and Marler, 2007; Catford et al., 2012; Greene and Blossey, 2012; Bernard-Verdier and Hulme, 2015). Brown and Schoknecht (2001) found that ORV provided a favorable medium for the dominance of *Stipa capensis*; an annual noxious grass in the deserts of Kuwait. Similarly, in the present study, the cover percentage of native plant species was highest in the undisturbed area away from the road tracks. The intact native species cover is usually more resistant to invasion (Davis et al., 2000; Grime, 2002; Leishman and Gallagher, 2015). Another explanation is that native species were fully utilizing moisture and nutrients under undisturbed habitat and thus limiting invasibility away from the roadsides (Rau et al., 2014). Our results are supported by a study conducted in a desert steppe in China in which Feng et al. (2012) found that cover of native plant species increased away from road verges.

The population density of the most abundant native species (*Anthemis deserti*, *Filago desertorum*, *Pulicaria undulata*, *Rhanterium epapposum*, *Rumex vesicarius* and *Plantago boissieri*) was reduced by ORV in different microhabitats. Reduction in density was highest under track followed by inter-track and road verges (Table 3). *Anthemis deserti* density was reduced by 97% under track compared to undisturbed natural vegetation. Similarly, *Filago desertorum* density was reduced by 88.2% under road tracks compared to undisturbed natural vegetation. Density of *Pulicaria undulata* was reduced by 92.3% under track compared to undisturbed natural vegetation. *Rhanterium epapposum* was almost absent in road track habitat (99.5% reduction compared to undisturbed vegetation). The density of *Rumex vesicarius* and *Plantago boissieri* was reduced by 93% and 92.6% compared to undisturbed vegetation respectively (Table 3). These results are in agreement with the observation of noticeable declines in herbaceous and perennial plants in sand

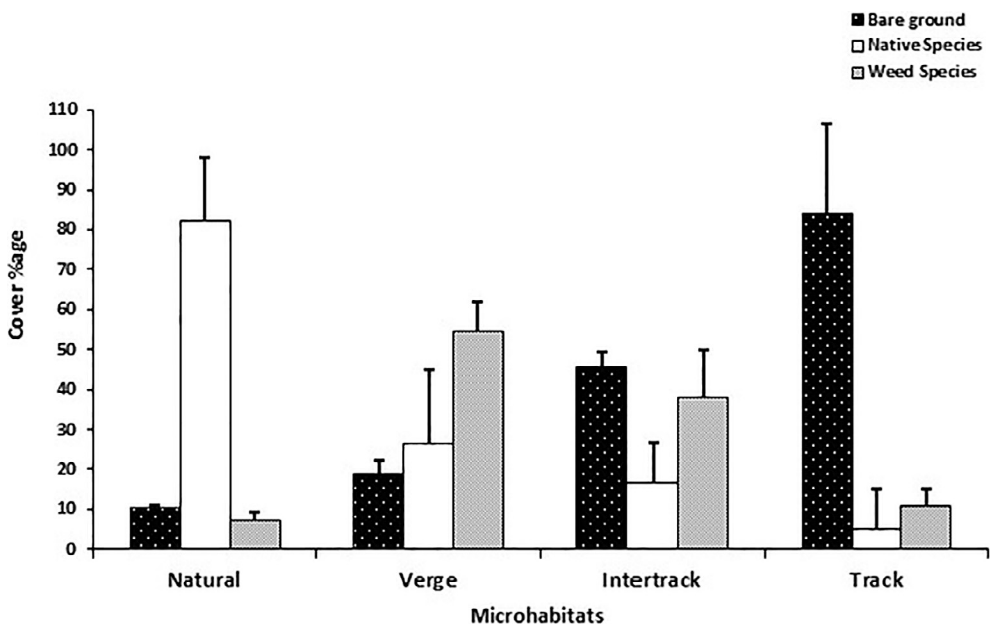

Fig. 4. Bare ground cover and canopy cover of native and weed plant species in a non-fenced area in Raudhat Khuraim as affected by off-road vehicle traffic.

Table 3
Density (plant/m^2) of most dominant native and weed plant species under natural undisturbed vegetation and microhabitats created by off-road vehicle driving (Mean ± SD).

Species	Natural undisturbed area	Micro-habitats			F-Value
		Verge	Inter track	Track	
Native species					
Anthemis deserti	85.3 ± 16.5	30.4 ± 8.4	18.4 ± 4.2	2.3 ± 1.2	62.28**
Filago desertorum	60.2 ± 15	55.3 ± 8.5	18.2 ± 5.1	7.1 ± 2.5	72.4**
Plantago boissieri	42.1 ± 7.4	32.3 ± 4.5	10.4 ± 2.5	3.1 ± 0.95	54.8**
Pulicaria undulata	18.2 ± 4.5	5.1 ± 2.5	2.3 ± 3.5	1.4 ± 0.95	22.4*
Rhanterium epapposum	18.1 ± 5.4	10.1 ± 2.8	0.2 ± 0.01	0.1 ± 0.02	12.8*
Rumex vesicarius	60 ± 3.5	25.5 ± 5.5	12.3 ± 4.2	4.2 ± 2.5	72.5**
Weeds					
Convolvulus pilosellifolius	18.3 ± 3.5	55.4 ± 5.5	12.7 ± 4.2	5.4 ± 1.4	38.4**
Cynodon dactylon	28.2 ± 3.2	60.3 ± 8.5	80.1 ± 5.1	22.3 ± 2.8	62.4**
Malva parviflora	35.5 ± 2.8	122.4 ± 6.4	60.2 ± 4.1	18.6 ± 1.4	75.4**
Melilotus indica	22.3 ± 1.2	64.1 ± 3.3	55.4 ± 4.2	18.2 ± 2.3	34.5**
Polypogon monspeliensis	10.5 ± 3.4	42.6 ± 6.4	8.3 ± 2.5	1.4 ± 0.95	25.4**
Trigonella stellata	8.3 ± 2.4	18.7 ± 4.5	35.4 ± 3.1	5.6 ± 1.7	12.4*

dune habitat in California (Luckenbach and Bury, 1983) and other studies reviewed by Lovich and Bainbridge (1999) in Mojave and Sonoran deserts of California.

With Off-road vehicle traffic, weeds increased in abundance. The most abundant weeds were two perennials; *Convolvulus pilosellifolius* and *Cynodon dactylon*, three annual forbs; *Malva parviflora*, *Melilotus indica* and *Trigonella stellata* and one annual grass; *Polypogon monspeliensis* (Table 3). Weed density varied in response to ORV in different microhabitats. Generally, weeds were most abundant in road verges and/or inter-tracks. Both *M. indica* and *C. pilosellifolius* increased by almost three folds in verges compared to undisturbed vegetation. Similarly, the density of *P. monspeliensis* increased over four folds in road inter-tracks compared to the undisturbed vegetation. The population density of *C. dactylon* was a three fold under inter-tracks compared to undisturbed vegetation. The density of *T. stellata* was 35.4 plants per m^2 in road inter-tacks compared to only 8.3 m^{-1} under the undisturbed vegetation (Table 3). Lonsdale and Lane (1994) have emphasized the role of ORV in spreading alien and weed species. Off-road vehicle traffic facilitate the spread of alien and weed species (Mortensen et al., 2009). Cowie and Werner (1993) indicated that track verges created by ORV were suitable habitat for invasive weed communities.

Desert soils have high spatial heterogeneity in most important nutrients such as nitrogen and phosphorus. This heterogeneity is further exacerbated by intense disturbances such as ORV, thus has a strong impact on plant community structure (Schlesinger et al., 1996). The spatial distribution of plant species in the current study could be related to soil nutrient heterogeneity and/or alteration of soil moisture status as inferred from the impact of ORV on soil bulk density and porosity.

4. Conclusion

Off-road vehicle driving has created local microhabitats (road verges, inter-tracks, and tracks) varying in species cover, density and composition. In these microhabitats, ORV altered soil texture, physical and/or chemical properties. Off-road vehicle had an impact on vegetation composition, cover, density and growth. Cover of native species decreased in all microhabitats, giving the way to weed encroachment (reaching as high as 56%). The ORV impact on density of native vegetation was species dependent and varied with habitat. *Rhanterium epapposum* was the most affected and was almost absent in road track habitat (99.5% reduction compared to undisturbed vegetation). The most abundant weeds in the study site were two perennials; *Convolvulus pilosellifolius* and *Cynodon dactylon*, three annual forbs; *Malva parviflora*, *Melilotus indica* and *Trigonella stellata* and one annual grass; *Polypogon monspeliensis*. Weed density varied in response to ORV in different microhabitats but generally increased compared to undisturbed areas. These changes in vegetation composition and structure coupled with alteration of soil properties because of ORV could be taken as indicators of land degradation leading to desertification in under fragile ecological conditions and intensive human activities in rangelands of Saudi Arabia.

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