FOLIA OECOLOGICA – vol. 37, no. 2 (2010). ISSN 1336-5266

Response of earthworms biomass and diversity to windthrow events and soil properties in Hyrcanian forests of Iran

Yahya Kooch[1], Seyed Mohsen Hosseini*[2]

[1, 2]Department of Forestry, Natural Resource Faculty, Tarbiat Modares University, Nour, Mazandaran, P. O. Box 46414-356, Iran

Abstract

Kooch, Y., Hosseini, S. M. 2010. Response of earthworms biomass and diversity to windthrow events and soil properties in Hyrcanian forests of Iran. *Folia oecol*., 37: 181–190.

Uprooting is a major disturbance factor in most natural forests. Little work has been done concerning the effects of uprooting on soil properties and fauna. This paper focuses the effects of tree uprooting on some soil properties, earthworm biomass and species diversity in Sardabrood forests of Chalous in Hyrcanian forest, northern Iran. For this purpose, twenty seven single-tree gap sites in mixed beech forests were selected at 700–1,300 m altitude range, seventeen sites dominated by beech (*Fagus orientalis* Lipsky) and ten by hornbeam (*Carpinus betulus* L.). Four microsites were distinguished at each site: mound top (mound), pit bottom (pit), gap in the canopy (gap) and closed canopy (canopy). Soil samples were taken at 10 cm depth from all microsites. Earthworms were collected by hand sorting, simultaneously with the soil sampling. Soil acidity, water content, total carbon, total nitrogen and carbon to nitrogen ratio were measured in the laboratory. The impact of uprooting disturbance on soil properties was found significant. The total earthworm number and biomass differed significantly among the mentioned sites and microsites. The number and biomass amount of earthworms showed decreasing trend from undisturbed (closed canopy) to disturbed sites (gap, pit and mound). This trend is mainly caused by number and biomass of endogeic ecological group of earthworms. No earthworms were found in mound microsites. Thus, the windthrow generally reduced the activity and abundance of the earthworms. Our results suggest that windthrow should be considered effectively influencing soil diversity in context of forest ecology. This is significant for evaluating forest management policies and practices with respect to impacts on soil and also for the use of soils as indicators of forest ecosystems.

Key words

earthworms, gap, pit and mound, soil, uprooting

Introduction

In disturbance ecology, disturbances are considered as an important part of dynamics of plant communities (Samonil et al., 2009). The most important type of disturbances in the temperate forests is blowdown connected with the disturbance of soils (Ulanova, 2000). Tree uprooting has important influences on forest ecology and

---

*Corresponding author´s address: Tarbiat Modares University, Noor, Mazandaran, Iran, P.O. Box 46414-356; tel.: +98-122-6253101-3; fax: +98-122-6253499; e-mail: hosseini@modares.ac.ir

implications for forest management (Ulanova, 2000; Peterson, 2007; Phillips et al., 2008). Ice storms, firing and other factors may cause uprooting, but wind is the most common cause (Peterson, 2007). Windthrow events have significant impacts on forest structure, species composition, gap succession and microtopography (Peterson, 2007).

Soil formation processes are affected by different disturbances in forest ecosystems (Ulanova, 2000). One of the most important effects of windthrow is its influence on the rate and quality of soil formation processes (Samonil et al., 2008). Tree uprooting has different effects on the soil of forest ecosystems (Gabet et al., 2003). Tree uprooting is a pervasive source of bio-perturbation in forests, with significant direct effects on soils, as well as indirect effects on soil formation and sediment transport. The direct effects include soil mixing, soil profile inversion, local redistribution of sediment mass, and creation of characteristic pit and mound topography. Indirect effects include exposure of unprotected sediment to erosion and mass wasting, and creation of microscale differences in weathering, moisture flux, organic matter dynamics, and microclimate in the pit and mound topography (Phillips et al., 2008).

Because of the complexity of tree uprooting process and the time elapsed since uprooting, the size of pits and mounds varies greatly. Aproximately 10 to 50 percent of the forest floor in temperate forests may be covered by pit and mound topography (Schaetzl et al., 1990). Tree uprooting and pit and mound topography are not randomly distributed. They are strongly associated with ecosystems having parent material and soil favouring shallow rooting and systems with severe windstorms (Phillips and Marion, 2006). For ecosystems with wet mineral or organic soils (high water tables), rocky soils or soils developing root restricting horizons is typical high incidence of uprooting (Peterson, 2007). Tree uprooting and pit and mound features create heterogeneous conditions in soil ecosystem. In case of an uprooted mature tree, an average of 12 to 16 m^2 of soil to a depth of one meter or more may be disturbed (Norton, et al. 1989).

Soil processes are controlled by a set of relatively independent state factors including climate, organisms, relief, parent material, time and by a group of interactive controls such as disturbance regime and human activities (Scharenbroch and Bockheim, 2007). Forest gaps are a key component of the disturbance regime and examples of natural interactive controls with direct impacts on state factors including climate and organisms. Forest gaps represent dramatic top-down trophic interactions between vegetation and the soil microbial mediated processes (Chapin et al., 2002). Gaps may be responsible for the creation of nutrient hot spots or islands of fertility that increase forest productivity and overall soil diversity (Scharenbroch and Bockheim, 2007; Scharenbroch and Bockheim, 2008).

Earthworms are perhaps the most important soil organisms in terms of their influence on organic matter breakdown, soil structural development, and nutrient cycling, especially in productive ecosystems (Kooch et al., 2008). Aristole called them the “intestines of the earth” and the eminent nineteenth century biologist, Charles Darwin, spent many years observing their major influence on the soil humus formation and transport (Kooch and Jalilvand, 2008). Despite of the vast increase in scientific literature on earthworms in recent years, they are major gaps in knowledge of their basic biology and ecology (Nachtergale et al., 2002; Kooch et al., 2008). However, to determine relations among biomass and diversity of earthworms, pit and mound disturbances and soil properties is essential for management of forest ecosystems. The goal of this study was to investigate windthrow effects on soil properties, earthworm biomass and species diversity in Hyrcanian forests of Iran. The survey was the first of this type in these forests.

Material and methods

Study area

This research was performed in Sardabrood forests located in lowland and midland of the Mazandaran province in northern Iran (36˚37'30"–36˚40'52" N, 51˚7'50"–51˚12'51" E). The study area was 2,347 ha, the maximum elevation 1,400 m and minimum 50 m. The lowest temperature was measured in December (7.5 °C), the highest in June (24.6 °C). The data on mean annual precipitation of the study area: 47.5 to 237.6 mm were provided by the Noushahr city meterological station, which is 10 km far from the study area. The soils are deep, moderately well drained. Their texture is silty clay and clay loam, with pH of 4.9 to 6.3. The bedrock is sandstone with silting and argillite, and lime stone. Presence of logged and bare roots of trees indicates rooting restrictions and heavy soil texture (*Sardabrood Forest Management*, 2003).

Soil sampling and analysis

In the summer of 2008, twenty seven single-tree gap sites in mixed beech forests at 700–1,300 m altitude range were selected, seventeen sites dominated by beech (*Fagus orientalis* Lipsky) and ten by hornbeam (*Carpinus betulus* L.) (Table 1). In all the areas, the pit and mounds resulted from the fall of a single tree. At each site, four microsites were distinguished: mound top (mound), pit bottom (pit), gap in the canopy (gap) and closed canopy (canopy). Soil samples were taken at 10 cm depth from all microsites. Large live plant material (root and shoots) and pebbles in each sample were separated by hand and discarded. The soil samples were air-dried and sieved. Soil acidity (with an electrode), water content (by drying soil samples at 105 °C for 24 hours), total carbon (Walkey and Black method), total nitrogen (Kjeldahl method) and carbon to nitrogen ratio were measured in the laboratory (Scharenbroch and Bockheim, 2007).

Sampling and identification of earthworms

The earthworms were collected by hand sorting simultaneously with the soil sampling, washed in water and weighed with a milligram precision. Earthworm species were identified (epigeic, anecic, and endogeic) based on their external characteristics using the key of BOUCH (Edwards and Bohlen, 1996). Biomass was defined as the weight of the worms after drying for 48 hours on filter paper at room temperature (60 °C) (Edwards and Bohlen, 1996).

Data analysis

Kolomogorov-Smirnov test was used for testing normality and Levene test for data homogeneity testing. Analysis of variance (one-way anova) and Duncan comparison were used to find differences in soil characteristics among the microsites. Nonparametric Kruskal-Wallis analysis of variance and Mann-Whitney comparison were used to find differences in earthworms number and biomass among sites and microsites, because in some cases the variance lacked homogeneity. Analysis of the whole data set was done in SPSS Ver. 13.5. Factor analysis is a statistic tool for exploring complex relationships among variables. Relationships between microsites and earthworms species were analyzed by Principle Component Analysis (McCune and Mefford, 1999).

Results

Soil properties

Analysis of variance has revealed significant differences in soil characteristics between the investigated microsites of beech and hornbeam sites (Table 2). The maximum and minimum acidity were observed in mound and canopy microsites, respectively, for both woody plants (Table 3). The highest water content (moisture) occurred in pit microsites and the least was observed on mounds (Table 3). In beech site, maximum amount of carbon related to canopy and the lowest was found in mound microsites; but in hornbeam site, the highest was observed in gap microsites (Table 3). Nitrogen manifested higher amounts in canopy microsites and the lowest value related to mound (Table 3). Carbon to nitrogen ratio was lower in canopy sites, the highest values were observed in pits for beech sites and on mound in hornbeam sites (Table 3).

Ecological groups of earthworms

Analysis of data showed that there were significant differences in number and biomass of earthworms ecological groups among the microsites (Table 4) and sites

Table 1. Characteristics of uprooted beech and hornbeam trees

Species	Tree number	Average D. B. H. [cm]	Average altitude [m]	Dominant slope	Slope aspect
Fagus orientalis Lipsky	17	45.35 (35–52)	1,202.1 (1,110–1,295)	40–50	Northeast
Carpinus betulus L.	10	48.60 (42–52)	771.5 (725– 910)		

Table 2. Analysis of variance for soil characteristics in study area

Soil character / Site	SS		DF		MS		F		Sig.	
	B	H	B	H	B	H	B	H	B	H
pH	7.99	0.76	3	3	2.66	0.25	35.92	7.98	0.000**	0.000**
Water content	15198.7	7674.17	3	3	5066.23	2558.05	128.20	33.36	0.000**	0.000**
Carbon	5.84	3.62	3	3	1.94	1.21	4.57	3.96	0.006**	0.015*
Nitrogen	0.15	0.17	3	3	0.05	0.05	72.89	125.16	0.000**	0.000**
Carbon to nitrogen ratio	665.69	663.96	3	3	221.89	221.32	7.29	9.69	0.000**	0.000**

**Difference is significant at the 0.01 level.
*Difference is significant at the 0.05 level.
DF, degree of freedom; B, beech site; H; hornbeam site.

(Table 5). Earthworms number and biomass displayed more amounts in canopy microsites, and the lowest were observed on mound microsites (Table 4). The hornbeam sites had more abundant earthworms in comparison to the beech sites (Table 5).

Table 3. Mean values of soil characteristics in different microsites of study sites

Site	Microsite	pH	Water content	Carbon	Nitrogen	Carbon to nitrogen ratio
Beech	Mound	6.82 (0.03)a	15.98 (0.84)d	2.59 (0.13)b	0.12 (0.006)c	21.05(1.39)ab
	Pit	6.11 (0.09)b	55.72 (1.97)a	2.68 (0.18)b	0.12 (0.003)c	22.00 (1.69)a
	Gap	6.68 (0.04)a	29.38 (1.26)c	3.00 (0.16)ab	0.17 (0.008)b	17.67 (1.37)bc
	Canopy	6.03 (0.07)b	43.80(1.75)b	3.34 (0.15)a	0.24 (0.006)a	14.04 (0.68)c
Hornbeam	Mound	7.66 (0.05)a	14.84 (0.84)c	2.35 (0.04)b	0.11 (0.005)b	20.37 (0.90)a
	Pit	7.43 (0.01)b	53.74 (4.32)a	2.37 (0.29)b	0.13 (0.007)b	18.67 (2.75)a
	Gap	7.65 (0.04)a	37.61 (2.39)b	3.04 (0.17)a	0.25 (0.006)a	12.05 (0.74)b
	Canopy	7.34 (0.08)b	37.49 (2.34)b	2.84 (0.03)ab	0.26 (0.007)a	10.95 (0.38)b

Values are the means ± St. error of the mean (in parentheses).
Within the same column the means followed by different letters are statistically different ($P < 0.05$).

Table 4. Kruskal-Wallis analysis for number and biomass of earthworms in different microsites

Site – Microsite /		Earthworm	Epigeic		Anecic		Endogeic	
Statistical character		Groups	Biomass	Number	Number	Biomass	Number	Biomass
Beech	Microsite	Mound	0	0	0	0	0	0
		Pit	1	10.47	0	0	0	0
		Gap	0	0	1.47	10.76	0	0
		Canopy	0.52	2.76	0	0	1.23	7.41
	Statistical characters	Chi square	15.242	15.849	30.477	30.459	19.404	19.398
		DF	3	3	3	3	3	3
		Sig.	0.002**	0.001**	0.000**	0.000**	0.000**	0.000**
Hornbeam	Microsite	Mound	0	0	0	0	0	0
		Pit	2.10	31	0.30	1	0	0
		Gap	1	5.50	2.80	34.30	0	0
		Canopy	1.30	10.40	4.50	13.20	2.80	26.90
	Statistical characters	Chi square	12.105	12.444	17.775	18.338	28.800	28.783
		DF	3	3	3	3	3	3
		Sig.	0.007**	0.006**	0.000**	0.000**	0.000**	0.000**

**Difference is significant at the 0.01 level.
DF, degrees of freedom.
Mean of earthworms' numbers presented in m^2 and biomass in $mg\ m^{-2}$.

Table 5. Mann-Whitney analysis for number and biomass of earthworms in study sites

Earthworm /	Epigeic		Anecic		Endogeic	
Statistical character	Number	Biomass	Number	Biomass	Number	Biomass
Mann-Whitney U	945	950.50	957.50	951.50	1207	1201
Wilcoxon	3291	3296.50	3303.50	3297.50	3553	3547
Z	–3.31	–3.26	–3.41	–3.46	–1.66	–1.733
Sig.	0.001**	0.001**	0.001**	0.001**	0.095 ns	0.083 ns

**Difference is significant at the 0.01 level.
ns, non significant differences ($P > 0.05$).

Earthworm groups and soil properties

In beech sites, principle component analysis showed that percentage of eigenvalue for the first and second axis were about 53.91% and 31.69%, respectively. PCA biplots of microsites, soil characteristics and earthworm species are presented in Figure 1. The number of epigeic is linked to positive direction of axis 1, but number and biomass of anecic are connected to negative direction of this axis. The negative direction of axis 2 is linked to epigeic biomass and positive direction to number and biomass of endogeic. Mound and gap microsites covered left part of axis 1 and pit microsite occupied left part of axis 2. Right part of axis 2 corresponded to canopy microsite. Carbon and nitrogen are related to negative direction of axis 1 and carbon to nitrogen ratio linked to right part of this axis. Acidity and water content (moisture) covered left and right parts of axis 2, respectively (Fig. 1).

In hornbeam site, the first second of the PCA accounted for 81.38% of the total variance; 48.13% by axis 1, 33.25 % by axis 2. PCA biplots of microsites, soil characteristics and earthworm groups for hornbeam site are displayed in Figure 2. The negative direction of axis 1 comprises numbers of anecic and endogeic species and biomass of endogeic species. Number and biomass of epigeics related to right part of axis 2 and anecic biomass linked to left part of this axis. Canopy microsite covered the negative direction of axis 1, the pit and gap microsites occupied right and left parts of axis 2, respectively. Mound linked to right part of axis 1 with eigenvector 1.46 and left part of axis 2 with eigenvector equal to –1.47. Carbon and nitrogen involved negative direction of axis 1 and carbon to nitrogen ratio lay in positive section of axis 1. Acidity and water content linked to left and right parts of axis 2, respectively (Fig. 2).

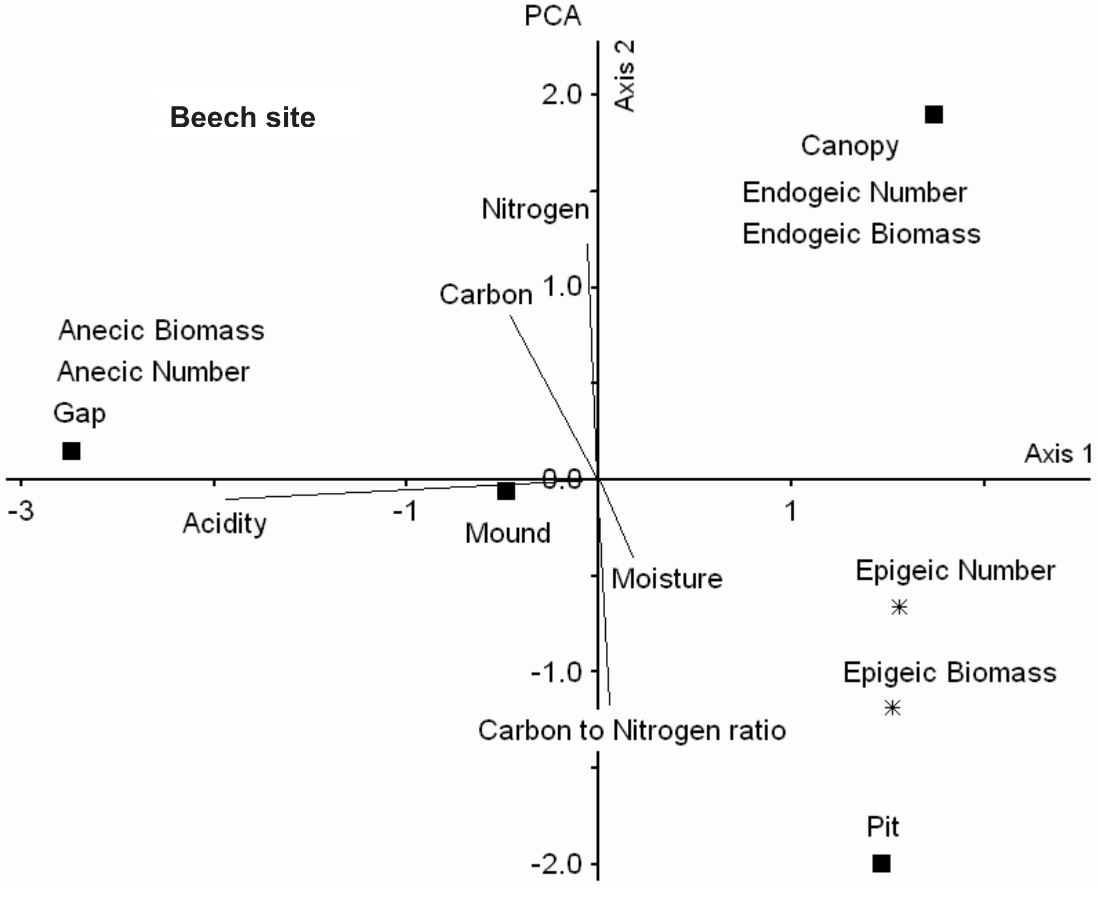

Fig. 1. PCA biplots of microsites, soil characteristics and earthworm species (**PC1:** eigenvalue = 3.23, percent of variance = 53.91, cumulative variance percent = 53.91 and **PC2:** eigenvalue = 1.90, percent of variance = 31.69, cumulative variance percent = 85.60).

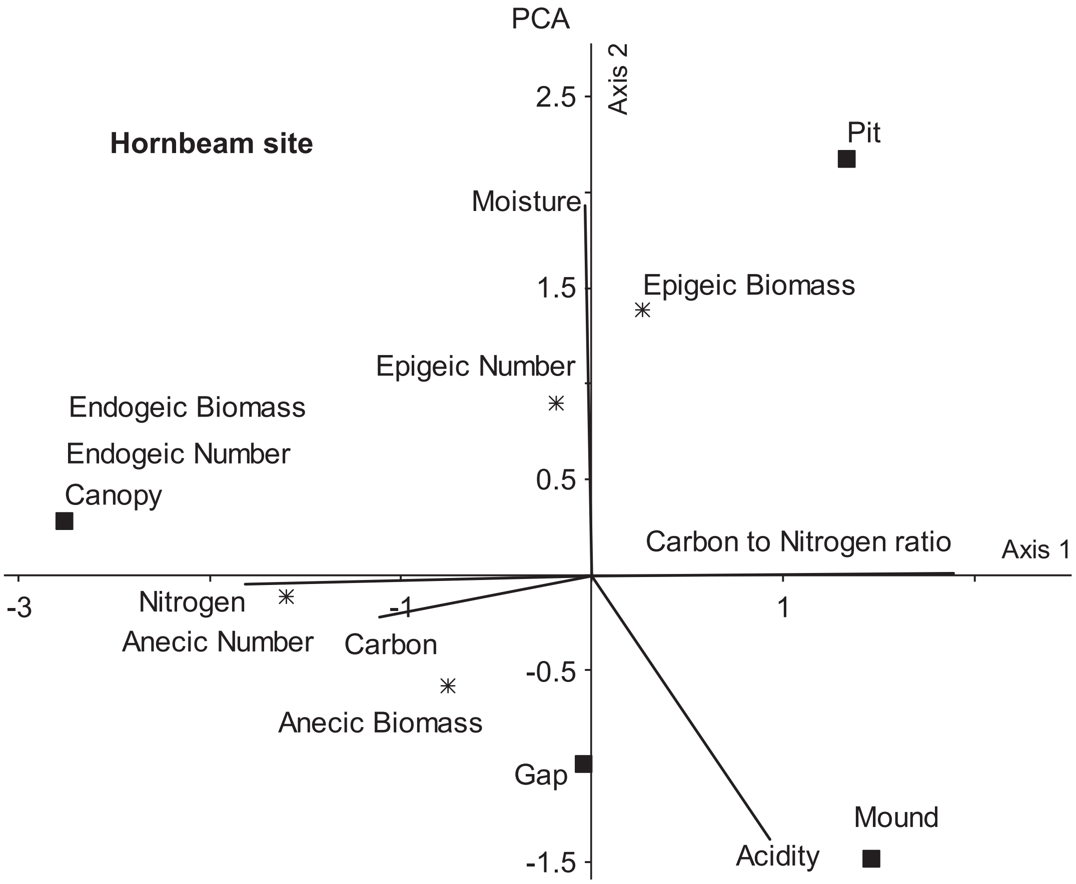

Fig. 2. PCA biplots of microsites, soil characteristics and earthworm species (**PC1:** eigenvalue = 2.88, percent of variance = 48.13, cumulative variance percent = 48.13 and **PC2:** eigenvalue = 1.99, percent of variance = 33.25, cumulative variance percent = 81.38).

Discussion

Soil properties

Results of this research showed that all the studied properties were variable among investigated microsites (Tables 2 and 3). The most significant differences were found in pit, mound and canopy microsites (Table 3). Soil acidity manifested significant differences in microsites with the most and least amounts in mound and canopy microsites (Table 3). Thus, it is possible that gap creation increased soil acidity and lowered pH in canopy microsites. Beech litters have low pH values, but within gaps with occurrence of disturbances and extensive changes, the decomposition rate is higher and organic matter cycle are better in comparison to the canopy. Therefore, the soil pH values were higher in gap microsites, which is in accordance with the results of Muscolo et al. (2007).

The highest average moisture content was found in pits, the least water was in mound microsites (Table 3) – in accordance with Barton et al. (2000). The results of the current research show that pit and mound features were associated with basic changes in soil characteristics (Lutz 1940; Peterson and Pickett, 1990; Bormann et al., 1995; Peterson, 2000) and changes in soil moisture (Beatty and Stone, 1986). The gap creation decreased soil water content, and central areas of gaps (mound microsites) had less moisture than border areas (gap microsites). Water content changes are very variable in different forest ecosystems (Mc Donald and Abbott, 1994; Gagnon et al., 2003). Chen et al. (1999) mentioned that gap creation in forest ecosystems induces moisture decreasing and temperature increasing in superficial soils.

Beech twigs and leaves need more time for decomposition than hornbeam species. This is more evident in old forest stands with higher litter volume in understory (Huttl et al., 2000). Thick humus layers provide favourable conditions for moisture preservation in forest lands. Spongy character under closed canopy improves water and moisture preservation capacities in comparison with positions without closed canopy. Humus reduction within gaps can be related to more solar radiation and increased microclimate temperature (Page and Cameron, 2006). Gaps have more plant diversity than closed canopy (Shure et al., 2006). Colonisation by diverse plant species using different soil horizons is due to increased root respiration followed by increased temperature that can be effective in humus reduction.

In beech sites, the maximum values of carbon were found in canopy microsites, the lowest on mound microsites; whereas in hornbeam sites, the most amount of carbon was observed in gap microsites (Table 3). Clinton and Baker (2000) reported the following distribution pattern for organic carbon at Coweeta Basin in North Carolina one year after a windthrow event: 2.15% mound, 2.11% pit wall, 1.42% pit bottom, and 4.73% in the undisturbed area. Beatty and Stone (1986) report organic matter distribution as 5.7% (3.31% C) for mound, 17.8% (10.32% C) for pit, and 10.0% (5.8% C) for undisturbed sites. Thus, the changes in carbon amounts are different in diverse forest ecosystems. Nitrogen had higher values in canopy, and the lowest were related to mound (Table 3). It is worth to notice that soil characteristics had different responses to various microsites.

Nitrogen was significantly increasing with closing canopy cover. Soil nitrogen contents are controlled by several factors such as soil moisture and temperature, carbon accessibility, decomposers species, soil acidity, soil texture, the value of absorbed nitrogen by roots and its return to litter (Persson et al., 2000). It is possible that bacteria converting organic nitrogen to mineral form are activated in a specific temperature range. Therefore, soil temperature displays multiple effects which can explain different correlation values (from positive to negative) in nitrogen content mentioned in different studies (Schmidt et al., 2002). The presence of microbial agents and oozing of created acids by activity of these organisms have an important role in carbon storage (Frazer et al., 1990). Nachtergale et al. (2002) mentioned that mounds have low carbon and nitrogen contents due to leaching and drainage (mounds represent hilly areas on soil surface). This fact has been confirmed by our research, too (Table 3).

Carbon to nitrogen ratio, is an index for determination of humus and litter decomposition amount. Therefore, it is appropriate for calculation of litter volume and weight reduction (Taylor et al., 1989). Carbon to nitrogen ratio was found lower in canopy and the highest value was observed in pits for beech sites and mounds in hornbeam sites (Table 3). Barton et al. (2000) investigated the amounts of carbon, nitrogen and values of carbon to nitrogen ratio in various microsites of pit and mound type. He found that the values of these characters were associated with undisturbed areas, and that there were significant differences between these and the other microsites.

Earthworm ecological groups

In general, most earthworms are sensitive to soil acidity as their numbers and biomass are lower in soils with low pH. Several studies of the issue resulted in finding that earthworms preferred pH close to buffer (Neirynck et al., 2000). Deleporte (2001) introduced soil pH as an effective negative agent affecting earthworm abundance. The hornbeam site had higher pH values, so it provided more appropriate conditions for abundance and biomass of earthworm ecological groups (Tables 4 and 5). Rahmani and Saleh Rastin (2000) observed that number and biomass of earhworms in hornbeam stands were higher than in oak-hornbeam and beech stands. However, no significant difference between oak-hornbeam and beech stands was observed.

In the beech site, epigeic ecological groups (belonging to epi-anecic under-category) found in pit and canopy microsites (Table 4) were related to high moisture amounts in these microsites (Table 3). Almost 80 to 90% of earthworms´ fresh weight represents water, thus soil moisture is essential for their living, and soil drying can cause their death (Saleh Rastin, 1978). Considering the moisture of 55.72% in pit microsites (Table 3), this moisture amount is due to gathering more epigeics (Table 4). The most earthworms, especially anecic species, prefer positions with rich nutrient supply. These species consume litters with low C/N content. Endogeic and anecic species are more resistant to inappropriate soil textures and to drought. They can migrate in deeper layers and avoid soil drought, especially in summer season (Hale and Host, 2005).

In the hornbeam site, different earthworms groups were found in all studied microsites except of mound microsites (Table 4). The superficial soil with mounds is hilly, and has more volume and higher temperature in comparison to other surfaces (Londo et al., 2001). On the other hand, soil temperature exerts effects on earthworms number and biomass and on their distribution (Brady, 1990). Therefore, low moisture and high temperature represent fatal conditions for earthworms on mounds (Nachtergale et al., 2002), and, consequently, no earthworms were found in mound microsite in both of site types (Table 4). The high amount of epigeic biomass within the pits is related to hygrophillous earthworms. Some of earthworms are semi-aquatic and prefer positions with high moisture and deep water (Schwert, 1990).

Nachtergale et al. (2002) mentioned that the increase of epigeics biomass in pits is a response to more tree litter gathered within these microsites. Pits creation in forest floor produce an especial condition – due to increase of litter thickness and water content, thus the epigeics biomass will increase. Carbon to nitrogen ratio in closed canopy microsite results from assemblage of earthworms diverse groups in this hornbeam microsite. In summary, it seems that the suitable temperature and moisture, absence of inappropriate chemical substances such as tanin, polyphenol, and low carbon to nitrogen ratio (especially in closed canopy microsites) created favourable conditions for increasing biologic activities of earthworms in hornbeam site compared to the beech site. Therefore, the presence and abundance of earthworms diverse groups are more visible in the hornbeam site.

The results of PCA for the two sites indicated that the axis 1 and axis 2 accounted for most of the total variance. Also, position of microsites, soil characteristics and earthworm ecological groups manifest special conditions – due to gathering and abundance of earthworms. Closed canopy microsites in beech sites were associated with the highest density and biomass of endogeics, and had high correlation with positive direction of axis 2. Gap microsites had the most abundance of anecic species, and showed high correlation with negative direction of axis 1. Epigeic species occupied pit microsites and had high correlation with soil moisture. In hornbeam sites, presence of different factors and combination of environmental factors were an obstacle of complete differentiation of earthworms ecological groups in pit and gap microsites (Figs 1 and 2).

The results of this research show that the number and biomass of earthworms had decreasing trend from undisturbed (closed canopy) to disturbed sites (gap, pit and mound), and no earthworms were found in mound microsites. Saint-Germain and Mauffette (2001) suggest that the ice storms introduced disturbances and reduction in beetle populations in maple forest ecosystem. Bouget (2005) and Gandhi et al. (2008) mention that windthrows are associated with decrease in forest beetles populations. Furthermore, the created disturbance had the most impact on endogeic ecological group of earthworms. These earthworms group were not visible in disturbed areas (gap, pit and mound). It is supposed that this earthworms groups are more sensitive to severe light conditions and higher temperature within gaps in comparison to the other earthworm groups. As individuals belonging into this group have more excavation abilities than the other groups (Kooch and Jalilvand, 2008; Kooch et al., 2008), they migrate to deeper layers of soil and no endogeic was found in 0–10 cm depth. On the other hand, in closed canopy, with less light supply and moderate temperature conditions on soil surface, endogeics were found migrating to soil surface.

Conclusions

The results of this study show that earthworms can serve as bioindicators for evaluation of changes in forest stands after disturbance events. The windthrow generally reduced the activity and abundance of earthworms. Our results suggest that windthrow should be considered as an effective factor influencing soil diversity in context of forest ecology. This is significant for evaluating forest management policies and practices with respect to impacts on soil and also for the use of soils as indicators of forest ecosystems.

References

Barton, D., Corey, C., Baker, R. 2000. Catastrophic windthrow in the southern Appalachians: characteristics of pits and mounds and initial vegetation responses. *Forest Ecol. Mgmt*, 126: 51–60.

Beatty, S.W., Stone, E.L. 1986. The variety of soil microsites created by tree falls. *Can. J. Forest Res.*, 16: 539–548.

Bormann, B.T., Spaltenstein, H., Mc Clellan, M.H., Ugolini, F.C., Cormack, K., Nay, S.M. 1995. Rapid soil development after windthrow disturbance in pristine forests. *J. Ecol.*, 83: 747–757.

Bouget, C. 2005. Ground beetle communities on windthrow gaps in broadleaved temperature forests: gap and gap size effects. In Lovei, G., Toft, S. (eds). *European* carabidology 2003. *Proceedings of the 11th European Carabidologists' Meeting, Arhus, Denmark, 21–24 July* 2003. DIAS report. Plant production, No 114. Tjele: Danish Institute of Agricultural Sciences, p. 25–40.

Brady, N.C. 1990. *The nature and properties of soils*. New York: Macmillan. 621 p.

Chapin F. S., Maston P. A., Mooney H.A. 2002. *Principles of terrestrial ecosystem ecology*. New York: Springer. 436 p.

Chen, J., Saunders, S.C., Crow, T.R., Naiman, R.J., Brosofski, K.D., Mroz, G.D., Brook Shire, B.L., Franklin, J.F. 1999. Microclimate in forest ecosystem and landscape ecology. *Bioscience*, 49: 288–297.

Clinton, B.D., Baker, C.R. 2000. Catastrophic windthrow in the Southern Appalachians: characteristics of pit and mounds and initial vegetation responses. *Forest Ecol. Mgmt*, 126: 51–60.

Deleporte, S. 2001. Changes in the earthworm community of an acidophilous lowland beech forest during a stand rotation. *Soil Biol.*, 37: 1–7.

Edwards, C.A., Bohlen, P.J. 1996. *Biology and ecology of earthworms*. London: Chapman and Hall. 426 p.

Frazer D.W., McColl J.G., Powers R.F., 1990. Soil nitrogen mineralization in a clear cutting chronosequence in a northern California conifer forest. *Soil Sci. Soc. Amer. J.*, 54: 1145–1152.

Gabet, E.J., Reichmann, O.J., Seabloom, E.W. 2003. The effects of bioturbation on soil processes and sediment transport. *A. Rev. Earth Planet. Sci.*, 31: 249–273.

Gagnon J.L., Jokele E.J., Moser W.K., Huber D.A. 2003. Dynamics of artificial regeneration gaps within a longleaf pine flatwoods ecosystem. *Forest Ecol. Mgmt*, 172: 133–144.

Gandhi, K., Glimore, D.W., Katovich, S.A., Mattson, W.J., Zasada, J.C., Seybold, S.J. 2008. Catastrophic windstorm and fuel-reduction treatments alter ground beetle (Coleoptera: Carabidae) assemblages in North American sub-boreal forest. *Forest Ecol. Mgmt*, 256: 1104–1123.

Hale, C Host, E. 2005. *Assessing the impacts of European earthworm invasions in beech- maple hardwood and aspen-fir boreal forests of the western Great Lakes region*. National park service Great Lakes inventory and monitoring network report GLKN/2005/11. Duluth, MN: Natural Resources Research Institute, Centre for Water and the Environment, University of Minnesota Duluth. 37 p.

Huttl R.F., Schneider B.U., Farrell E.P. 2000. Forests of the temperate region: gaps in knowledge and research needs. *Forest Ecol. Mgmt*, 32: 83–96.

Kooch, Y. Jalilvand, H. 2008. Earthworms as ecosystem engineers and the most important detritivors in forest soils (Review). *Pakist. J. Biol. Sci*., 11: 819–825.

Kooch, Y., Jalilvand, H., Bahmanyar, M.A., Pormajidian, M.R. 2008. Abundance, biomass and vertical distribution of earthworms in ecosystem units of Hornbeam forest. *J. Biol. Sci*., 8: 1033–1038.

Londo, A.J., Traugott, T.A., Dicke, S.D., Roberts, S.D. 2001. Bucket mounding as a mechanical site preparation technique in northern forest wetlands. *N. J. Appl. For*., 18: 7–13.

Lutz, H.J. 1940. *Disturbance of forest soil resulting from the uprooting of trees*. Yale University. School Forest Bulletin, 45. New Haven: Yale University. 37 p.

Mc Cune, B. Mefford, M. 1999. *Multivariate Analysis of Ecological data Version 4.17. MJM Software*. Oregon, USA: Gleneden Beach. 233 p.

Mc Donald P.M., Abbott C.S. 1994. *Seedfall, regeneration, and seedling development in group selection openings*. Res. Paper PSW-RP-220. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture. 13 p.

Muscolo a., Sidari M., Mercurio R. 2007. Influence of gap size on organic matter decomposition, microbial biomass and nutrient cycle in Calabrian pine (Pinus laricio, Poiret) stands. *Forest Ecol. Mgmt*, 242: 412–418.

Nachtergale, L., Ghekiere, K., Schrijver, A.D., Muys, B., Lussaert, S., Lust, N. 2002. Earthworm biomass and species diversity in windthrow sites of a temperate lowland forest. *Pedobiologia*. 46: 440–451.

Neirynck, J.S, Mirtcheva, S., Sioen, G., Lust, N. 2000. Impact of Tilia platyphyllos Scop. Fraxinus excelsior L., Acer pseudoplatanus L., Quercus robur L., and Fagus sylvatica L. on earthworm biomass and physico-chemical properties of loamy topsoil. *Forest Ecol. Mgmt*, 133: 275–286.

Norton D.A. 1989. Tree windthrow and forest soil turn over. *Can. J. Forest Res*.,19: 386–389.

Page L.M., Cameron A.D. 2006. Regeneration dynamics of Sitka spruce in artificially created forest gaps. *Forest Ecol. Mgmt*, 221: 260–266.

Persson T., Rudebeck A., Jussy J.H., Colin-Belgrand M., Prieme A., Dambrine E., Karlsson P.S., Solberg R.M. 2000. Soil nitrogen turnover – mineralization, nitrification, and denitrification in European forest soils. In Schulze, E.-D. (ed.). *Carbon and nitrogen cycling in European forest ecosystems*. Ecological studies, 142. Berlin: Springer, p. 297–331.

Peterson, C.J. 2000. Damage and recovery of tree species after two different tornadoes in the same old growth forest: a comparison of infrequent wind disturbances. *Forest Ecol. Mgmt*, 135: 237–252.

Peterson, C.J. 2007. Consistent influence of tree diameter and species on damage in nine eastern North America tornado blowdowns. *Forest Ecol. Mgmt*, 250: 96–106.

Peterson, C.J., Pickett, S.T.A. 1990. Microsite and elevation influences on early forest regeneration after catastrophic wind throw. *J. Veget. Sci*., 1: 657–662.

Phillips, J.D., Marion, D.A. 2006. The biomechanical effects of trees on soils and regolith: beyond tree throw. *Ann. Assoc. Amer. Geogr*., 96: 233–247.

Phillips, J., Marion, D.A., Tukington, A.V. 2008. Pedologic and geomorphic impacts of a tornado blowdown event in a mixed pine-hardwood forest. *Catena*,75: 278–287.

Rahmani, R., Saleh Rastin, N. 2000. Abundance, vertical distribution and seasonal changes in earthworm's populations of Oak-Hornbeam, Hornbeam and Beech Forest in Neka, Caspian Forests, Iran. *Iran. J. natur. Res*. 53: 37–52, (in Persian).

Saint - Germain, M., Mauffette, Y. 2001. Reduced ground beetle activity following ice damage in maple stands of southwestern Quebec. *For. Chron*., 77: 651–656.

Saleh Rastin, N. 1978. *Soil biology*. Tehran: Publishing of Tehran University. 325 p., (in Persian).

Samonil, P., Antolik, L., Svoboda, M., Adam, D. 2009. Dynamics of windthrow events in a natural fir-beech forest in the Carpathian Mountains. *Forest Ecol. Mgmt*, 257: 1148–1156.

Samonil, P., Sebkova, B., Douda, J., Vrska, T. 2008. Role of position within the windthrow in forest floor chemistry in the flysch zone of the Carpathians. *Can. J. Forest Res*., 38: 1646–1660.

Sardabrood Forest Management. 2003. Organization of Forest and Range and Watershed Management, Islamic Republic of Iran. 328 p., (in Persian).

Scharenbroch B.C., Bockheim J.G. 2007. Impacts of forest gaps on soil properties and processes in old growth northern hardwood – hemlock forests. *Pl. and Soil*, 294: 219–233.

Scharenbroch B.C., Bockheim J.G. 2008. The effects of gap disturbance on nitrogen cycling and retention in late-successional northern hardwood-hemlock forests. *Biogeochem*. 87: 231–245.

Schaetzl R.J., Burns S.F., Small T.W., Johnson, D.L. 1990. Tree uprooting: review of types and patterns of soil disturbance. *Phys. Geogr*., 11: 277–291.

Schmidt I.K., Jonasson S., Shaver G.R., Michelsen A., Nordin A. 2002. Mineralization and distribution of nutrients in plants and microbes in four arctic ecosystems: responses to warming. *Pl. and Soil*, 242: 93–106.

Schwert, D.P. 1990. Oligochaeta: Lumbericidae. In Dindal, D.L. (ed.). *Soil biology guide*. New York: John Wiley and Sons, p. 341–356.

Shure D.J., Phillips D.L., Bostick P.E. 2006. Gap size and succession in cutover southern Appalachian forests: an 18 year study of vegetation dynamics. *Pl. Ecol.*, 185: 299–318.

Taylor B.R., Parkinson D., Parson W.F. 1989. Nitrogen and lignin content as predictors of lignin decay rates. A microcosm test. *Ecology*, 70: 97–104.

Ulanova, N.G. 2000. The effects of windthrow on forests at differential spatial scales: a review. *Forest Ecol. Mgmt*, 135: 155–167.

Reakcia biomasy a diverzity dážďoviek na vývraty a pôdne vlastnosti v hyrkánskych lesoch v Iráne

Súhrn

Vývraty spôsobujú významné škody vo väčšine prírodných lesov. V oblasti skúmania vplyvu vývratov na vlastnosti lesných pôd a na lesnú faunu sa však doposiaľ urobilo dosť málo. Táto práca sa zaoberá vplyvom vývratov na určité vlastnosti pôd a na biomasu dážďoviek a ich druhovú diverzitu na lokalite Sardabrood v údolí Chalous v hyrkánskych (kaspických) lesoch v severnom Iráne. Za týmto účelom bolo vybraných 27 stanovíšť s porastovými medzerami o šírke jedného stromu v zmiešaných bukových lesoch v nadmorskej výške 700 – 1 300 m. Na 17 z týchto lokalít dominoval buk, na 10 hrab. Na každej z lokalít boli rozlíšené štyri mikrolokality: vrchol kopy (mound), dno jamy (pit), medzera v korunovom zápoji (gap) a uzatvorený zápoj (canopy). Zo všetkých štyroch mikrolokalít boli odobrané vzorky pôdy z hĺbky 10 cm.

Dáždovky sa vyberali ručne počas odberu pôdnych vzoriek. V laboratóriu sa určovali tieto pôdne parametre: kyslosť pôdy, obsah vody, obsah celkového uhlíka a dusíka a pomer C/N. Zistili sme, že vývraty významne ovplyvňujú vlastnosti lesných pôd. Rozdiely v celkovom počte dážďoviek a v ich biomase medzi danými lokalitami a mikrolokalitami boli významné. Počet dážďoviek ako aj ich biomasa vykazovali klesajúci trend od nenarušených lokalít k najviac narušeným (medzera, kopa, jama). Tento trend bol výsledkom najmä počtu a biomasy dážďoviek patriacich do endogeickej ekologickej skupiny. Na mikrolokalitách s kopou neboli nájdené žiadne dážďovky. Z toho vyplýva, že vývraty vo všeobecnosti znižujú aktivitu a abundanciu u dážďoviek. Naše výsledky naznačujú, že vývraty možno považovať za významný faktor ovplyvňujúci pôdnu diverzitu v rámci ekológie lesa. Toto má význam pre posudzovanie lesohospodárskych opatrení vzhľadom na ich vplyv na pôdu a tiež aj pre využívanie pôd ako indikátorov stavu lesných ekosystémov.

Received April 14, 2010
Accepted May 17, 2010