LITTER INVERTEBRATE COMMUNITIES IN PINE FORESTS OF DIFFERENT AGE (BARANIVKA AREA, UKRAINE)

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Abstract
Litter invertebrate communities in pine forests of different age (cut, six-year-old, 45-, 62-, and 105-year-old) in the Baranivka area of Zhytomyr Polissya (northwestern part of Ukraine) were studied. Samples were collected in April, August, and November 2011. 99% of extracted invertebrates were represented by mites (Acari) and springtails (Collembola). With forest age, the following tendencies were observed: mean absolute density of mites, springtails, and all litter-inhabiting animals increased; relative abundance of mites increased, but relative abundance of springtails decreased; taxonomic richness of invertebrate communities increased. In all samples, the most represented taxon was suborder Oribatida. The most diverse litter invertebrate community was in the 45-year-old forest. Similar compositions of invertebrate community were in the 45-, 62-, and 105-year-old forests as well as the cut and six-year-old ones.
Key words: pine forest, litter invertebrates, Acari, Collembola, density, similarity.

Introduction

Forest litter plays an important role in the forest ecosystem. It influences chemical composition of a solution that enters the soil, regulates heat regime and water-physical characteristics of the forest soil. A litter contains organic matters at different stages of their decomposition and humification. The quantity of forest litter depends on the species composition, age, shape and type of stands, soil water regime, live soil cover, and other factors. Soil-inhabiting fauna coupled with soil microflora, contribute to the soil quality. They are associated with the decomposition and transformation of dead organic substances into inorganic ones (Curry, 1973; Knoepp et al., 2000; Seastedt, 1984; Tripathi et al., 2005; Wang et al., 2009). Conventional forest harvesting practices has a negative impact on these processes leading to the changes of the distribution, composition, and activity of the soil biological communities (Marshall, 2000). Many studies consider soil microarthropods as possible indicators of soil quality (Knoepp et al., 2000, Lindo, Visser, 2004).

In Ukraine, studies on structural organization of litter invertebrates were conducted in steppe forests (Бригадиренко, 2007; Кульбачко, 1999). The objective of our work was to study litter-dwelling invertebrates in pine forests of Zhytomyr Polissya, especially quantitative and qualitative characteristics of their communities depending on the forest age.

Materials and Methods

The study was conducted in the Baranivka area of Zhytomyr Polissya. The area is located at the latitude of 50°18´ north and the longitude of 27°40´ east within the altitude of 156 m above the sea level in the northwestern part of Ukraine. The climate in this area is mild continental with warm and humid summer with a mean temperature in July +18.9 °C and mild winter with a mean temperature in January –5.7 °C. The total annual precipitation is 600 mm. The level of underground water is 2.5 to 3.5 m.

Litter was sampled at the beginning of April, August, and November 2011 in the fresh pine forests of the following age groups (abbreviated denotation is given in brackets): 1) cut, the 90-year-old forest was cut in December 2010; 2) non-closed forest, 6 years old (F 6); 3) young forest, 45 years old (F 45); 4) middle-aged forest, 62 years old (F 62) and 5) mature forest, 105 years old (F 105).

A sample was a square litter monolith sized 10 x 10 cm each (100 cm^2) with the thickness of a monolith equaled the thickness of the litter: in the cut forest – 1-2 cm, six-year-old – 0.5-1 cm, 45-year-old – 3 cm, 62-year-old – 3-4 cm, and 105-year-old – 3-5 cm**.** A total of 75 samples were examined (5 treatments x 5 sampling occasions x 3 seasons). Invertebrate extraction was conducted using modified Tullgren funnels (diameter 15 cm) containing inserted wire mesh with cells 2x2 mm. As a source of heat electrical bulb was used. Invertebrates dropped through the exit hole of the funnel into collecting bottles containing 70% alcohol. Extraction time lasted two days. The total numbers of individuals in major groups were calculated with dissecting microscope at 40x magnification. Mites were classified to suborders and/or families using compound microscope at 100x magnification.

To characterize the composition of invertebrate communities and their diversity, the following ecological indices were used: density, percentage relative abundance, a comparison of two samples with Student's t-test, Shannon's index of biodiversity, inverse of Simpson's index, and index of similarity after Marczewski and Steinhaus.

The relative abundance (percentage of total) of microarthropod suborders was calculated using the formula: number of individuals in a suborder / total number of individuals x 100 (1).

The Shannon's index of biodiversity (*H'*) was calculated using the formula: $H' = -\Sigma (p_i \ln p_i)$ (2), where *H'* is Shannon's index; p_i is the relative abundance of each species, calculates as the proportion of individuals of a given species (n_i) to the total number of individuals in the community (*N*): *ni/N* (Magurran, 2004).

The diversity index, inverse of Simpson's, was calculated using the formula: $1/D = 1/\Sigma p_i^2$ (3), where *D* is Simpson's index and p_i is the proportion of individuals of a given species (Magurran, 2004).

Marczewski and Steinhaus index of similarity (MS) was calculated using the formula: s=c/(a+b–c) (4), where *s* is a similarity of two compared communities, *a* – the number of taxa in community A, *b* – the number of taxa in community B, and c – the number of taxa common for A and B (Magurran, 2004).

Results and Discussion

In all litter samples, invertebrate communities were composed predominantly of mites (Acari) and springtails (Collembola), the representatives of miroarthropods, which accounted for up to 99% of extracted animals (Table 1, Fig.1). Our data are consistent with findings of other authors who pointed out that these two groups of microarthropods are prevalent components of soil-litter fauna (Lindo and Visser, 2003; Wang et al., 2009). According to literature, they are responsible for the decomposition process, and their abundance directly correlates with the litter mass loss rates (Seastedt, 1984; Tripathi et al., 2005; Wang et al., 2009). Among other extracted invertebrates were representatives of the following taxa: Aranae, Pseudoscorpionida, Annelida, Nematode, Centipedes, Coleoptera, Hymenoptera, and insects larvae.

The annual mean density of all extracted animals differed considerably depending on the forest age: the highest number, 66,320 ind m^{-2}, was observed in the 105- year-old forest but the lowest, 6,500 ind m^{-2}, – in the six-year-old one. In the cut and six-year-old forest, the density of invertebrate community was the lowest. Comparing these two forests, there was a slight decline in the quantity of all animals and mites in the six-year-old forest (Table 1). This effect is probably related to changes in the litter quantity and quality and, as a result, to negative impact of the environment on the soil properties and available food resources. According to Marshall (2000), and Lindo, Visser (2004) harvesting leads to the reduction and redistribution of the matter, compaction, changes in plant cover, and modification of microclimate and directly affects microarthropod communities.

Starting from six-year-old forest, the total number of animals in the litter increased with the age of forest (Table 1, Fig. 1). The most significant growth in animals' abundance was in the 45-year-old forest compared to the six-year-old when the density of all arthropods increased more than 7.5 times, mites – 8.6, and springtails – 5.2 times. The relative abundance of Acari ranged from 70 to 82% of all extracted animals. Their annual mean density varied from 4,520 ind m^{-2} in the six-year-old forest to 53,707 ind m^{-2} in the 62-year-old forest.

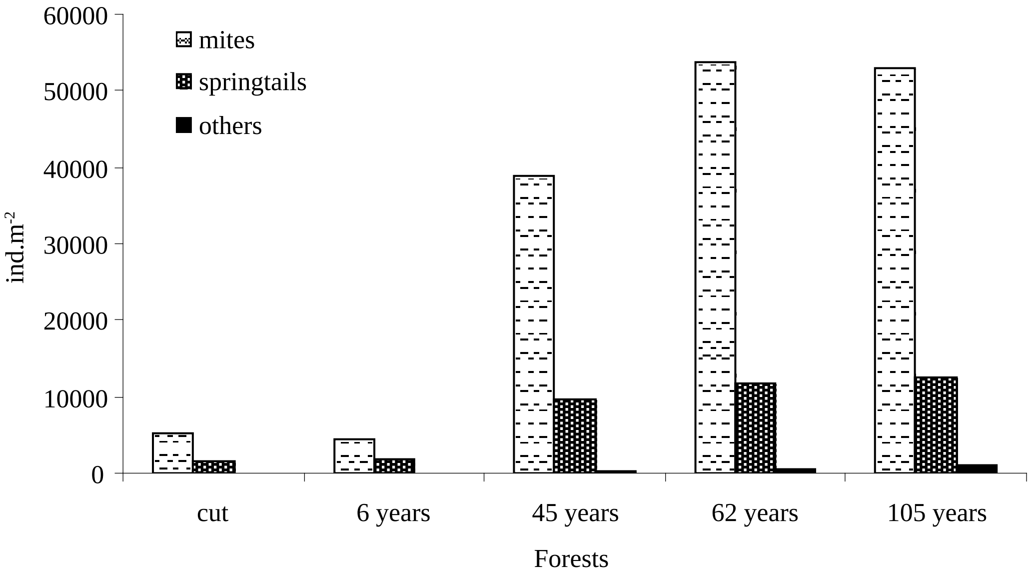

Figure 1. Annual mean density of mites, springtails and other invertebrates in the litter of pine forests of different age.

Table 1

Composition and annual mean density of litter invertebrates in the pine forests (F) of different age (years)

Taxa	Cut		F (6)		F (45)		F (62)		F (105)	
	ind m^{-2}	%	ind m^{-2}	%	ind m^{-2}	%	ind m^{-2}	%	ind m^{-2}	%
Acari:										
Prostigmata (total)	1,667	24	1,094	17	11,847	24	25,586	24	13,974	21
Eupodidae	213	3	127	2	1,740	4	2,113	3	1,893	3
Tydeidae	93	1	100	2	1,127	2	2,013	3	1,827	3
Bdellidae	140	2	93	1	1,467	3	1,873	3	1,727	3
Rhagidiidae	73	1			640	1	860	1	640	1
Cunaxidae					260	< 1	260	< 1	187	< 1
Pseudocheylidae	40	< 1	7	< 1			200	< 1	213	< 1
Paratydeidae					93	< 1	127	< 1		
Scutacaridae					107	< 1	373	< 1	1,020	2
Other Prostigmata	1,107	16	767	12	6,413	13	7,767	12	6,467	10
Mesostigmata (total)	173	2	127	2	2,574	5	2,240	3	3,466	5
Phytoseiidae					560	1	500	< 1	893	1
Rhodacaridae					847	2	560	< 1	1,013	2
other Gamasides	173	2	127	2	1,167	2	1,180	2	1,560	2
Oribatida	3,187	46	2,847	44	22,320	46	33,880	51	33,320	50
Astigmata	173	2	453	7	2,067	4	2,000	3	2,193	3
Total Acari	5,200	75	4,520	70	38,807	79	53,707	82	52,953	80
Collembola										
Collembola	1,640	24	1,887	29	9,753	20	11,693	18	12,420	19
Other invertebrates:										
Insects larvae	60	< 1			93	< 1	113	< 1	713	1
Coleoptera					7	< 1	213	< 1	7	< 1
Hymenoptera									20	< 1
Centipedes					13	< 1	13	< 1	47	< 1
Other insects			13	< 1	40	< 1	107	< 1	120	< 1
Areneae			13	< 1					13	< 1
Pseudoscorpionida									20	< 1
Nematode					140		67	< 1	7	< 1
Annelida			67	1			7	< 1		
Total	60	< 1	93	1	293	1	520	1	947	1
All invertebrates	6,900		6,500		48,853		65,920		66,320	
N of taxa	11		12		19		22		23	
H' index	1.54		1.44		1.74		1.66		1.72	
1/*D* index	3.35		3.38		3.68		3.19		3.31	

Mite population in all studied samples included Oribatid, Prostigmatid, Mesostigmatid, and Astigmatid mites. The relative contribution of these suborders to the total mite abundance changed slightly with forest age (Fig. 2). The main contributors to the mite population were Oribatid and Prostigmatid mites which accounted for 87 to 93% of mite populations. Suborder Oribatida was the most numerous in forests of all ages. It constituted from 58 to 63 % of all mites (Fig. 2). Oribatida mites also dominated among all extracted animals. Their relative abundance ranged from 44 to 51% (in the six-year-old and 62-year-old forests respectively) of all invertebrates in the litter (Table 1). Many studies reported Oribatid mites as the most frequently found animals of a soil mesofauna community (Lindo and Visser, 2004; Silvan et al., 2000; Wallwork, 1983; Wang et al., 2009). The trophic activities of Oribatids, namely the consumption of fungal biomass and comminution of dead plant materials, result in fecal pellets, which enlarge surface area for primary decomposition by bacteria and fungi and contribute to soil microstructure (Pawluk, 1985).

Prostigmata mites were the second most abundant suborder of mites. They accounted for 17% of all animals in the six-year-old forest and from 21 to 24% in other age groups (Table 1). Their contribution to mite abundance was from 24 to 32% (Fig. 2). Representatives of eight families of Prostigmatid mites, namely Eupodidae, Tydeidae, Bdellidae, Rhagidiidae, Cunaxidae, Pseudocheylidae, Paratydeidae, and Scutacaridae were identified. Three of them, Cunaxidae, Paratydeidae, and Scutacaridae, were not present in the cut forest. The six-year-old forest lacked the same families like the cut forest, and Rhagidiidae. Mesostigmatid mites constituted from 2% in cut and F (6) to 5% in F (45) and F (105) of all extracted invertebrates (3-7% of all mites). Two families of Mesostigmatid mites, Phytoseiidae and Rhodacaridae, were identified in the forests starting from 45 years old and older (Table 1). Many of Prostigmatid and almost all of Mesostigmatid mites are predators; however, some species are fungal feeders (Christine et al., 2001). Cohort Astigmata accounted for 2 to 7% of all invertebrates in samples (3-10% of all mites). Their highest relative abundance was in the six-year-old forest. With forest age, their quantity diminished. According to qualitative characteristics of mite community, the richest was 62-year-old forest followed by 105- and 45-year-old forests; the poorest was six-year-old one.

Springtails constituted 18% in F (62) to 29% in F (6) of all invertebrates in the litter. Their lowest density, 1,640 ind m^{-2}, was observed in the cut forest (Table 1, Fig.1). With forest aging, their density increased and reached the highest value (12,420 ind m^{-2}) in the 105-year-old forest. The relative contribution of springtails was inversely proportional to the mite's one: relative density decreased from six-year-old to 62-year-old forest. The literature suggests that abundance of both, Acari and Collembola correlates positively with microbial and fine-root biomass (Kandeler, 1999; Lindo and Visser, 2003; Marshall, 2000). Other invertebrates in the litter gradually increased in numbers from 60 ind m^{-2} in the cut forest to 947 ind m^{-2} in the mature forest (Table 1). Their contribution to the litter invertebrate population was stable (around 1%) in forests of all examined ages.

Taxonomic richness of invertebrate communities increased with the age of forest. The least number of taxa (11) was found in the cut forest and the greatest number (23) – in the 105-year-old one (Table 1). The Shannon's index of diversity (*H'*) ranged from 1.44 in the six-year-old to 1.74 in the 45-year-old forest. According to this index, studied forests can be arranged in the following order (from highest value of index to smallest): F (45) – F (105) – F (62) – cut – F (6).

The inverse Simpson's index of diversity (1/*D*) was highest in the 45-year-old forest (3.68) and the lowest (3.19) in the 62-year-old one (Table 1). According to this index, studies forests are arranged in the following order (from highest to lowest value): F (45) – F (6) – cut – F (105) – F (62).

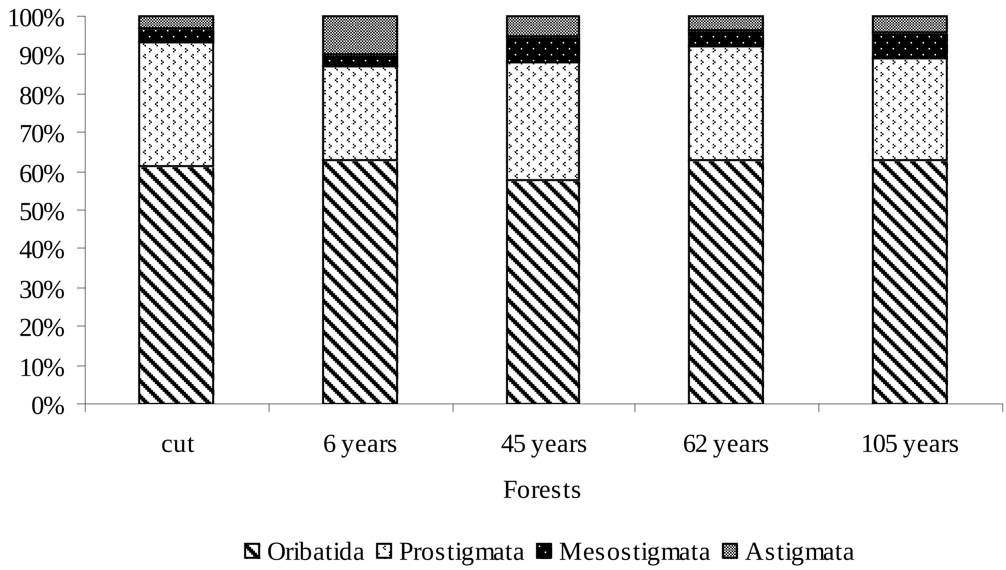

Figure 2. Percentage contribution of mite suborders to the total numbers of mites in pine forests of different age.

Table 2

Index of similarity after Marczewski and Steinhous in forests (F) of different age (years): a – for all invertebrates, b – for mites

	Cut		F (6)		F (45)		F (62)	
	a	b	a	b	a	b	a	b
F (6)	0.64	0.89						
F (45)	0.5	0.57	0.41	0.5				
F (62)	0.52	0.64	0.5	0.57	0.91	0.93		
F (105)	0.5	0.69	0.48	0.62	0.78	0.86	0.79	0.93

he index of similarity after Marczewski and Steinhous (MS) indicates that 45-, 62-, and 105-year-old forests have similar invertebrate community composition (Table 2, a). The most similar communities (MS = 0.91) were in forests of 45 and 62 years old. The least similar (most different) communities were in the six-year-old forest and 45-year-old one (MS = 0.41). Low MS index was also between six-year-old forest and 62- and 105-year-old ones as well as between cut forest and forests of 45 years old and older.

For mites, highly similar community structure was observed in 45-year-old forest and older (MS index ranged from 0.86 to 0.93) and in the cut and the youngest forest (MS = 0.89). The less similar and more diverse mite population was in the following pairs of forests: six-year-old and 45-year-old (MS = 0.5), six-year-old and 62-year-old (MS = 0.57) and cut and 45-year-old (MS = 0.57) (Table 2, b).

Statistical analysis of invertebrate densities between pairs of forests shows that differences vary from highly significant to non-significant (Table 3). It is highly significant between the following pairs: cut and young forest, cut and middle-aged, cut and mature forest as well as between non-closed and any other age group for total number of individuals, mites, and springtails. There were no significant differences between six-year-old and cut forests, 45- and 62-year-old, 45- and 105-year-old, and 62- and 105-year-old forests.

The density of all litter-inhabiting mesofauna and its major groups in pine forests varies significantly during the year (Fig. 3). In the cut and six-year-old forests, the lowest density was observed in summer. The highest number of animals in the former forest was in spring but in the latter – in fall. In the 45-year-old forest and older, the most inhabited litter was in summer. In these forests, the differences between summer and fall invertebrate abundance were statistically significant ($p<0.05$). The lowest abundance in the 45- and 62-year-old forests was in fall, and in the 105-year-old – in spring. Spring to summer comparison of invertebrate abundance in the oldest forest was statistically significant ($p<0.01$).

Significant seasonal variations were also observed in mites' abundance (Fig. 3). In all forests, except six-year-old one, the lowest absolute density of mites was in fall. In 45- and 105-year-old forests, the highest mites density was observed in summer whereas in the cut and 62-year-old one – in spring. Statistically significant differences in mean values of mite density in spring, summer, and fall were in the cut forest ($p<0.05$). Summer and fall mite abundance differed in 45-, 62-, and 105-year-old forests ($p<0.05$); spring and summer abundance was also statistically different in the oldest forest ($p<0.01$).

The highest abundance of collembolan species in the cut, 62-, and 105-year-old forests was in summer, in six-year-old – in fall, whereas in the 45-year-old – in spring. However, there were no significant differences in their abundance in all forests except F (45) between spring and fall communities ($p<0.05$). Literature analysis indicates that seasonal peaks of soil mesofauna abundance, especially Collembola, depend on the weather conditions (Pernin et al., 2006). Collembola are more sensitive to desiccation than mites, which are covered with cuticle. We cannot draw

Table 3

Statistical significance of the differences of mean values of litter invertebrate densities in forests (F) of different age (years) between pairs of sites: a –invertebrates (total); b – mites; c– springtails (*P<0.001, **** P≤0.0001, n.s. – nonsignificant)**

	Cut	F (6)	F (45)	F (62)
F (6)	a, b, c – n.s.			
F (45)	a****, b****, c****	a***, b****, c***		
F (62)	a****, b****, c***	a****, b****, c***	a, b, c – n.s.	
F (105)	a***, b***, c****	a****, b***, c****	a, b, c – n.s.	a, b, c – n.s.

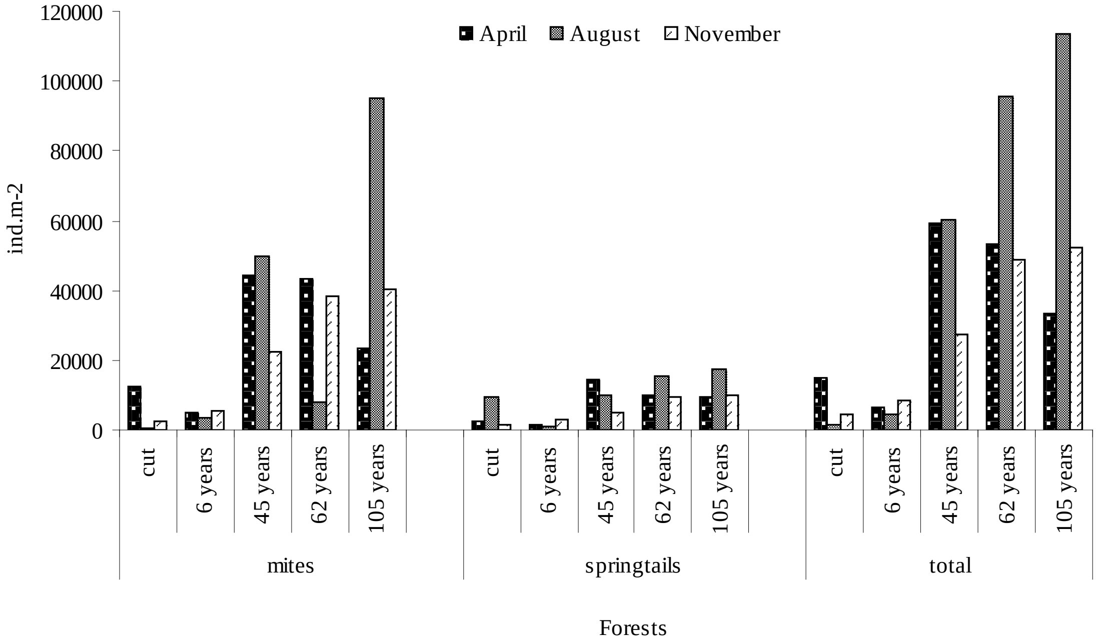

Figure 3. Density dynamics of mites, springtails, and total invertebrates in forests of different age during the year.

any definite conclusions on the seasonal fluctuations in the litter mesofauna abundance observed in our study yet, as it requires additional observations.

Conclusions

1. In all studied forests, 99% of extracted invertebrates were represented by Acari and Collembola. Mean absolute density of litter-inhabiting animals increased with the age of forest. The most significant growth of mite's, springtails, and total animal's abundance was observed in the 45-year-old forest compared to six-year-old one.
2. The contribution of Acari to litter communities ranged from 70 to 82%. Their absolute and relative density increased with forest aging. Oribatid mites dominated in forests of all ages and accounted from 44 to 51% in all extracted animals.
3. Collembola amounted 18 to 29% of the litter-dwelling invertebrates. With forest age, their absolute density increased but their relative contribution decreased.
4. Taxonomic richness of invertebrate communities increased with forest aging. The least number of taxa (11) was found in the cut forest and the greatest number (23) – in the 105-year-old one. According to Shannon's (*H'*), and inverse Simpson's (1/*D*) indices of diversity, the 45-year-old forest had the most diverse litter invertebrate community.
5. Index of similarity after Marczewski and Steinhous (MS) indicated that the 45-, 62-, and 105-year-old forests as well as the cut and six-year-old ones had the most similar composition of invertebrate community.
6. Mite's, springtails and total invertebrate abundance were subject to considerable seasonal variations.

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