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Monthly fluctuations in litterfall in forest communities, part of the LTER-BG network

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Abstract. Litterfall is a crucial component of forest ecosystems that links the tree canopy and soils. It is one of the indicators that must be monitored in the sites of the "Bulgarian Network for Long-Term Ecosystem Research - LTER BG", which is a part of the "European Network for Long-Term Ecosystem Research". The present study aimed to determine the production of total litterfall and its components (leaves, flowers and fruits, branches and seeds) and their monthly fluctuations at beech and spruce ecosystems situated at different altitudes. Litterfall quantities were studied in three sample plots in beech and spruce forests in the Balkan Mountains, located in sites of the LTER BG network. The monthly dynamics of deciduous forest show, as expected, the highest amounts of litterfall during the autumn months, with the leaf fraction dominating, followed by the cupulas and seeds. The average annual amount for beech forests was 506.5 g.m^{-2}. In spruce forests, the annual amount was 623.28 g.m^{-2}, with the largest percentage being needles, followed by cones and branches. The annual dynamics of litter in spruce forests show the presence of litter in all months of the year with a predominant fraction of needles. The difference in altitudes determines the monthly variations in litter fractions in beech forests. Further studies can continue with the study of the chemical composition of the litterfall in order to clarify the cycling of elements.

Key words: litterfall, stocks, annual dynamics.

Introduction

The Long-Term Ecosystem Research (LTER) network was found from world-wide researchers to understand ecosystem processes and functions and their long-term response to environmental, societal, and economic drivers. The holistic approach of standard observations included the minimum set of variables and relevant method protocols, which was a basis to meet global sustainability. The standard observations cover five spheres: geospheric, hydrospheric, atmospheric, biospheric, and sociospheric, where specific measurements and protocols were implemented in terrestrial and aquatic ecosystems.

Important indicators of the sustainable structure, condition, and function of forest ecosystems are floristic composition, phytocoenotic structure, photosynthesis, and growth.

Litterfall is a crucial component of forest ecosystems that links the tree canopy and soils. It includes all matter that fall to the forest floor, such as leaves, branches, fruits, and other plant parts. It increases forest cover and supports the recovery of biodiversity, forest functions, and ecosystem services (Brancalion & Holl, 2020). On one hand, the litterfall is studied for the purpose of restoration strategies and maintaining biodiversity, and on the other hand, for the restoration of soil fertility and the microbiome. The decomposition of litterfall influences soil structure, aeration, water infiltration, and affects the forest health and productivity (Prescott, 2002).

Williams-Linera et al. (2021) paid attention to the importance of monitoring litterfall production as a dynamic indicator of the recovery of ecosystem functioning. According to their research, the flower and fruit components of the litterfall are indicators of reproductive functional recovery of the ecosystem. Also, the reproductive component of the litterfall in mature forests would display seasonality. They revealed that differences in both litterfall production and reproductive components will be related to tree species composition and density.

Figueira Gazell et al. (2012) concluded that it does not have a relation between production of forest litter and tree species richness, but the tree species richness will play an effective role in litterfall production, when the forest becomes more mature.

The present study aimed to determine the production of total litterfall and its components (leaves, flowers and fruits, branches and seeds) and their monthly fluctuations at beech and spruce ecosystems situated at different altitudes.

Materials and methods

Object of investigation

The research focuses on natural beech (*Fagus sylvatica* L.) communities and spruce stands (*Picea abies* (L.) Karsten) in the West Balkan Range mountain in Bulgaria. Fig. 1 shows their location. Table 1 describes the compartments' main characteristics. The climate is moderately continental and mountainous. The annual precipitation is 625-794 mm yr^{-1} (own meteorological station, 2024-2025), and the soils are Cambisols (WRB, 2006). Three sample plots (two in beech forests and one in a spruce stand) with dimensions of 2000 m^2 each have been laid out.

Sample plot 1 is located in a beech community. The first phytocoenotic horizon has a total projective cover of 80%. The ediphycator is the common beech (*Fagus sylvatica* L.). A shrub phytocoenotic horizon is not formed. The herbaceous phytocoenotic horizon has a projective cover of 80%. It is formed by 24 species, of which 19 are herbaceous, 2 are shrubs, and 3 are trees. The predominant species is *Luzula luzoloides* (Lam.) Dandy.

Sample plot 2 is located in a spruce community. The first phytocoenotic horizon has a total projective cover of 80%. The ediphycator is the common spruce (*Picea abies* L.). A shrub phytocenotic horizon is not formed. The herbaceous phytocoenotic horizon has a projective cover of 30%. It is formed by 17 species, of which 10 are herbaceous, 4 are shrubs, and 2 are trees. The predominant species is *Oxalis acetosella* L.

Sample plot 3 is also located in a beech community. The first phytocoenotic horizon has a total projective cover of 70%. The ediphycator is the common beech (*Fagus sylvatica* L.). The shrub phytocoenotic horizon is 30%. The herbaceous phytocoenotic horizon has a projective cover of 100%. It is formed by 26 species, of which 21 are herbaceous, 2 are shrubs, and 3 are trees. The predominant herbaceous species is *Galium odoratum* (L) Scop.

Methods

The litterfall was collected during the 2024-20025 year. It was collected monthly through four square 0.25 m^2 catchers at each sample plot installed above ground (Ukonmaanaho et al., 2020). It was fractionated into leaves, branches, cupules, seeds, etc., and dried to absolute dry weight for 48 hours at a temperature of 85°C for leaves and 105°C for other fractions. Then, it was weighed on an analytical balance with an accuracy of 0.01 g.

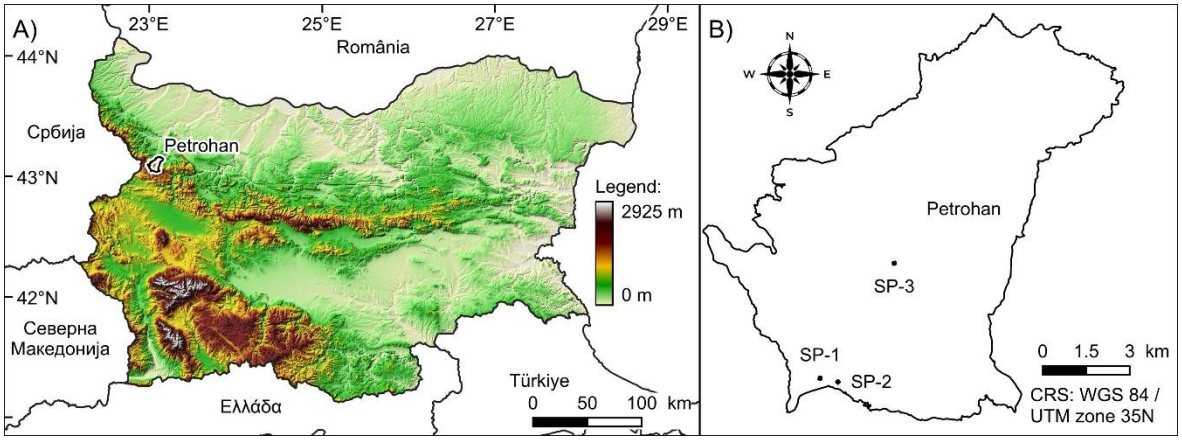

Fig.1. Location of sample plots (SP 1 beech, SP 2 spruce, SP 3 beech).

Table 1. Characteristics of the stands in the sample plots.

Sample plots	Altitude, m	Geographic coordinates	Age, yr	Canopy	Number of trees	Slope, %	Origin	Exposition	Average height, m	Average diameter, cm
SP 1 beech	1428	43.12098686 23.12089266	170	80	75	18.3	natural	W	30	52
SP 2 spruce	1405	43.12008723 23.12850354	90	80	100	4.4	artificial	W	31.8	43.1
SP 3 beech	698	43.15793658 23.15000939	140	70	61	6.1	natural	S	30.5	42

Results and Discussion

As a result of the conducted studies of litterfall in spruce forests, it was found that the annual amount was 623.28 g.m^{-2}, of which 332 g.m^{-2} were needles, 182 g.m^{-2} were cones, 79 g.m^{-2} were branches, 16.37 g.m^{-2} were lichens, and 11.5 g.m^{-2} were male reproductive organs. The distribution of the total amount by months is presented in Fig. 2.

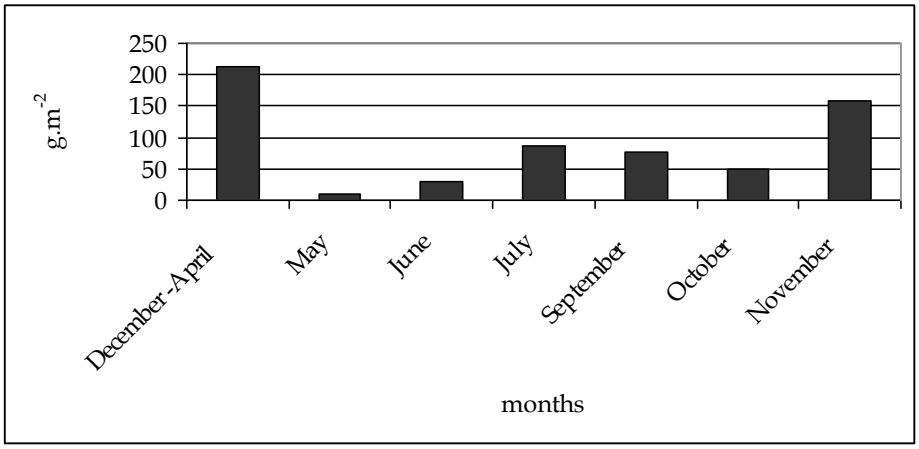

Fig. 2. Monthly distribution of total litterfall stock in spruce forests (g.m^{-2}).

The largest amount was observed in April, with the litterfall mainly represented by needles (39%) and cones (37%), branches were 19%, and the least were lichens - 3% and male reproductive organs - 0.3%. This large amount was due to the accumulation of litter during the winter months, when it was not collected. In the period May – November, the litter was in smaller quantities, varying between 10 g.m^{-2} in May, increasing until July, then decreasing until October and peaking at 159 g.m^{-2} in November. In all months, the fraction of needles predominates (92-31%), followed by that of cones (14-57%), branches were between 3-19%, and in the smallest quantities were lichens, from 1 to 3%, and male reproductive organs, 0.3 to 4% (Table 2).

Our results are similar to those from spruce forests in Finland (Saarsalmi et al., 2007), where litter amounts of 677 g. m^{-2} were found, and needles also predominated. The authors indicate that of the stand characteristics, the average tree height has the greatest influence on litter amount.

Other studies in the Czech Republic (Kopáček et al., 2015) on litter in spruce communities indicate amounts of 420 g. m^{-2}. The lower amount may be because the studies were conducted in forests damaged by bark beetles.

In the beech forests in SP 1, the total amount of annual litter was 502 g.m^{-2}, with leaves having the largest share (231 g.m^{-2}). Next in quantity were leaf scales and flowers (88 g.m^{-2}), cupules (80 g.m^{-2}), branches (57 g.m^{-2}), and seeds (47 g.m^{-2}). The quantity was greatest in autumn with a maximum in October (Fig. 3). It was lowest in the spring months, where the litter is mainly formed by the leaf scales and flower fraction (55-100%) - Table 3. In the autumn months, the amount of litter was mainly formed by the leaf fraction (35-73%), followed by that of seeds (14-29%), cupules (11-40%), and branches (1-39%).

Table 2. Amount of litter by fractions in different months in spruce forests (g.m^{-2}).

Litterfall fractions	December-April	May	June	July	September	October	November
lichens	7.36	0	0	1.27	1.53	0.73	5.48
cones	82.56	0	0	12.3	43.28	0	43.79
needles	83.4	9.73	27.41	54.59	24.12	45.93	86.57
male reproductive organs	0.76	0	1.27	2.79	2.42	0.97	3.29
branches	39.76	0	0.99	14.58	1.56	2.33	19.32

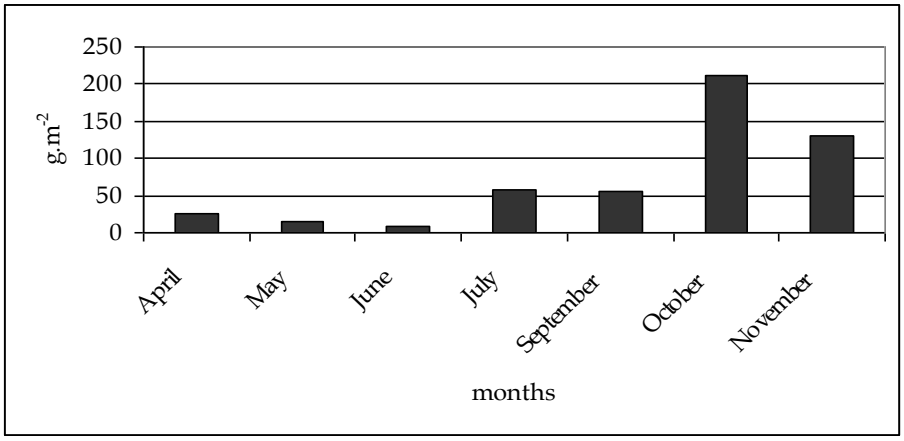

Fig. 3. Monthly distribution of the total amount of litter in beech forests - SP 1 (g.m^{-2}).

Table 3. Amount of litter by fractions in different months in beech forests SP 1 (g.m^{-2}).

Litterfall fractions	April	May	June	July	September	October	November
leaf scales	13.79	14.04	9.41	50.48	0	0	0
leaves	0	0	0	2.37	28.43	154.693	45.63
branches	9.52	0	0	2.42	0.44	0	44.44
cupulas	1.18	0	0	1.41	10.81	26.4667	39.93
seeds	0.2	0	0	0	16.18	29.76	0.52

In beech forests in SP 3, the total amount of annual litter was 511 g.m^{-2}, with the largest share being leaves (311 g.m^{-2}), followed by branches (72 g.m^{-2}), leaf scales and flowers (56 g.m^{-2}), cupules (49 g.m^{-2}), and seeds (23 g.m^{-2}). The largest amount was in autumn with a maximum in November (Fig. 4). It was lowest in the summer months, where the litter was mainly formed by the leaf scales and flower and leaf fractions - Table 4. In the autumn months, the amount of litter was mainly formed by the leaf fraction (69-79%), followed by that of seeds (12-19%), cupules (5-18%), and branches (0.4-16%).

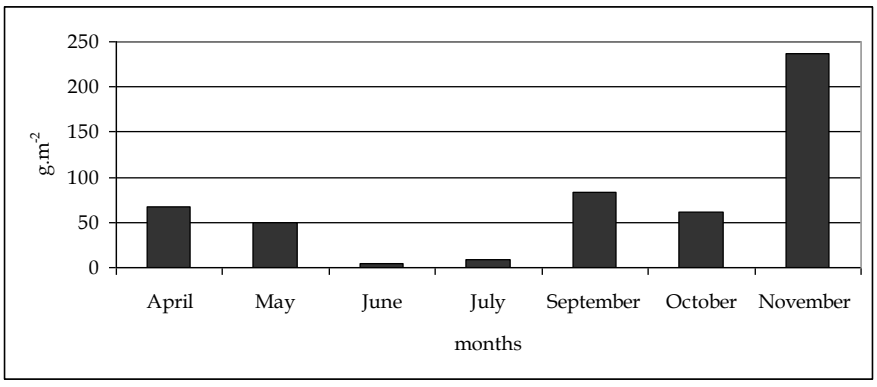

Fig. 4. Monthly distribution of the total amount of litter in beech forests - SP 3 (g.m^{-2}).

Table 4. Amount of litter by fractions in different months in beech forests of the SP 3 (g.m^{-2}).

Litterfall fractions	April	May	June	July	September	October	November
Leaf scales and flowers	30.8	21.7	0.74	3.17	0	0	0
leaves	8.92	7.5	3.37	5.05	57.4	42.01	186.95
branches	13.2	20.48	0	0	0.3	0.46	37.4
cupulas	14.6	0	0	0	10.25	10.95	12.81
seeds	0	0	0	0	15.56	7.29	0.27

In our previous studies of litter in beech forests, similar results of 537.34 g.m^{-2} were obtained for beech forests in the Balkan Mountains and lower - 213.34 g.m^{-2} for those in the Vitosha Mountains, 350.8 g.m^{-2} for Osogovo Mountain and 627.9 g.m^{-2} for Ograjden Mountain (Dimitrova et al., 2025). For beech forests of similar age in Macedonia, amounts of 498 g.m^{-2} for total annual litter have been reported (Hristovski et al., 2014)

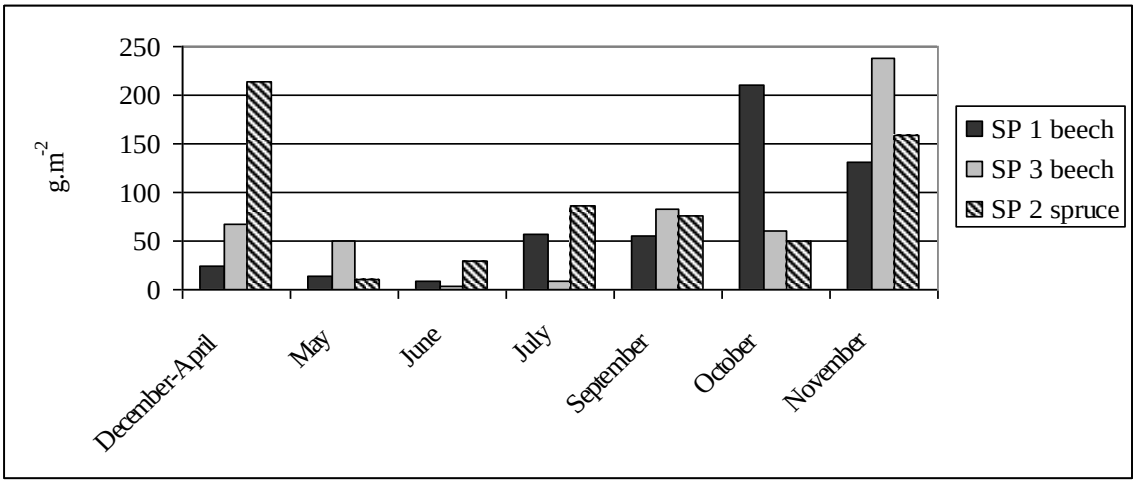

Fig. 5. Monthly distribution of total litter in beech (SP 1 and SP 3) and spruce forests (g.m^{-2}).

In coniferous forests, compared to deciduous forests, we do not have an autumn maximum in the amount of litter. Another difference was the presence of lichens in the litter in spruce forests, which was absent in beech forests.

The difference in altitude at the beech sample plots (SP 1, 1400 m, and SP 3, 700 m) predetermines a difference in ecological conditions - a greater amount of precipitation in SP 1 compared to SP 3 and a difference in temperature regime. In beech forests at higher altitudes (SP 1), vegetation begins later than in those at lower altitudes (SP 3), which is reflected in the amount of litter in April and May. It was mainly composed of leaf scales and flowers, and in SP 3, it was greater than in SP 1. During the summer months, the amount of litter was expected to be lower (Fig. 5). During the autumn months, an increase in the amount of litter was observed in both sample areas, which was mainly due to the leaf fraction, with the higher sample area (SP 1) having a maximum in October, and the lower one (SP 3) having a maximum in November.

The total amount of litter in the two beech sample plots was almost the same, which was most likely due to the fact that the plots were in forests of similar age (SP1 - 170 years and SP 3 - 140 years), in which no significant difference in the course of physiological processes was expected, which would be reflected in a change in the amount of leaf mass. The differences in the projective cover of the tree canopy (80% in SP 1 and 70% in SP 3) and the number of trees (75 in SP 1 and 61 in SP 3) in the sample plots were also insignificant.

Comparing the individual litter fractions, a predominant part of the leaves was found, as in the higher lying sample area SP 1, they were less than half of the litter (46%), and in the lower lying one, the leaf fraction formed the main part of the

litter (61%). Regarding the cupules and seeds, an opposite relationship was found. In SP 1, they were 16 and 9%, respectively, and in SP 3, 10 and 4.5%.

Conclusion

The annual dynamics of litter in spruce forests show the presence of litter in all months of the year, with a predominant fraction of needles. The annual dynamics of litter in beech forests have an expected autumn maximum, with the main fraction being leaf mass.

The difference in altitude and atmospheric conditions of sample plots influences the monthly fluctuations of litterfall. This difference in this case does not affect the amount of total litter.

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