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Effects of Pit and Mound Landscape on Soil Ecosystem Engineers at Local Scales-a Case Study in Hyrcanian Forest

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Abstract Earthworms comprise a major proportion of the total invertebrate biomass in terrestrial ecosystems and they are often called "ecosystem engineers". Felling of trees by wind occurs continually in forest ecosystems. Many of trees are uprooted by windthrow, annually. The uprooting of old trees creates multiple microsites (e.g. pit and mound landscape) that are main source for soil heterogeneity. Efforts have been made in this study to determine the impact of pit and mound landscape on earthworm assemblages. Due to, the experimental forest station of Tarbiat Modares University studied that is located in Mazandaran province, northern Iran. For this purpose, twenty hectare areas considered and numbers of thirty four uprooted trees were found. Five microsites were distinguished including mound top, mound wall, pit bottom, pit wall and closed canopy. Soil samples were taken at 0~15 cm, 15~30 cm and 30~45 cm depths from all microsites using core soil sampler with 81 cm^2 cross section. Soil pH, water content, organic carbon, total nitrogen and carbon to nitrogen ratio measured in the laboratory. The earthworms were collected simultaneously with the soil sampling by hand sorting method. As a result, in this study soil characters changes had significantly impact on earthworm abundance at local scales. Earthworm's (epigeic, anecic and endogeic) density and biomass had more amounts in pit bottom whereas, no earthworms found in mound top and wall microsites. Principle Component Analysis (PCA) performed on earthworm population and environmental variables showed that water content and C/N ratio are potential indicators of earthworm abundance change.
Keywords Forest disturbance; Tree uprooting; Earthworm; Soil character; PCA

1 Introduction

Soil organisms are known to affect plant growth by enhancing mineralisation of soil organic matter and modifying physical and chemical properties of soil (Bardgett et al., 2005). Within soil organisms, earthworms are in term of biomass and activity among the most important detritivores in terrestrial ecosystems (Edwards, 2004). They are also known to affect plant growth, generally positively, via five main mechanisms (Brown et al., 2004; Laossi et al., 2010): (1) an increased mineralization of soil organic matter (2) the production of plant growth substances via the stimulation of microbial activity; (3) the control of pests and parasites; (4) the stimulation of symbionts and (5) modifications of soil porosity and aggregation, which induces changes in water and oxygen availability to plant roots. Earthworms have been viewed as ecological engineers (Kooch and Jalilvand, 2008) and their activities profoundly affect soil physical and biological properties that can directly or indirectly alter plant-related processes such as resourceallocation, growth and recruitment (Szlavecz et al., 2011). Earthworms of the family *Lumbricidae* are ubiquitous inhabitants of terrestrial ecosystems, with the majority of species found in the Holarctic: from Canada and the USA through to Eurasia and Japan (Nechitaylo et al., 2010).

Earthworms are subject to physical, chemical and biological changes in soil, so they have a major role in soil structure and performance (Rahmani, 2000).

Earthworm activity in soil, transfer minerals to different horizons and also organics to lower horizons of soil (Rahmani and Saleh Rastin, 2000). Creation of holes in path of earthworms increases water penetration and soil aeration. It has been shown that 60% of earthworm's paths at soil depth of 15 cm and 18% of earthworm's paths at soil depth of 80 cm have been covered by tree roots (Rahmani and Saleh Rastin, 2000). Results of some studies on castings (worm dung) indicate abundance and diversity of fungal species (Groffman et al., 2004); bacterial plate counts, moisture content and concentrations of soluble organic-C are higher than the adjacent soil (Valckx et al., 2006). Moreover, most of the physico-chemical characteristics of castings are more than those of the underlying soil in both arable and natural vegetation areas. Earthworms have the highest biomass of earthen invertebrates. Also they cause remarkable increase in soil microorganisms and have an important effect on soil invertebrate's diversity and feed cycle (Rahmani and Saleh Rastin, 2000; Groffman et al., 2004).

Natural disturbances represent the key factor in natural forest dynamics (Frelich, 2002; Janasova et al., 2010). In the concept of disturbance ecology, disturbances are considered as an important part of soil ecosystem and plant communities dynamics (Samonil et al., 2009; Kooch and Hosseini, 2010). The most important type of disturbsnces in the temperate forests is blowdowns connected with the direct disturbance of soils (Kooch et al., 2010). Tree uprooting has important influences on forest ecology and implications for forest management (Phillips et al., 2008). Trees uprooting and pit and mound landscape creating is in general more likely in shallower and wetter soils, or where restrictive horizons limit root penetration. However, the size of trees seems to be more important than soil characteristics with respect to both the likelihood of uprooting and the amount of soil disturbed (Peterson, 2007). In general, consistent positive relationships exist between tree diameter and blowdown risk, and uprooting and wind damage varies among species, related to wood strength, rooting habit, and other factors. Shallow rooting increases wind throw vulnerability (Phillips et al., 2008). With considering mountainous position of hyrcanian forests in northern Iran and presence of trees with high diameters (old trees), therefore, it is imagined that many of trees are prone to uprooting by windthrow event.

It is now well known that forest disturbances generally result in significant variability of earthworm populations in temperate landscapes (Hendrix and Bohlen, 2002; Kooch and Hosseini, 2010) with significant ecological implications for ecosystem functioning (Barros et al., 2004; Gonzalez et al., 2006). Consequently, earthworms should serve as good indicators of environmental changes that occur by disturbance (Decaens and Jimenez, 2002; Tondoh et al., 2007; Kooch and Hosseini, 2010). Relationships of earthworms and soil properties have been well-documented for agricultural systems (Lamande et al., 2003; Decaens et al., 2004; Winsome et al., 2006) and forests (Whalen, 2004; Marhan and Scheu, 2005; Heneghan et al., 2007). In comparison, few studies have examined the density and biomass of earthworms in disturbed soils (Kooch and Hosseini, 2010). Up to now, however, only few studies (Haynes et al., 2003; Dlamini and Haynes, 2004) have simultaneously studied changes in earthworm communities and soil parameters, in response to forest disturbance in Iran (Kooch and Hosseini, 2010). It is not clear whether earthworm populations are mainly controlled by the amount of food, its quality, or the chemical properties of their environment (Aubert et al., 2003; Scheu et al., 2003; Gonzalez et al., 2003). Therefore, determining the relation among earthworm's biomass and diversity with created microsites by uprooting trees (pit and mound landscape) and edaphic conditions are essential for management of forest ecosystems. The present study is intended to address these issues by: (i) assessing the impact of forest disturbance on earthworm assemblages along a gradient of pit and mound landscape, and (ii) identifying soil variables associated with changes in earthworm abundance and diversity. Specifically, two main hypotheses were tested: (i) earthworm communities significantly change along the pit and mound landscape and, (ii) soil water content is the main driver of earthworm assemblage change.

2 Material and Methods

2.1 Study site

This research was conducted in experimental forest station of Tarbiat Modares University located in a temperate forest of Mazandaran province in the north of Iran, between 36˚31´ 56″N and 36˚32´11″N latitudes and 51˚47´ 49″E and 51˚47´ 56″E longitudes. The maximum elevation is 1700 m and the minimum is 100 m. Minimum temperature in December (6.6˚C) and the highest temperature in June (25˚C) are recorded, respectively. Mean annual precipitation of the study area were from 280.4 to 37.4 mm at the Noushahr city metrological station, which is 10Km far from the study area. For performing this research, a limited area of reserve parcel (relatively undisturbed) considered that was covered by *Fagus orientalis* and *Carpinus betulus* dominant stands. This limitation had an inclination 60~70 percent with northeast exposure at 546~648 m a.s.l. Bedrock is limestone-dolomite with silty-clay-loam soil texture. Presence of logged and bare roots of trees is indicating rooting restrictions and soil heavy texture (Kooch et al., 2010).

2.2 Soil sampling and analysis

Due to, twenty hectare areas of experimental forest station of Tarbiat Modares University studied and numbers of thirty four uprooted trees were found. In the all of areas, the pit and mounds resulted from the fall of a single tree. Pits needed to be at least 0.3 m above the general soil surface and mounds 0.3 below (Scharenbroch and Bockheim, 2007). For this purpose, Five microsites were distinguished including mound top, mound wall, pit bottom, pit wall and closed canopy. Soil samples were taken at 0~15 cm, 15~30 cm and 30~45 cm depths from all microsites using core soil sampler with 81 cm^2 cross section (Rahmani and Zare Maivan, 2004). Large live plant material (root and shoots) and pebbles in each sample were separated by hand and discarded. The air-dried soil samples were sieved (aggragates were crushed to pass through a 2 mm sieve) to remove roots prior to chemical analysis. Soil pH (with an electrode), water content (by drying soil samples at 105℃ for 24 hours), organic carbon (Walkey and Black method), total nitrogen (Kjeldahl method) measured in the laboratory (Jafari Haghighi, 2003).

2.3 Earthworm's samping and identification

The earthworms were collected simultaneously with the soil sampling by hand sorting, washed in water and weighed with mili gram precision. Species of earthworms were identified (epigeic, anecic, and endogeic) by external characteristics using the key of BOUCH (Kooch and Hosseini, 2010). Epigeic worms feed on plant litter, dwell on the soil surface or within the litter layer, tend to be heavily pigmented, and are small to medium sized. Anecic worms feed on plant litter and soil, live in nearly vertical permanent burrows, are dorsally pigmented, and large. Endogeic species are soil-feeders, are not heavily pigmented, from extensive horizontal burrow systems, and range in size form small to large. Earthworm species do not always fall clearly into these three main categories and may even exhibit traits of different groups at different life stages or under different environmental conditions (Kooch and Jalilvand, 2008). Biomass was defined as the weight of the worms after drying for 48 hours on filter paper at room temperature (60˚C) (Kooch and Hosseini, 2010).

2.4 Statistical analysis

Normality of the variables was checked by Kolmogrov-Smirnov test and Levene test was used to examine the equality of the variances. Differences between pit and mound microsites and depths in soil characteristics were tested with two-way analysis (ANOVA) using the General Linear Model (GLM) procedure, with microsites (mound top, mound wall, pit bottom, pit wall and closed canopy) and depths (0~15 cm, 15~30 cm and 30~45 cm) as independent factor. Interactions between independent factors were tested also. Duncan test was used to separate the averages of the dependent variables which were significantly affected by treatment. Significant differences among treatment averages for different parameters were tested at $P \leq 0.05$. Nonparametric Kruskal-Wallis analysis of variance was used to find differences in earthworm's density and biomass of microsites, beacsuse in some cases there was no homogeneity of variance. Analyses of whole data were done in SPSS Ver. 11.5 of statistical program. Factor analysis is statistic technique for achievement to complex relationships among variables. For this purpose, relationships between microsites, earthworm's assemblage and soil parameters were analysed by Principle Component Analysis (Mc Cune and Mefford, 1999).

3 Results

3.1 Soil characters

The greatest value of water content resulted in pit bottom and beneath layers of soil and the least was detected in mound top and 0-15cm depth. Significantly statistical differences (P < 0.01) were considered for this character (Table 1). Soil pH was significantly (P < 0.01) higher in mound wall and top. Fewer amounts were found in pit bottom (Table 1). Organic matter and carbon significantly (P < 0.01) increased in pit bottom whereas the least was observed in mound wall. These characters were decreased with increasing of soil depth (Table 1). Compare mean of total nitrogen in the microsites and depths indicated that pit bottom and 0-15cm depth had the higher amounts (P < 0.01) than in the others. Mound wall and 30-45cm depth includes the least value (Table 1). Greater amounts of carbon to nitrogen ratio were found in mound wall and 30-45cm depth whereas pit bottom had lower values, significantly (P < 0.01) (Table 1).

3.2 Ecological groups of earthworms

Analysis of data showed that abundance of earthworm's ecological groups had significant differences among microsites and soil depths (Table 2). Earthworm's (epigeic, anecic and endogeic) density and biomass had more amounts in pit bottom whereas, no earthworms found in mound top and wall microsites (Table 2). Studying of soil depths indicating that epigeic gathered in 0~15 cm depth, anecic preferred 15~30 cm and endogeic were assemblaged in soil deeper layers (Table 2).

3.3 Principal component analysis (PCA)

Principle component analysis showed that percentages of eigenvalue for the first and second axis are about 90.691% and 8.71%, respectively. These two axes are indicating 99.41% of total variance (Table 3). Eigenvectors of soil characters for these axes presented in table 4. PCA bibplots of microsites, soil characters and earthworm showed in figure 1. As can be seen in this figure, the mound top and wall have different condition in comparison to the others. These microsites involve quarter 3 of principal components. Whereas, pit bottom and wall presented different position than in closed canopy and captured quarters 4 and 1, respectively. Closed canopy was located in quarter 2 of axis. Earthworm's assemblage in quarter 4 of principal components is indicating more appropriate condition of soil ecosystem in pit bottom microsite.

4 Discussion

This research has confirmed the significant effect of different microsites and soil depths on earthworm abundance and biomass. Earthworms are sensitive to acid condition and theirs abundance are decreased with reducing of soil pH (Tondoh et al., 2011). According to previous studies, earthworms are interested in buffer condition of soil pH (Neirynck et al., 2000; Kooch and Jalilvand, 2008; Kooch et al., 2009; Kooch and Hosseini, 2010). The result of Deleporte (2001) research pointed that soil pH is an effective agent on earthworm's population. In current study, the pit microsites presented lower pH in comparison to the other microsites. Whereas, higher densities of earthworms were found in these microsites, also. Although, soil pH was less acid on mound microsite, but earthworms population were assemblaged in pit microsites. As can be seen in table 1, pit bottom includes more amounts of soil water content. Water constitutes 80 to 90% of the body weight of earthworms (Kooch and Hosseini, 2010), so soil moisture are essential for theirs live and will kill by reason of soil drying (Kooch and Hosseini, 2010; Na et al., 2011; Snyder et al., 2011; Scharenbroch and Johnston, 2011). Regarding to water content of 58.52 % in pit bottom, this amount is due to more assembelage of earthworm's different groups. Mounds creats hilly surfaces on superficial soil and include more soil volume and temperature in compare to other surfaces (Londo, 2001; Kooch et al., 2008). On the other hand, soil temperature is effcetive on density and biomass of earthworms and distribution (Kooch et al., 2008). Therefore, low moisture and high temperature created fatal conditions for earthworms on mound microsite (Nachtergale et al., 2002). By this reason, no

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Table 1 Mean of soil characters in pit and mound microsites and soil depths

Variables / characters		Water content (%)	pH	Organic Matter (%)	Organic carbon (%)	Total Nitrogen (%)	C/N ratio
Microsites	Mound top	11.86 (0.12)e	6.91 (0.05)a	3.47 (0.01)d	2.00 (0.00)d	0.11 (0.00)d	17.55 (0.09)b
	Mound wall	12.92 (0.16)d	6.96 (0.04)a	3.38 (0.01)e	1.96 (0.00)e	0.10 (0.00)e	18.39 (0.12)a
	Pit wall	51.95 (0.13)b	6.51 (0.04)bc	3.96 (0.03)b	2.35 (0.01)b	0.15 (0.00)b	15.54 (0.05)d
	Pit bottom	58.52 (0.21)a	6.38 (0.04)c	5.51 (0.01)a	3.20 (0.00)a	0.20 (0.00)a	15.41 (0.06)d
	Closed canopy	40.69 (0.18)c	6.62 (0.04)b	3.68 (0.02)c	2.14 (0.01)c	0.13 (0.00)c	16.38 (0.10)c
	F-value	23064.18**	26.74**	5139.57**	8255.46**	3025.96**	255.06**
Soil depths (cm)	0-15	34.73 (1.50)b	6.66 (0.04)	4.11 (0.06)	2.39 (0.04)a	0.15 (0.00)a	16.36 (0.11)c
	15-30	35.30 (1.50)	6.70 (0.04)	3.94 (0.05)	2.31 (0.03)b	0.14 (0.00)b	16.56 (0.11)b
	30-45	35.53 (1.49)a	6.68 (0.03)	3.94 (0.05)	2.29 (0.03)c	0.13 (0.00)c	17.04 (0.11)a
	F-value	13.64**	0.27ns	105.70**	150.01**	133.94**	31.76**
	Interaction	22.85**	0.25 ns	131.54**	198.89**	59.71**	11.14**

Note: ** Different is significant at the 0.01 level. (ns): Non significant differences (P > 0.05); Values are the means ±St. error of the mean; Within the same column the means followed by different letters are statistically different (P < 0.05)

Table 2 Kruskal-Wallis analysis for earthworm's density and biomass

Earthworm groups / variables		Epigeic		Anecic		Endogeic	
		Density (n/m^2)	Biomass (mg/m^2)	Density (n/m^2)	Biomass (mg/m^2)	Density (n/m^2)	Biomass (mg/m^2)
Microsites	Mound top	0.00	0.00	0.00	0.00	0.00	0.00
	Mound wall	0.00	0.00	0.00	0.00	0.00	0.00
	Pit wall	0.00	0.00	0.26	2.49	0.66	6.86
	Pit bottom	1.11	11.30	0.92	10.04	1.79	20.55
	Closed canopy	0.33	3.21	0.66	4.88	0.92	8.13
Statistical characters	Chi square	128.08	127.86	207.13	206.43	388.13	406.02
	DF	4	4	4	4	4	4
	Sig.	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**
Soil depths (cm)	0-15	0.78	7.76	0.45	4.23	0.35	3.61
	15-30	0.08	0.94	0.65	6.22	0.63	6.70
	30-45	0.00	0.00	0.00	0.00	1.04	10.99
Statistical characters	Chi square	132.14	130.42	124.54	118.90	37.33	25.91
	DF	2	2	2	2	2	2
	Sig.	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**

earthworms were found in mound microsite of current research. The distribution of the earthworm population was dynamic, but overall distribution was closely linked to temperature and moisture with dramatic reductions of earthworm numbers associated with very dry conditions. Suthar (2011) pointed that soil moisture shortage and extreme temperature variability are the most important of the major limiting factors for earthworm dispersal. High temperature is often associated with soil moisture shortage and therefore earthworm mortality in hyrcanian forests soils of Iran has been attributed to soil moisture shortage rather

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Table 3 Statistical parameters resulted in PCA for soil characters

Axes	Eigenvalue	Percentage of variance	Cummulative variance
1	5.44	90.69	90.69
2	0.52	8.71	99.41
3	0.03	0.55	99.97
4	0.00	0.03	100.00

Table 4 Eigenvectors of soil characters for the PCA axes

Row	Soil characters	Axis 1	Axis 2
1	pH	-0.07	-0.00
2	Organic matter	0.42	-0.05
3	Organic carbon	0.42	-0.04
4	Total nitrogen	0.59	-0.02
5	C/N ratio	-0.15	-0.01
6	Water content	1.22	0.11

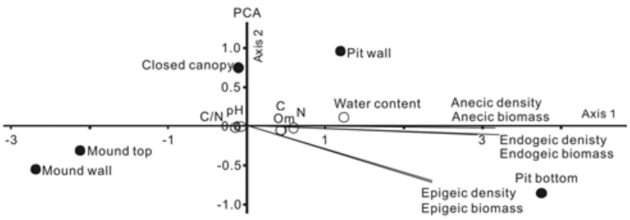

Figure 1 PCA bibplots of microsites, soil characters and earthworm species

than to temperature extremes (Kooch et al., 2008). The soil moisture availability and diversified landscape patterns are probably responsible for the earthworm colonization in this region.

High assemblage of earthworm biomass within pit is related to earthworm's higrophillous. Some of earthworms are semi-aquatic and prefer positions with high water content (Schwert, 1990; Kooch et al., 2008). Nachtergale et al (2002) pointed that the increase of epigeics biomass in pits is a reaction to more assemblage of trees litters within this microsite. Pits creation in forest ecosystem produce an especial condition as is due to increase of litter thickness and water content, thus the epigeics biomass will increase. Many researchers claimed that less abundance of earthworms in acid condition is related to lack of calcium ion in soil ecosystem (Sanjabi, 2004). The most earthworms especially anecic, prefer rich environments of nutrient source with lower carbon to nitrogen ration. Endogeic and anecic species are more resistance to soil inpropre textures and are able to withstand dry conditions (Kooch and Jalilvand, 2008). Thus, these species are able to migration in soil deeper depths for avoiding of dryness (Hale and Host, 2005). Whereas epigeic species are more asseblaged on soil surface and upper layers of mineral soil (Hale and Host, 2005). These subjects are visible in this study also. According to obtained results the epigeic, anecic and endogeic species were more gathered in 0~15 cm, 15~30 cm and 30~45 cm depths, respectively.

Soil C/N ratio is the other effective factor that can be considered in relation to earthworms' groups' assemblage of different positions. Wood (1995) found that earthworm population and biomass will increase in soil with low C/N ratio. Rahmani (1999) also pointed that earthworm densities are affected by C/N ratio, as earthworms assemblages are reduced with increasing of this ratio. Neyrinck et al (2000) reported that the low C/N ratio in soil ecosystem is due to gathering of different earthworms. Antunes et al (2008) demonstrated soil C/N ratio as an abiotic factor and the most important effective factor on earthworm's populations in forest sites. Kooch et al (2009) introduced the soil C/N ratio factor as the most important of effective factor on earthworm populations in plant ecological groups of Chalous lowland forests located in north of Iran. In our study, the least amounts of soil C/N ratio found in pit position, thus more earthworms' densities were detected in this microsite. Principal component analysis confirmed the accuracy of above phrase. Also, earthworms abundance were correlated to theirs biomass ($r = 0.99^{**}$) that is according to obtained results in Haynes et al (2003) research. The analysis of factor analysis in this research showed that the earthworm's assemblage in quarter 4 of principal components is indicating more proper condition of soil ecosystem in pit bottom microsite. A statistical result is indicating that high water content and low C/N ratio in pit position are the most effective factors for gathering of earthworm groups. Whereas, the soil dryness is the most important factor in mound landscape, negatively.

5 Conclusion

According to results, members of the *Lumbricidae* family require an adequate amount of moisture in their environment and therefore rarely occur in dry regions. In general, the earthworms showed a patchy distribution in microhabitats with abundant soil moistures contents. Also, earthworm abundance in different habitats was related to the C/N ratio contents in soils. Earthworms are introduced as a good bio-indicator for forest site quality in disturbed regions. Consequently, they can therefore be considered as potential indicators of soil quality.

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