Spruce forest litter structure, distribution, and water retention along hiking trails in the Ukrainian Carpathians

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Abstract: Almost 24% of the Ukrainian Carpathian ecosystems are assigned to the conservation fund due to their ecological values and attraction to numerous tourists. The forest litter in mountain forest stands plays an important role in terms of its ability to mitigate the impact of tourist activities, and erosion processes along with its contribution to the soil mineralization. Water interception, infiltration, and retention ability of forest litter have an impact on hydrological processes of forest ecosystems. At the same time, the accumulation and spatial distribution of litter can be affected not only by environmental conditions, but also by tourism. In this study, 13 Norway spruce (Picea abies L.) stands distinguished by average distance to the trail were chosen to investigate whether there are any differences in litter structure, water retention, and infiltration abilities as well as litter accumulation in areas along popular hiking trails in the Ukrainian Carpathians. Results showed that the litter thickness has increased with altitude and slope steepness. Moreover, results of one-way ANOVA demonstrate a significant difference (P < 0.05) in litter stock between two groups of sample plots: established directly to adjoin hiking trails and at a distance. Therefore, the forest litter stock nearby hiking trails may indicate that trampling caused by tourists has a negative impact on litter accumulation. However, no statistical difference was found (P > 0.05) in the accumulation of litter along three trails and altitudes across all surveyed forest stands. Results of the immersion test showed that the litter infiltration rate has a significant negative correlation with the maximum mass of absorbed water (r = -0.62, P < 0.05), litter stock (r = -0.69, P < 0.01), and retained precipitation (r = -0.62, P < 0.05). Despite our assumption, the infiltration rate was lower for sites distanced from the hiking trail in comparison with adjoining ones. According to our measurements, the water holding capacity of the litter varies from 42.3 t·ha⁻¹ to 187.3 t·ha⁻¹ regardless of the stand composition. Further, the precipitation amount retained by litter varies between 4.2 mm and 18.7 mm. Insignificant differences in litter fractional structure and accumulation were observed in pure spruce stands and mixed spruce-beech with an admixture of beech up to 20%. Further observational and modelling studies are necessary to clarify the role of the beech share in stand composition in relation to fractional structure and water interception and retention ability.

Keywords: forest debris; litter fractions; litter stock; moisture capacity; Norway spruce

A range of ecosystem services is provided by mountain forest ecosystems, both to people living in mountainous areas and to people living in urban areas, e.g. biodiversity hotspots, freshwater supply, controlling soil erosion, and serving as key destinations for tourism and recreational activities, etc. Simultaneously, mountain tourism is a significant contributor to several problems, including plastic pollution, soil erosion, biodiversity loss, variety of forest ecosystem disturbances (Fomicheva et al. 2021; Romeo et al. 2021). In particular, recreational activity in accessible parts affects the mountain forest ecosystem in the ground-related sphere, e.g. forest floor and topsoil. Moreover,

such activities as hiking have a multitude of effects on the soil because severely compacted soil can accelerate runoff and soil loss, especially in mountain forest watersheds (Leote et al. 2022).

Preventing soil erosion processes through rainfall interception, and reduction of runoff energy with further water reaching the soil are performed by floor litter structural components (Miyata et al. 2009; Li et al. 2014; Gomyo, Kuraji 2016). Forest litter consists of different compounds such as needles, leaves, branches, bark, fruits, cones, and plant debris. Each of them influences litter decomposition, accumulation, and mineralization in a different way as well as erosion control (Ukonmaanaho et al. 2008). The interception storage capacity varies with litter type and rain intensity. Litter uneven spatial distribution, and the diversity of tree species under which it is formed cause different abilities for water absorption (Li et al. 2020). In mountain forests there is a noticeable impact of altitude on the amount of litter, species under the canopy, nutrients and moisture (Labaz et al. 2014). Leaf litter reduces the surface runoff better than needle litter, but both perform more efficiently than the bare soil (Xia et al. 2019; Yue et al. 2020). Spruce needles in litter are rich in lignin and phenolic compounds, which could explain slower decay rates of litter, especially for spruce monocultures (Šantrůčková et al. 2006). In addition to pure spruce forests, there are also mixed stands of beech and spruce in the Carpathians. Spruce litter and beech litter have some similar features like lignin content and other chemical compounds. Despite a certain similarity, decomposition processes of spruce needles and beech leaves take place at a different rate (Albers et al. 2004; Berger, Berger 2012). Therefore, thick formation of forest litter is observed in pure spruce forests which is also associated with reduced tree growth (Berger, Berger 2014). Tree leaves decompose more rapidly than spruce needles due to different environment for reducers under the canopy of conifers and broadleaves. Active decomposing organisms in the litter of deciduous trees are more favourable for the decomposition of organic matter (Laganière et al. 2010).

Although, forest canopy is no less important for water interception than ground vegetation and forest litter. In general, the interception ability of tree crowns and evaporative potential are greater than in litter due to direct exposure to wind and solar radiation, but the litter storage capacity is greater.

There is a better-known trend when broadleaf litter interception and storage capacity are higher than those of coniferous litter. However, the result could be affected by factors such as climate, study region and particular tree species which were studied (Bulcock, Jewitt 2012; Du et al. 2019). Extensive tourist activities in particular areas could affect ground vegetation as well as forest litter, which leads to soil erosion (Pickering, Barros 2015).

The objective of our study was to compare the forest litter distribution, ratio of fractional components and water retention ability of the litter within spruce stands along hiking trails. We hypothesized that (i) the amount of litter is reduced in areas adjoined to hiking trails, (ii) distribution of litter structural components along accessible hiking trails is different in comparison with sites distanced from the trail, (iii) the altitude has an impact on litter accumulation in mountain regions. Moreover, we expected a major difference in water infiltration rate and water retention between trampled forest litter and undisturbed litter due to a high use of investigated trails.

MATERIAL AND METHODS

Study area. The Carpathian Mountains are considered one of Europe's largest mountain ranges with a high potential for rural tourism development. Especially in recent years, a raising number of tourists were noticed within the Carpathian region. The study sites are located precisely in the forests of the Ukrainian Carpathians within Ivano-Frankivsk administrative region (Figure 1), where a significant increment in the domestic tourism share from 16.6% and 17.4% in 2018 and 2019, respectively, to 41.2% in 2020 is observed (State Statistics Service of Ukraine 2021) and where the main part of the Ukrainian Carpathians is located. More than 40% of the Carpathian region is covered by forests and almost 24% of the mountain forests of the region is assigned to the conservation fund due to its ecological values (Kiseliuk et al. 2009). Hence, the Carpathian region has the highest amount and concentration of national parks in Ukraine, among which the Carpathian National Natural Park is the largest one and attracts numerous visitors because the highest peaks are located on its territory. Carpathian National Park and adjoined Hryniavy State Forestry enterprise, where the survey was conducted, represent a variety of mountain ecosys-

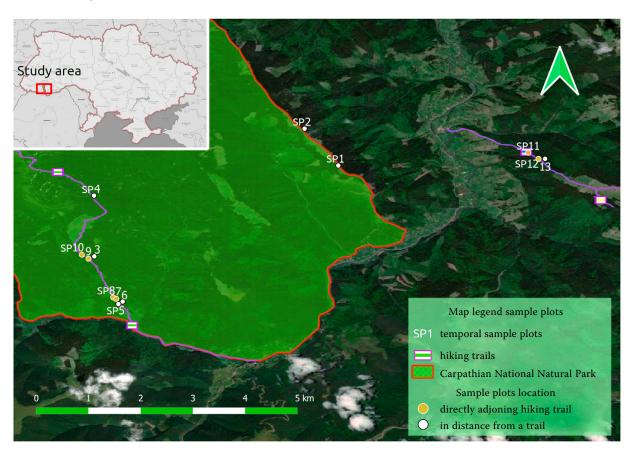


Figure 1. Study sites located in Ukrainian Carpathians

tems of the Ukrainian Carpathians. For instance, at lower altitudes up to 1 000–1 100 m a.s.l. of the Ukrainian Carpathians prevail deciduous forests (beech, beech-fir, beech-fir-spruce), the altitudes of 1 100–1 600 m a.s.l. are covered with pure spruce mainly, the subalpine zone extends from 1 600 m a.s.l. to 1 850 m a.s.l. and harbours mountain pine and juniper. Norway spruce stands occupy 79% of the forests within the park and mainly are natural (73%). The mean annual temperature is 5.1–7.2 °C and the mean annual precipitation is 944 mm. The parent rock of the Carpathians is mainly Carpathian Flysch covered with mountain brown forest soil (Kiseliuk et al. 2009; Slobodiyan 2012; Carpathian National Nature Park 2022).

Field data collection. We have established 13 circular sample plots (SP) at elevations between 1 030 m a.s.l. and 1 510 m a.s.l. within the pure spruce altitudinal vegetation belt. The coordinates and descriptive data of the surveyed territory are shown in Table 1. The study was carried out in 9 coniferous stands and 4 mixed stands of Norway spruce (*Picea abies* /L./ H. Karst.) and European beech

(Fagus sylvatica L.). Whereas mountain tourism is not widespread and concentrated along accessible parts, sites were selected along three different hiking trails, six of them are located to adjoin trails (SP 7-12) and seven more plots (SP 1-6, 13) are established at a 20-100 m distance. All of the circular sample plots had the same area of 500 m² and were established upslope on the relatively flat surfaces. Eight sample plots (SP 3-10) are in protected conservation areas where forest management has not been carried out during the last 40 years at least and they are a part of the Carpathian National Natural Park (Vysokohirne nature-oriented science and research department), two other plots (SP 1, 2) are located on the border of the Carpathian NNP and three plots (SP 11-13) are in commercially managed forests of Hryniavy State Forestry Enterprise (Figure 1). Investigated hiking trails have different width that varies from 2 m to 5 m (including wide zones of hikers' rest spots) on different trail sections. In some cases, it is difficult to determine the edge of the designated trail due to active trampling of its trailside.

Table 1. General characteristics of the study plots established in Norway spruce stands; sample plots (SP) 1 and 2 are located along hiking trail "Zelene village – Shkorushnyi Mount", SP 3–10 along hiking trail "To Mount Pip Ivan Chornohirskyi" and SP 11–13 Hiking trail "Zelene village – Uhorski skeli rocks"

| SP No. | Coordinates | Average distance from the hiking trail (m) | Altitude (m) | Steepness (°) | Dominant species (%) | Age (years) | Mean height (m) | Mean diameter (cm) | | | Stem volume with bark (m³·ha-1) |
|-----------|----------------------------|--|-----------------|------------------|----------------------------|----------------|-----------------------|--------------------------|-------|------|---------------------------------------|
| 1 | 48.039752°N 24.724784°E | 100 1 100 1 20 1 | 1 385 | 23 | 100% NS | 66 | 28.0 | 34.9 | 480 | 45.9 | 612 |
| 2 | 48.049179°N 24.716173°E | | 1 317 | 15 | | 65 | 24.0 | 28.1 | 940 | 58.4 | 680 |
| 3 | 48.016455°N 24.662150°E | | 1 260 | 11 | | 50 | 24.0 | 22.7 | 1 680 | 68.2 | 753 |
| 4 | 48.032033°N 24.662097°E | | 1 510 | 13 | | 59 | 16.9 | 23.3 | 1 120 | 47.7 | 412 |
| 5 | 48.004258°N 24.668548°E | | 1 030 | 18 | | 58 | 29.3 | 31.5 | 780 | 60.9 | 850 |
| 6 | 48.004760°N 24.669101°E | 40 | 1 040 | 19 | | 63 | 32.3 | 31.8 | 700 | 55.6 | 857 |
| 7 | 48.005725°N 24.667520°E | | 1 070 | 9 | 100% NS | 79 | 30.4 | 32.3 | 800 | 65.6 | 948 |
| 8 | 48.005914°N 24.667421°E | | 1 070 | 8 | 94% NS-B | 75 | 31.7 | 35.5 | 600 | 59.3 | 886 |
| 9 | 48.016013°N 24.660599°E | adjoined | 1 280 | 4 | 100% NS | 50 | 22.0 | 20.5 | 2 760 | 91.3 | 977 |
| 10 | 48.017019°N 24.659046°E | | 1 305 | 21 | 100% NS | 34 | 19.9 | 24.4 | 1 040 | 48.7 | 486 |
| 11 | 48.043020°N 24.773406°E | | 1 040 | 8 | 86% NS-B | 62 | 24.9 | 26.7 | 1 800 | 75.3 | 900 |
| 12 | 48.041410°N 24.776077°E | | 1 090 | 2 | 93% NS-B | 67 | 26.4 | 28.3 | 1 280 | 78.5 | 985 |
| 13 | 48.041077°N 24.776265°E | 20 | 1 095 | 2 | 80% NS-B | 48 | 25.4 | 32.4 | 640 | 51.6 | 629 |

NS - Norway spruce; NS-B - Norway spruce with admixture of European beech

A survey of forest litter samples was conducted at the end of vegetation period before litterfall (August 2021) for each of the 13 stands. Litter probe spots were randomly located within the sample plots under tree canopy at a 1 m distance at least from the tree stem (Basylevich 1983).

For fraction analysis litter samples were collected from 10 square sites of 1 m² per each sample plot from the soil. Based on the recommendations of Karpachevskyi (1981), all the collected litter samples were placed in sealed plastic bags and transported to the laboratory for further analysis.

To simplify the analysis, we divided the whole litter samples into an active part, which is decomposed faster due to better interaction with microorganisms, and inactive part (includes non-foliage fractions). Litter sample weight was measured within each fraction: active (roots, dead organic material, leaves and needles) and inactive fraction (bark, branches, cones and seeds, mineral components). Our experimental design excludes the separation of leaves, needles and forest floor plant debris as different fractions of litter due to lack of data of annual litterfall.

The investigation of litter interception capacity was conducted according to the methods of Karpachevskyi (1981) and Vorobeychik (1997) with the use of aluminium trays (21 cm \times 30 cm) in an immersion test with 5 replications per plot. Litterfall was collected into the trays and transported to the laboratory. Water saturation exposure time of trays under water lasted 4 h followed by 30 min of draining. The mass of absorbed water was calculated considering the oven-dry litter weight that was obtained in the drying cabinet after 72 h at 105 °C.

Based on DSTU ISO 10381-4:2005 (2005), composite samples of soil from each forest stand were used for the determination of fertility. Soil probes were collected from the 0–10 cm topsoil layer and transferred to the certified agrochemical laboratory, where humus content analysis was conducted according to DSTU 4362:2004 (2005).

Simultaneously the soil moisture content of litter survey was measured in the field with a WH-2 electronic soil moisture meter (MISOL, China) in a 10-fold replicate in the 0–10 cm topsoil layer under the previously collected litter.

To determine the water infiltration rate 3 metal cylinders of 100 mm in height and 100 mm in diameter were used. Cylinders were inserted into the soil depth of 50 mm (position of the lower sharpened edge of the ring below the surface) and filled with water with following time tracking until complete absorption.

Data evaluation and statistics. Based on the results of field measurements and laboratory analysis Pearson's correlation coefficient was used to calculate the relationship between environmental parameters and forest stands characteristics within investigated sample plots. Furthermore, this coefficient was used to assess water interception and infiltration ability of forest litter. Parameters were considered to be significantly correlated when they were at or above the 95% confidence level (P < 0.05). To test whether the differences in litter distribution between different hiking trail location, elevation, and average distances from sample plots to the trail were statistically significant (P < 0.05), one-way ANOVA or Kruskal-Wallis test was performed. Preliminarily, each parameter of obtained data was checked for normality using the Shapiro-Wilk normality test. If the treatments satisfied the assumptions of the ANOVA, this method was used. Otherwise, a nonparametric method (the Kruskal– Wallis test) was performed, which allows groups to be compared without assuming that the values are normally distributed. All statistical analyses were performed using R (Version 4.0.2, 2017).

RESULTS

Litter characteristics and stock. The main characteristics of forest litter in observed stands are represented in Table 2. Forest litter accumulation and decomposition processes have not been affected by forestry treatments on SP 1–10 due to their location within the national park. Likewise, no traces of forestry treatments were found on SP 11–13 (located on the territory of the state enterprise).

The thickest litter layers were collected in the highest zone (1 510 m a.s.l.) under pure spruce stand (SP 4). The litter under stands at lower altitudes is nearly three times thinner and obviously the litter stock is affected. General correlations between chosen characteristics were also analysed (Figure 2).

Results show a strong positive correlation between altitude and litter thickness (r = 0.69, P < 0.01), also with humus content (r = 0.61, P < 0.05). Generally, the amount of litter was affected not only by its

Table 2. Mean values and structural components of forest litter

| SP | Dominant species | Litter thickness | | | Inactive fraction | | | | | |
|---|---|---------------------|--------------------------------|------|-------------------|------|--|--|--|--|
| No. | (%) | (cm) | $\overline{(t{\cdot}ha^{-1})}$ | | (%) | (%) | | | | |
| | Zelene village – Shkorushnyi Mount hiking trail | | | | | | | | | |
| 1 | 100% NS | 4.0 | 139.0 | 97.1 | 2.9 | 4.84 | | | | |
| 2 | 100% NS | 3.3 155.6 99 | | 99.4 | 0.6 | 4.77 | | | | |
| | To Mount Pip Ivan Chornohirskyi hiking trail | | | | | | | | | |
| 3 | | 1.3 | 74.9 | 88.1 | 11.9 | 5.19 | | | | |
| 4 | | 6.7 197.6 94.0 | | 6.0 | 5.44 | | | | | |
| 5 | | 2.0 | 135.9 | 98.0 | 2.0 | 2.77 | | | | |
| 6 | 100% NS | 1.8 | 175.6 | 95.3 | 4.7 | 1.36 | | | | |
| 7 | 100% NS | 2.5 | 75.2 | 91.8 | 8.2 | 4.83 | | | | |
| 8 | | 1.8 | 63.8 | 79.9 | 20.1 | 4.93 | | | | |
| 9 | | 2.0 | 49.8 | 81.5 | 18.5 | 4.93 | | | | |
| 10 | | 2.0 | 112.9 | 94.9 | 5.1 | 7.93 | | | | |
| Zelene village – Uhorski skeli rocks hiking trail | | | | | | | | | | |
| 11 | 86% NS-B | 2.5 | 87.3 | 85.3 | 14.7 | 0.77 | | | | |
| 12 | 93% NS-B | 2.5 | 91.3 | 78.4 | 21.6 | 4.12 | | | | |
| 13 | 80% NS-B | 2.5 | 102.3 | 92.3 | 7.7 | 4.64 | | | | |

SP – sample plot; NS – Norway spruce; NS-B – Norway spruce with admixture of European beech

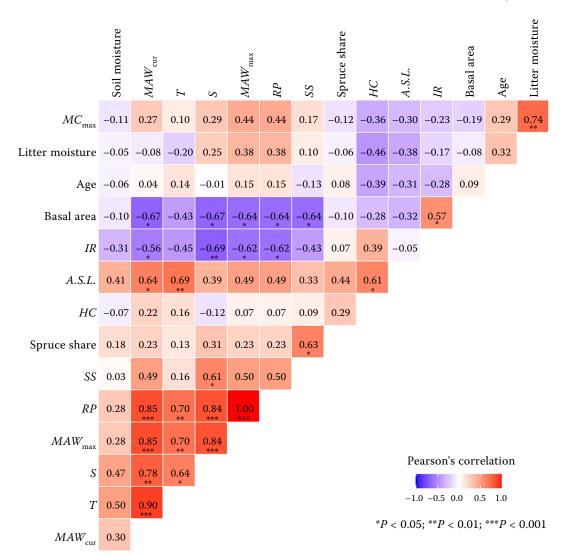


Figure 2. Correlation matrix of investigated variables

 $MAW_{\rm cur}$ – mass of absorbed water over current state; $MAW_{\rm max}$ – mass of absorbed water; $MC_{\rm max}$ – moisture capacity; RP – retained precipitation; HC – humus content; SS – slope steepness; T – litter thickness; S – litter stock; A.S.L. – altitude; IR – infiltration rate

thickness (r = 0.64, P < 0.05), but also by the tree basal area (r = -0.67, P < 0.05).

During the establishment of sample plots with subsequent litter collection, the visual difference in litter capacity between areas along hiking trails and in the forest was observed. Therefore, one-way ANOVAs (the factor litter stock) were performed to test differences between groups of sample plots: directly adjoining hiking trails and those established at a distance. Results of ANOVA showed a significant difference (P < 0.05) between two groups of litter stock which indicates that tourist

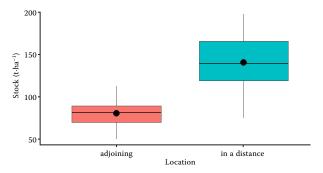


Figure 3. Litter accumulation within distinguished groups of plots: directly adjoining hiking trails and established in a distance

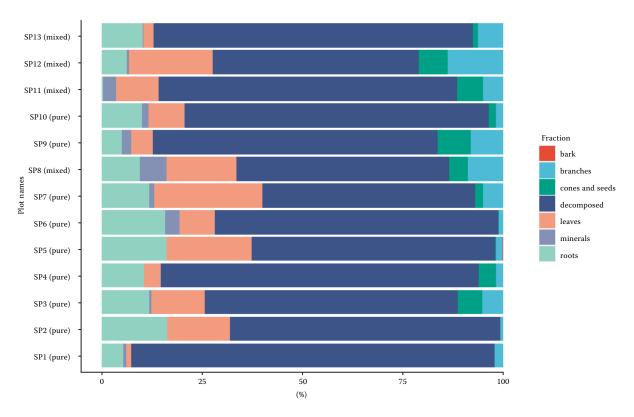


Figure 4. Litter fractions share based on the mean value of each fraction weight

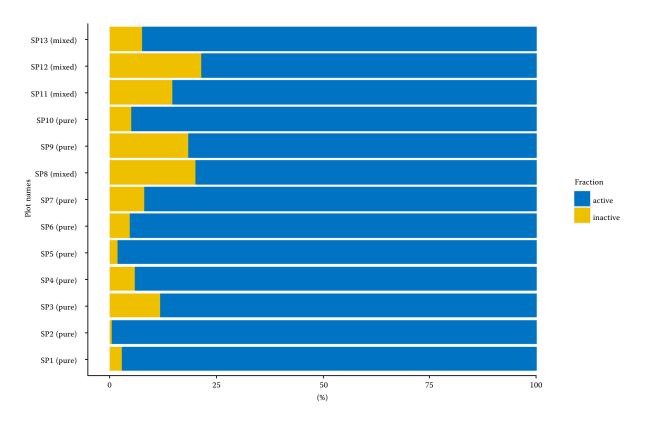


Figure 5. Active (roots, dead organic material, leaves and needles) and inactive (bark, branches, cones and seeds, mineral components) fractions distribution

Table 3. Mean values of water interception litter characteristics

| SP No. | Distance from the hiking trail | Soil moisture Litter moisture | | MAW_{cur} | MAW_{max} | MC_{\max} | RP | IR | Stock |
|-----------|--------------------------------|-------------------------------|------|----------------------|-----------------------|-------------|------|-------------------------|-----------------------|
| | (m) (%) | | %) | (t·l | (t∙ha ⁻¹) | | (mm) | (mm·min ⁻¹) | (t·ha ⁻¹) |
| 1 | 30 | 22.7 | 17.8 | 113.7 | 137.6 | 102.2 | 13.8 | 6.4 | 139.0 |
| 2 | 100 | 38.8 | 61.5 | 93.7 | 187.3 | 123.0 | 18.7 | 26.0 | 155.6 |
| 3 | 100 | 51.3 | 18.7 | 26.8 | 42.3 | 51.0 | 4.2 | 105.0 | 74.9 |
| 4 | 20 | 59.3 | 15.7 | 144.2 | 168.2 | 109.6 | 16.8 | 47.8 | 197.6 |
| 5 | 25 | 30.3 | 10.9 | 69.2 | 79.8 | 82.1 | 8.0 | 27.7 | 135.9 |
| 6 | 40 | 33.0 | 82.1 | 63.8 | 127.8 | 164.0 | 12.8 | 63.7 | 175.6 |
| 7 | | 24.7 | 46.2 | 67.0 | 94.3 | 159.7 | 9.4 | 105.7 | 75.2 |
| 8 | adjoined | 22.0 | 32.5 | 47.6 | 73.5 | 92.4 | 7.3 | 126.3 | 63.8 |
| 9 | | 21.0 | 16.7 | 38.1 | 49.9 | 70.9 | 5.0 | 202.4 | 49.8 |
| 10 | | 24.7 | 26.9 | 88.0 | 110.3 | 133.0 | 11.0 | 141.9 | 112.9 |
| 11 | | 37.0 | 46.0 | 62.7 | 87.6 | 161.9 | 8.8 | 54.3 | 87.3 |
| 12 | | 35.0 | 26.4 | 60.3 | 79.4 | 110.1 | 7.9 | 95.3 | 91.3 |
| 13 | 20 | 25.0 | 33.3 | 65.1 | 94.9 | 105.8 | 9.5 | 59.9 | 102.3 |

SP – sample plot; $MAW_{\rm cur}$ – mass of absorbed water over current state; $MAW_{\rm max}$ – maximum mass of absorbed water; $MC_{\rm max}$ – maximum moisture capacity of the litter; RP – retained precipitation; IR – infiltration rate

activity (especially with vehicles) has an impact on litter accumulation and spatial distribution (Figure 3). In general, litter volume per hectare was higher for all plots located at a distance from tourist routes in comparison with plots along the trails.

Moreover, we have used different hiking trails (three) as a factor, according to their location, as well as altitude of the forest stands to test the difference in litter accumulation. However, results of ANOVA revealed no significant differences (P > 0.05) in the accumulation of litter stock along different trails and altitudes across all surveyed plots.

Distribution of litter fractions. Detailed distribution of litter fractions under investigated stands is presented in Figures 4 and 5. We did not take into account mushrooms and dead animals, if they are not already a part of dead organic material. Amount of decomposed litter in pure spruce stands varies from 53% to 90.4%. Leaves are the second main litter fraction that varies from 1.3% to 27% of total volume. Litter fractions showed a similar structure distribution within stands as well as between ridges where the trails are located. In general, active parts of the forest litter surveyed across all sample plots are significantly larger in comparison with inactive components (P < 0.05).

A substantial part of the forest litter is represented by roots and varies from 0.4% to 16% of stock. The lowest rates up to 10% are observed mainly in mixed beech-spruce stands (SP 8, 11–13) and one pure spruce stand (5.5%). We conclude that the features of the parent rock along with the shallow root system of spruces affect their spreading in forest floor litter and topsoil.

Water interception response. During the immersion test the effects of forest litter on water interception and infiltration were investigated. The mass of absorbed water, litter moisture capacity and infiltration rate are summarized in Table 3.

Results show that the litter infiltration rate has a negative correlation with the maximum mass of absorbed water (r = -0.62, P < 0.05), litter stock (r = -0.69, P < 0.01) and retained precipitation (r = -0.62, P < 0.05), which represents the interpretation of the immersion method in the equivalent of rain intensity. A significant difference (P < 0.05) in the infiltration rate was observed between established adjoining and more distant sample plots (Figure 6). No significant difference in litter moisture, soil moisture was observed between distinguished groups (P > 0.05). A considerably weaker correlation was found with humus content (r = 0.39, P > 0.05) and litter thickness (r = -0.45, P > 0.05). Initial lit-

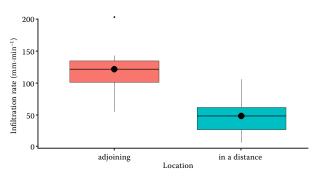


Figure 6. Water infiltration rate within distinguished groups of plots

ter moisture ranged from 10.9% to 82.1% and it could be explained not only by the species composition but also by the slope part and its exposure. Although there is no significant difference (P > 0.05) in litter moisture between sample plots in different locations according to the results of the Kruskal-Wallis test. In contradiction to a widely held opinion that broadleaf litter could intercept more water than needle-leaf litter due to larger leaf areas, our results show that in pure spruce stands the forest litter (SP 1, 2, 4, 6, 10) stored more water than the litter in other studied mixed spruce-beech stands. However, the lowest values of absorbed water mass and moisture capacity were also observed in pure spruce stands (SP 3, 5, 9). We conclude that obtained results can mostly be explained by the amount of litter stock. Therefore, litter samples from SP 1, 2, 4, 6, and 10 absorbed not only the largest water amount, but also the highest values of litter stock were defined within those stands. Also, Pearson's correlation analyses indicated that the litter stock had a positive relationship with the maximum mass of absorbed water (r = 0.84, P < 0.01) and similarly to the mass of absorbed water over current state (r = 0.78, P < 0.01) (Figures 7–8).

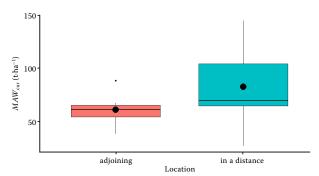


Figure 7. Maximum mass of absorbed water over current state of the forest litter ($MAW_{\rm cur}$) within distinguished groups of sample plots

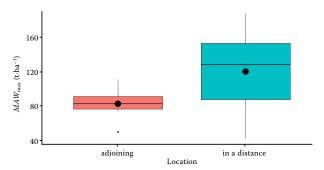


Figure 8. Maximum mass of absorbed water by forest litter (MAW_{max}) within distinguished groups of sample plots

DISCUSSION

Different forms of tourist activity such as horse riding, biking, and hiking have a substantially negative impact on mountain ecosystems, e.g. forest floor and soil erosion development (Pickering, Barros 2015). Based on the results, there is a noticeable difference in the amount of forest litter in sample plots that directly adjoin hiking trails and that were established at a distance. A lower litter volume along the studied trails represents uneven litter accumulation affected by tourist activity in protected areas. Therefore, Drewnik et al. (2019) indicated an increasing intensity of erosion processes due to tourist traffic in the Bieszczady Mts. located in Poland. Obviously, biking or other vehicles cause more damage than hiking, but at lower levels of use the impact from such activities as hiking and biking shows similarities (Pickering, Barros 2015). The illegal use of trucks and bikes on the trails (to Pip Ivan Mountain) of the Carpathian National Natural Park as well as using non-formal trails and trailside areas is observed constantly within the studied areas. Moreover, Tomczyk et al. (2016) revealed that additional widening of the trail tread is the result of trampling the trailside vegetation by tourists due to the desire to avoid degraded sections of the trails.

Results of further analyses showed that litter accumulation within observed stands was affected by litter thickness, slope steepness, tree basal area, but there is no evidence of altitude impact on the litter stock. Similarly, results of other studies (Labaz et al. 2014; Zagyvai-Kiss et al. 2019) showed the increasing litter thickness with altitude on poor soils under the spruce stands and leaf litter under pure beech stands was nearly three-fold thinner on average. Litter accumulation is always higher in the understory of mature spruce forests than in any broadleaf stands.

The rate of litter decomposition is accelerating from coniferous to deciduous stands (Šantrůčková et al. 2006; Berger, Berger 2012). We conclude that the mixed spruce-beech stand with admixture of beech less than 20% showed no impact on litter accumulation and requires a deeper investigation about litter under mixed stands with more substantial admixture and in comparison with pure beech stands in a particular area. However, soil types along with forest litter composition have a greater impact on litter accumulation than annual litterfall. Although the number and intensity of forest treatments such as thinning could potentially affect litter accumulation (Tecimen et al. 2019; Novák et al. 2020), we have not observed any significant difference between managed and unmanaged tree stands.

The research conducted by Ukonmaanaho et al. (2008) revealed that about 2% of aboveground tree biomass returned annually to the forest floor as litterfall, which was observed in spruce and pine stands. The obtained value is common for Finnish forests, but it gives some idea of the nutrient accumulation in forest ecosystems. As can be seen from Figure 4, decomposed organic material is the most substantial fraction of litter under pure spruce and spruce-beech stands. Results revealed that forest litter collected on SP 1 (pure spruce) and SP 13 (20% beech admixture) has the highest proportion of decomposed organic material (90.4% and 79.5%, respectively). We assume that 20% admixture of beech did not have any significant impact on litter fractions.

Despite our hypothesis, the ratio of the active/in-active litter fraction shows no significant difference within average distance from the trail. The active part of forest litter varies from 78.4% (mixed spruce-beech stand) to 97.1% (pure spruce stand). In particular, these fractions support the highest mineralization activity and humification processes. Although the result of the study (Albers 2004) reveals that spruce litter accumulation is not due to the recalcitrance of spruce needles to decay. A substantial part of the investigated litter fractions is root (mainly fine root, up to 16%), which is typical of spruce stands due to the shallow rooting system of spruce.

Water interception plays an important role in the forest hydrological cycle. It prevents not only water erosion, but also a threshold process which describes how much precipitation is required before infiltration and other important processes take place (Bulcock, Jewitt 2012). For our research, we used the immersion test to estimate the forest litter wa-

ter interception and infiltration capacity under needle-leaf and mixed stands (Table 3). According to Li et al. (2014) the leaf litter substantially reduces surface runoff, furthermore, it has a positive impact on surface roughness and infiltration process. The present study demonstrates that the infiltration rate was affected by litter stock, retained precipitation and mass of absorbed water. Moreover, results showed that the highest values of absorbed water up to 187.3 t·ha⁻¹ were measured under pure spruce stands. Despite our expectation, the water infiltration rate was higher along hiking trails with disturbed litter surface than at a distance from the trails. Therefore, a complex litter research had to be completed simultaneously with a wide investigation of soil properties, e.g. compaction and porosity.

However, the percentage of maximum capacity that was intercepted by litter under mixed stands varies from 73.5% to 161.9%, which is relatively the same result in comparison with pure stands. In particular, it shows that forest litter could absorb and store an amount of water almost 1.5 times higher than its dry mass. The relations between litter interception and species composition were not indicated due to a small admixture of beech (10-20%) within investigated stands. Similarly, Du et al. (2019) found a negative correlation between the amount of intercepted water and slope steepness without any relations to tree species. In contrast, Xia et al. (2019) reported that broadleaf litter could store more water than needle-leaf litter under simulation of natural rainfall. We noted some limitations in the experiment. First of all, the immersion test using sample trays for determining the amount of intercepted water within litter has a certain disadvantage due to exceeding the values of actual water input during natural rainfall. The second thing, this test does not allow us to estimate the impact of different natural rainfall duration and intensity. However, with the higher rainfall intensity and duration, the interception storage capacity can increase in the needle-leaf litter under coniferous stand along with broadleaves (Ilek et al. 2014; Li et al. 2020).

CONCLUSION

The results of this research demonstrated that there is a significant difference in litter stock accumulation between sites directly adjoined to the hiking trail and those surveyed at a 20–100 m distance. Thus, the impact of tourism is confirmed in the observed

area of the Ukrainian Carpathians. Using the trailside as a non-formal trail potentially leads to litter trampling and soil erosion processes along with biodiversity loss. However, no statistical difference was found (P > 0.05) in the accumulation of litter along three trails and altitudes across all surveyed forest stands.

The litter thickness is mainly affected by altitude, which also affects the humus content. Insignificant differences in the litter fractional structure were observed in pure spruce stands and mixed spruce-beech with admixture of beech up to 20%. The active part of forest litter dominates in each surveyed stand. Considering the impact of anthropogenic factors (tourist activity) on litter accumulation, the water interception ability of spruce litter has not been affected significantly. Maximum amount of absorbed water varies from 42.3 t⋅ha⁻¹ to 187.3 t·ha⁻¹. Precipitation amount retained by litter varies between 4.2 mm and 18.7 mm and interception capacity depends mainly on the forest litter stock. Opposite to our hypothesis, the infiltration rate was lower on distanced sites in comparison with adjoined ones. Further observational and modelling studies are necessary to clarify the role of the beech share in stand composition in relation to fractional structure and water interception ability.

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