Changes in Austrian pine forest floor properties in relation with altitude in mountainous areas

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ABSTRACT: Altitudinal studies has become of interest to ecologists concentrated on functional alterations aiming to clarify the effects of limiting factors. Nutrient element release from forest floor (FF) decomposition is suppressed by those factors such as low temperature, shortened vegetation period concluding FF accumulation at high elevation fields. To draw out a response to the FF decomposition issue, FF layers as leaf + fermentation (L + F) and humus (H) were collected from 37 representative sample plots along an altitudinal gradient (from 1,400 m to 1,710 m) on Kaz (Balikesir-Turkey) mountain. Mass, pH, organic matter (OM) and total nitrogen (Nt) contents of FF were investigated to explain the relation between decomposition and altitudinal effects. The results revealed that total FF mass and (L + F), (H) sub-fraction masses through elevation show an insignificant relation with the altitude. No significant difference was found between the altitudinal groups in the OM content of L + F. Besides there are significant negative correlations between OM contents (%) of L + F and H layers and altitude with the coefficient values 0.342 ($P < 0.05$) and 0.597 ($P < 0.01$), respectively. The Nt content of L + F layer also increases through the elevation revealing a medium correlation with altitude (0.368; $P < 0.05$). The increasing Nt and decreasing OM contents show better decomposition rates at higher sites regardless of the altitude induced climatic changes. We assume that the forest floor accumulation under tree canopies provides a better decomposition relying on the microclimatic environment mediated by tree canopies, in spite of the altitude.

Keywords: altitude; *Pinus nigra*; forest floor; decomposition; organic matter; humus

The release of nutrients from litter decomposition is a fundamental process in the internal biogeochemical cycle of an ecosystem and decomposers recycle a large amount of carbon that was bound in the plant or tree to the atmosphere. The forest floor (FF) which is overlaid on the forest soil contains decomposed and being decomposed fractions of plant litter materials that are partially or in time released nutrient elements bearing organic residues (Brady 1990). The accumulation of FF is a function where tree litter fall positively and decomposition negatively operate (Fisher, Binkley 2000).

Nutrient recycle and tree nutrition are mostly restricted by the low temperature suppressing microbial activities at high altitudinal sites whereas the shortened vegetation period reduces the decomposition potential. The elevated tree line altitude signals that the global warming effect induced a reduced carbon sequestration amount. As the soil organic carbon constitutes the uppermost carbon reserve and progressive warming will bring about the evolvement of soil and FF carbon through continuous decomposition, in the context of raised fuel oil gases in the atmosphere will result in enhanced global

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Table 1. Data on annual, 5 summer months and January mean temperatures (°C) and precipitation (mm) from the Biga Peninsula meteorological station

Elevation (m)	Annual		5 summer months	(V + V I+ VII + VIII + IX)	January	
	precipitation (mm)	temperature (°C)	precipitation (mm)	temperature (°C)	precipitation (mm)	temperature (°C)
600	960.5	12.2	153.3	18.9	141.0	3.5
800	1,031.2	11.5	163.2	18.1	153.2	3.0
1,000	1,134.4	10.6	181.6	17.2	169.0	2.3
1,200	1,237.6	9.7	199.0	16.3	184.8	1.6
1,400	1,340.9	8.8	218.8	15.3	200.5	0.8

(Kantarci, Sevgi 1997)

warming. Studies over the past few decades show a strong consensus on the release of soil organic carbon through the increasing temperature and they summarized a positive correlation between the two factors. The potential net transfer of CO_2 to the atmosphere was also considered in the perspective of the inequality of decomposition and net primary production (Coűteaux et al. 2002).

Under similar environmental conditions the structural characteristics of stands (age, mean dbh, basal area) and wood production lead to differences in the spatial and temporal patterning of inorganic nitrogen pools in organic horizons (Aubert et al. 2005) such as quality of soil organic matter with regard to N mineralization (Côte et al. 2000). Nitrogen and carbon cycles are initiated by decomposition of FF material under harsh environmental conditions in the high elevation surroundings. Since the decomposition conditions are inappropriate, the litter on the FF is expected to be accumulated, which is supposed to be a threat to the site productivity due to the immobilization of nutrients in the litter or liberated by the precipitation (Dames et al. 1998). Litter decomposition, one of the most vital processes of forest ecosystems, is controlled essentially by soil organisms, environmental conditions and by the characteristics of litter (Usman et al. 2000). Mineralization of N contained in dead organic matter, while providing energy for microbial metabolism, makes inorganic N available for plant uptake (Perez et al. 2003). Some studies point out that the elevation has a remarkable effect on microbial activities (Knoepp, Swank 1998; Dilly et al. 2001) taking into account nitrogen mineralization and nitrification rates while others support the irrelevance of temperature on the microbial activity in terms of the microbial respiration rate (Niklińska, Klimek 2006). Thus in this study we aimed to elucidate the interactions in mountainous conditions in the case of FF accumulation and decomposition rates under the effects of ecosystem components such as altitude and altitude induced climate on the FF characteristics.

Site characteristics

Our study plots were chosen on Kaz Mountain on the Biga Peninsula, which is situated between the parallels 26°48'45'' and 26°54'00'' and longitudes 39°46'30'' and 39°49'45''. The Biga Peninsula consists of two main mountainous massifs, Biga Mountain in the northern part and Kaz Mountain in the southern part. At the higher altitude from 1,400 m at Kaz Mountain there arise three peaks: at Bayramiç aspect, in the north, Babadağ (1,767 m), and at Edremit aspect, in the south, Sarikiz (1,726 m) and Karataş (1,774 m) with the highest summit.

According to long-term average values provided by the Biga Peninsula meteorological station, annual precipitation is 889.7 mm and 1,340 mm; mean temperature is 12.9°C and 8.8°C at 400 m and 1,400 m elevation, respectively (Table 1).

According to the Edremit meteorological station located on the southern aspect of the mountain the site has a definite summer drought with the annual mean temperature 16.4°C and with the total annual precipitation amounting to 697.2 mm.

The Biga Peninsula has a large variety of plant diversity where 1,000 species were distinguished and published being searched from Davis (1984). Two main elevation-climate belts were assigned rising from red pine (*Pinus brutia* L.) to Austrian pine (*Pinus nigra* Arnold) which were also divided into sub-belts such as lower, mid and upper. Besides, beech (*Fagus orientalis* Lipsky) and fir (*Abies bornmülleriana* Mattf.) stands were detected in the valleys and chiefly on the northern steep slopes where

Table 2. Some properties of the study site

Site properties (kg/(0.05 m × 1 m²))	Altitudinal ranges			
	1,400–1,500 m (*n* = 11)	1,500–1,600 m (*n* = 9)	1,600–1,700 m (*n* = 11)	> 1,700 m (*n* = 6)
Volume weight	38.14	37.44	54.06	61.4
Fine soil weight	24.95	24.28	33.13	34.63
Skeleton	13.19	13.17	20.93	26.77
Soil Nt	0.07	0.08	0.064	0.07
Soil C_{org}	1.52	1.77	1.12	0.96
Sand	16.78	16.38	20.08	26.28
Silt	2.72	2.3	3.34	3.28
Clay	3.87	3.75	4.52	4.05
pH (min.–max.)	4.27–7.33	4.42–5.64	4.85–6.63	4.63–6.52
Main rock	2 site Silicate, 9 site Gabro	Gabro	Gabro	Gabro
Stand canopy cover	0.40–0.65	0.4–0.7	0.05–0.80	0.01–0.10
Stand age	95–227	47–211	36–57	19–34
Tree number/ha	213–1,175	250–875	59–1,625	55–299

(Sevgi, Tecimen 2007)

it is humid with cloudy and foggy microclimate (Kantarci, Sevgi 1997). In addition, the study material and some specific properties of the study site are given in Table 2.

Sampling and analysis

The lower elevations of Kaz Mt. were presented by Sevgi (2003) revealing the records essential for the forthcoming studies at the peak of the mountain. The summit of the mountain takes up an approximately 4,000 ha area representing our study site, where the main tree species is black pine and which is managed under the administration of the Kaz Mountain National Park Directorate. At the study site totally 74 forest floor layer samples as leaf + fermentation (L + F) and humus (H) were collected from 37 sample plots to represent the whole study area. The sampling areas were selected by paying attention to the closed canopy cover within composing 2–3 sub-samples at a width 50 × 50 cm² where the sampling points were chosen randomly. Coarse woody debris were removed from forest floor samples, containing the roots, and then air dried and ground to prevent further fermentation. Layer samples were weighed after oven dried at 65°C for 24 hours. Actual pH was determined with a glass electrode of Hannas pH instrument in a suspension of 1/5 ml soil solution with distilled water

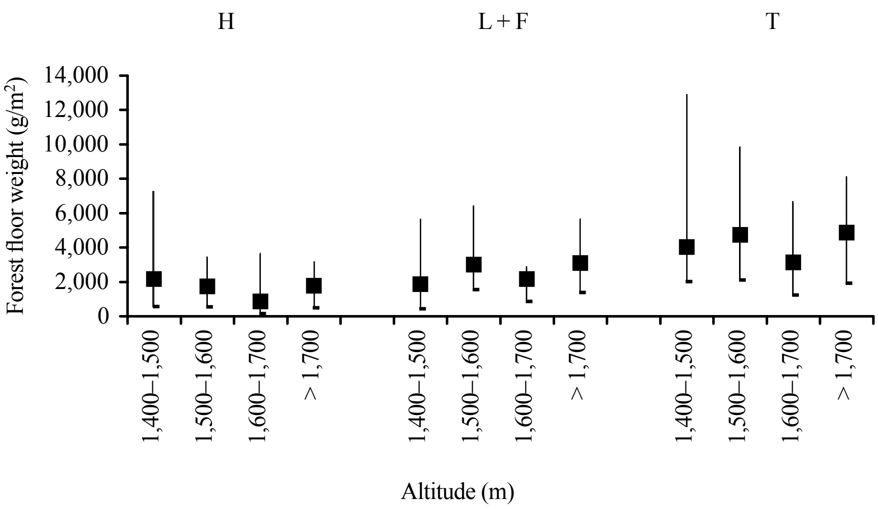

Fig. 1. Forest floor weight alterations in connection with the altitude

Table 3. Tukey's HSD variance analysis test ($P < 0.05$) of weight, total nitrogen (Nt), organic matter (OM) contents and pH (H_2O) of forest floor layers

Altitudinal ranges Forest floor layers	1,400–1,500 m (n = 11)	1,500–1,600 m (n = 9)	1,600–1,700 m (n = 11)	> 1,700 m (n = 6)
Weight L + F (g/m^2)	$1,856^a$	$3,001^a$	$2,160^a$	$3,098^a$
Weight H (g/m^2)	$2,166^a$	$1,732^a$	848^a	$1,768^a$
Weight total (g/m^2)	$4,023^a$	$4,732^a$	$3,132^a$	$4,866^a$
Nt L + F (%)	0.873^a	0.889^a	0.907^a	$1,265^b$
Nt L + F (g/m^2)	15.2^a	27.1^{ab}	19.1^a	41.9^b
Nt humus (%)	0.846^a	0.786^a	0.777^a	0.559^a
Nt humus (g/m^2)	16.1^a	14.4^a	5.6^a	9.1^a
OM L + F (%)	85.0^a	81.0^a	78.4^a	76.3^a
OM L + F (g/m^2)	$1,551^a$	$2,475^a$	$1,684^a$	$2,337^a$
OM humus (%)	54.4^a	43.5^a	37.0^{ab}	20.9^b
OM humus (g/m^2)	$1,042.0^a$	814.0^{ab}	305.2^b	319.4^b
pH L + F (H_2O)	4.52^a	4.16^a	4.44^a	4.52^a
Ranges	(3.52–5.54)	(3.99–4.33)	(3.99–4.85)	(4.11–5.00)
pH humus (H_2O)	5.06^a	4.48^a	5.01^a	4.95^a
Ranges	(4.14–6.80)	(3.98–5.09)	(4.52–5.56)	(4.49–5.72)

which was left to stand overnight and then shaken and measured after an hour (Gülçur 1974). Organic matter content was determined by Loss on ignition method (Gülçur 1974). The determination of total N was carried out by Kjeldahl method at the Tecator Kheltec Auto Analyzer 1030 (Jackson 1962; Gülçur 1974). The statistical analysis was conducted in SPSS 11.0 version and within the analysis we compared the altitudinal groups among each other and also regression and correlation analysis were done to find out the effect of altitude.

RESULTS

Weights of forest floor layer

Since the tree numbers/ha decrease markedly with increasing elevation, the comments related to kg/ha unquestionably give consequences implying that all the weight parameters decrease as the altitude increases. So the evaluations concerning weight were done according to the g/m^2 unit. The average values of total FF weights range between 1,856 and 3,098 g/m^2 at elevations 1,400–1,500 m and > 1,700 m, respectively (Table 3). The weight measurement (g/m^2) results show that the weight variations of FF and L + F and H sub-fractions through elevation are insignificant (Table 4). Both the L + F and H layers and the total weights reflect an undulating graph (Fig. 1).

Organic matter contents of forest floor layers

A negative relation was detected between OM contents (%) of L + F and H layers and elevation significant at $P < 0.05$ and $P < 0.01$ levels with the

Table 4. Correlation coefficients and significance levels of forest floor layers with altitude

Variables	L + F	H	Total
Weight (g/m^2)	0.234	–0.275	–0.012
Organic matter (%)	–0.342*	–0.597**	
Organic matter (g/m^2)	0.17	–0.543**	–0.092
Total nitrogen (%)	0.368*	–0.203	
Total nitrogen (g/m^2)	0.360*	–0.409*	0.15
pH	–0.001	–0.037	

**0.01 significance level, *0.05 significance level

Table 5. Significant linear models and the coefficient of correlation between forest floor properties and altitude

Variables	Model components			Variant estimates	
	R^2	*F* value	significance	coefficient	factor
L + F organic matter (%)	0.117	4.65	0.038	126.796	–0.0293
L + F Nt (%)	0.135	5.47	0.025	–0.4547	0.0009
L + F Nt (g/m²)	0.130	5.22	0.028	–70.706	0.0599
Humus organic matter (%)	0.357	19.39	0.000	190.063	–0.0946
Humus organic matter (g/m²)	0.294	14.61	0.001	5,385.06	–3.0078
Humus Nt (g/m²)	0.167	7.03	0.012	67.7034	–0.0358

coefficient values –0.342 and –0.597, respectively, revealing poor and moderate relation levels (Table 4). Relying on the results it can be concluded that the elevation has an adverse effect on OM contents of the mentioned FF layers, which is also indicated by an advantageous nutrition status. Furthermore, the linear models established between OM contents (%) of L + F and H layers and elevation have the R^2 values 0.117 and 0.357, respectively (Table 5).

Total nitrogen contents of forest floor layers

Positive relations were detected between Nt contents (% and g/m²) of L + F layer and altitude at a $P < 0.05$ significance level with the coefficient values 0.368 and 0.360, respectively (Table 4). The R^2 values of linear models established between Nt contents (% and g/m²) of L + F layer and altitude are 0.135 and 0.130, respectively (Table 5). While the relation between Nt content (%) of H layer and altitude was insignificant, the nitrogen content values per unit area (1 m²) were negatively significant at a $P < 0.05$ level with the coefficient value –0.409 whereas the relation model has the R^2 value 0.167.

Reaction of forest floor

The average pH values of L + F and H layers show a wavy sequence which decreases by the height of 1,500 m and then increases (Fig. 2); showing insignificant differences (Table 4). The min. and max. pH values for L + F and H layers are between 3.52–5.54 and 3.98–6.80, respectively (Table 3). The pH results for H demonstrate a high variation with a higher decrease at 1,600 m elevation, while L + F show a more constant contribution along the altitudinal gradient (Fig. 2). The decreased pH might be caused by reduced precipitation from the elevation 1,650 m, but the probability should be evidently corrected by the implication of more frequent meteorological measurements.

DISCUSSION

Weights of forest floor layer

Kantarci (1997) recorded an average weight of 4,072.75 g/m² ranging between 2,951–4,714 g/m² at ≥ 1,400 m at Aladağ Mt., Bolu with an upper range of our study. Güner (2006) found that while there is an insignificant relation between L and H layer weights,

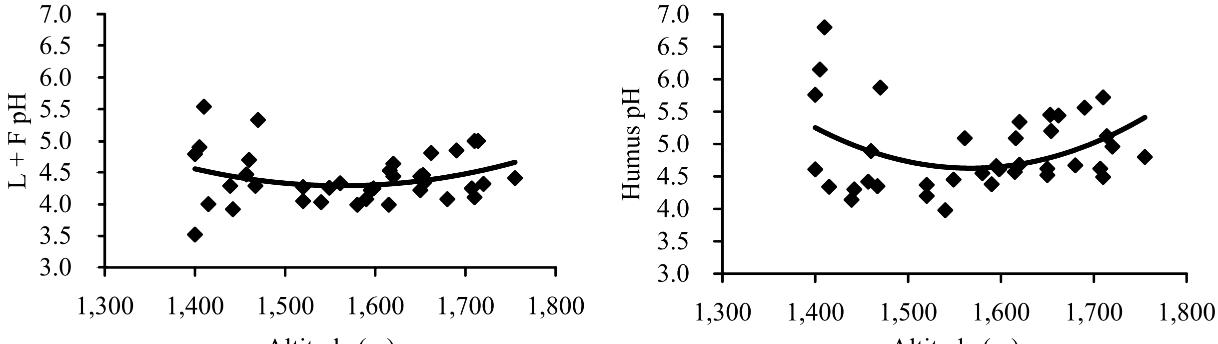

Fig. 2. pH alteration due to elevation at forest floor layers

a positive relation exists between F layer and altitude ($P < 0.01$). Similarly GARTEN and HANSON (2006) put forward that the FF amount does not follow a linear curve along the altitude relying on studies conducted in the Appalachian Mountains. The relation between FF weight and altitude differs due to various causes among which the prevailing climate and microbiological activities could be pronounced particularly. GARTEN and HANSON (2006) stated that the determination of decomposition rate is chiefly possible by controlling the microorganism activities which would be the source of overaccumulation of FF layers within the same tree litter fall addition conditions.

Organic matter and total nitrogen contents

Oppositely to our findings DOLEŽAL and ŠRUTEK (2002) observed a highly accumulated organic layer above the mineral soil below the altitude ~1,510 m which was the treeline for the western Carpathians where the treeline altitude is very close to our study area. MILLAR (1974), and IRMAK and ÇEPEL (1974) charged the suppressed decomposition situation to the anatomy of needles in accordance with LORENZ et al. (2004), who recorded that 31.7% of the initial mass was still remaining after 2 years for pine. Besides VANCE and CHAPIN (2001) recorded that in boreal forests where cold climatic conditions prevail spruce forests have indigestible forest floor within high C:N and low lignin:N ratios and modest soluble nitrogen content. In our study we recorded organic matter contents between 85.0–76.3% and 54.4–20.9% in L + F and H layers at the altitudinal order (Table 3). OM content of H layer shows a significant decrease along the altitude but the L + F layer does not show a distinctive decrease. According to USMAN et al. (2000) the rate of decomposition was significantly correlated with the initial nutrient concentration and material with higher C:N ratios had a longer duration of immobilization and in turn a slower release phase. This result helps to explain the relation between tree nutrition and fresh needle total nitrogen content. Our findings concerning total nitrogen (%) contents of L + F layers (Table 3) reveal similarity with NIKLIŃSKA and KLIMEK (2006), who emphasized that among the nutrients measured, only the total organic N concentration significantly increased with elevation in the soil organic layer. Oppositely (GARTEN 2000) stated that the soils of upper elevations are mainly characterized by the absence of N for biological demands. GARTEN (2006) recorded that the total nitrogen content of forest floor demonstrated the ranges between 0.58–0.66% and 1.15–1.32% that due to increased elevation from 335–560 m to 1,570–1,670 m respectively, while in our study site the Nt (%) content of L + F and H layers of forest floor demonstrated the value intervals between 0.873–1.265 and 0.846–0.559% respectively at elevations 1,400–1,500 m and > 1,700 m (Table 3). Contrary to the above-mentioned authors our results demonstrate that the altitude did not have an impressive effect on decomposition.

CONCLUSION

The forest floor layer has completely covered the whole area up to 1,650 m elevation, then stands constitute from individually distributed trees. At the upper elevations litter gathered from immediately below the tree canopies. Above the tree line the morphology of tree structure is damaged, the total unshed leaf amount decreased, less-shaded leaves of trees increased and upon that the litter accumulation amount is only slightly higher at the elevation above 1,700 m which is insignificant (Table 3). The weight difference should be reasoned from the sampling points which had to be taken from the canopy circle – very close to the tree stem. It is known that under low temperature climatic conditions a nutrient loss from leaf material is quite slight (HART, PERRY 1999). PAUSAS (1997) reported the half decomposition time as 3.5 years and MOORE et al. (1999) claimed the 3-year decomposition rate between 13 and 57%. Our findings reveal that unless the organic matter content of L + F and H layer changes dramatically (Table 3) but the total nitrogen of L + F increases, the forest floor accumulation under tree canopies provides a better decomposition relying on the microclimatic environment mediated by tree canopies, in spite of the altitude. Trees might retranslocate the nutrient elements in circumspection to avoid nutritional limitations at higher altitudes concluding lower nutrient and organic matter contents in forest floor litter. That argument has been challenged with the assumption that the nutrient retranslocation requirement decreases due to an increased leaf:stem rate at higher altitudes; causing to increased total nitrogen content of L + F layer (KÖRNER 1998) which is in agreement with our conclusion. The knowledge for high altitudinal lands needs to be achieved within time scale monitoring and the effects of climate and microorganism components through rising CO_2 fluxes.

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Změny nadložního humusu v závislosti na nadmořské výšce pod porosty borovice černé v horských oblastech

ABSTRAKT: Studie zabývající se funkčními změnami v závislosti na nadmořské výšce za účelem objasnění efektu limitních faktorů jsou dnes ve středu zájmů ekologů. Uvolňování nutričních prvků je zajišťováno rozkladem nadložního humusu, ve vyšších polohách závisí na následujících faktorech: nízké teploty, krátká vegetační doba, konečná akumulace nadložního humusu. K získání odpovědi na otázku rozkladu nadložního humusu v jednotlivých vrstvách – listy a drť (L+F) a humusové vrstvy (H) – byly v pohoří Kaz sebrány vzorky na 37 reprezentativních plochách napříč výškového gradientu (od 1 400 m do 1 710 m). Za účelem odhalení vztahu rozkladu nadložního humusu na nadmořské výšce byla sledována váha nadložního humusu, jeho reakce, podíl organické hmoty a celkový obsah dusíku. Výsledky studia nadložního humusu neprokázaly statisticky významný vliv nadmořské výšky na váhové změny jednotlivých subfrakcí (L + F), (H). Ačkoliv obsah organické hmoty v L + F a H vrstev se dramaticky nemění, zvýšený celkový obsah dusíku z L + F můžeme vysvětlit silnějšími rozkladnými procesy v závislosti na mikroklimatických podmínkách porostu.

Klíčová slova: nadmořská výška; *Pinus nigra*; nadložní humus; rozklad; organická hmota; humus

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