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PHYTOINDICATIVE ASSESSMENT AND ANALYSIS VEGETATION IN DISTURBED AREAS AFTER ILLEGAL AMBER MINING IN THE WESTERN POLISSYA OF UKRAINE

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Abstract

The article is presents results of studies on the vegetation of forest territories in the western part of Ukrainian Polissya, touched upon because of illegal amber mining. It has been established that the total species composition consists of 111 species, 80 genera and 30 families of vascular plants. Leading positions in the number of species occupy the families Poaceae and Asteraceae. According to the ratio of diagnostic species among the vegetation classes, representatives of the two classes *Molinio-Arrhenatheretea* and *Quercetea robori-petraeae* occupy the leading positions in the phytosociological structure, and in general, the distribution of species of the Braun-Blanquet's classes of the flora studied is consistent with the type of vegetation, which prevailed in the territories prior the violations. According to the Calinski-Harabasz criterion, clustering the relevés dataset into two groups (A and B) is most acceptable. The naturalness of species composition of cluster A is higher and is credibly different from cluster B. Phytoindication scores of most factors except humidity (*Hd*) are significantly different between clusters A and B. Additionally, the largest difference being observed in the nitrogen values, with the sites of the cluster A corresponding to soils with the lower nitrogen availability. The studied vegetation retaining sand is comprising some natural features of the surrounding type of vegetation of Ukrainian Polissya. Moreover, the relative remoteness from populated and industrial places, together with the conservation of the surrounding forests creates a potential for a substantial recolonization of the land by forest plant species. Despite this, it is advisable to conduct land restoration activities and monitor succession changes over longer period.

Key words: constant species, differentiating species, land restoration, partial flora, phytoindication.

Introduction

The anthropogenic transformation of the natural environment, including its main consequence – the changes of vegetation – is rampant in the modern world (McGrath et al. 2015, Alkama and Cescatti 2016, Zanon et al. 2018). Historically, the territory of Ukrainian Polissya has been under a significant anthropogenic impact caused by agricultural practices (Bozhok 1976, Alekseyevsky and Bakhmachuk 1992, Khomyak et al. 2018) and radionuclide contamination (Yablokov et al. 2010, Beresford et al. 2016). In recent years, another environmental problem has been aggravated in Ukrainian Polissya – the illegal amber mining, which has long-term, serious environmental, social and economic consequences (Kazymyr and Bedernichek 2017, Kovalevsky et al. 2017, 2019, Kovalevskyi and Kovalevskyi 2019).

Amber is a mineral of organic origin, a petrified resin of ancient gymnosperms (including representatives of the Cupressaceae, Taxodiaceae and some others), and is now highly valued in various fields of industries, particularly in jewellery, chemical, and pharmaceutical industry (Melnychuk and Krynytska 2018).

Adverse effects of illegal amber mining are related to the disturbance or destruction of natural biotopes on large areas and the lack of land reclamation after mining activities. The types of anthropogenic impact associated with amber mining can be divided into two subtypes – direct (pitting, water washing) and indirect (cutting, changing the water-mineral regime of soils, biological invasions). All these factors slow down the processes of natural restoration of vegetation cover significantly, sometimes making them impossible (Gordeychuk 2013, Kazymyr and Bedernichek 2017, Kovalevsky et al. 2017).

In the recent years, there has been a growing scientific interest in identifying new territories disturbed by illegal amber mining (Filipovich 2015, Filipovich and Shevchuk 2016, Masley et al. 2016, Shevchuk 2017, Yanchuk et al. 2017, Krasovskyi et al. 2018), the effects of mining on the environment, and its impact on the restoration of forest and wetland landscapes of Polissya, including the territories of Rivne (Gordeychuk 2013, Lehkyi and Kovalevskii 2018), Zhytomyr (Kovalevsky et al. 2017, 2019), and Volyn (Kazymyr and Bedernichek 2017) regions of Ukraine.

At the same time, our knowledge on changes in environmental regimes and transformation of habitats due to illegal amber mining activities still remains in sufficient and challenges the need for additional researches. Our study has been devoted to measure the mentioned points quantitatively using a method of phytoindication, which gives us a basis for understanding of underlying processes in vegetation and is certainly a necessary condition for the rational use and conservation of the disturbed area.

The purpose of our research was to study the structure of vegetation resulting of amber mining activities, and environmental analysis of habitats. The changes of this level of the ecosystem components directly affect the potential restoration of primary vegetation after reduction of anthropogenic impact. The anthropogenic impact not only affects vegetation, but also potentiates a change in the environmental conditions. Therefore, the application of phytoindication is still relevant from the point of view of predicting the future trend in the restoration of vegetation and assessing the potential recoverability of climax vegetation.

Region of Research

Figure 1 reveals the location of 6 amber mining sites where the vegetation studies and ecological assessment of habitats were conducted. The localities are in the central and western part of Ukrainian Polissya in the Northwestern Part of Ukraine.

General characteristics of the territories studied, as well as the scale and methods of amber mining are shown in Table 1.

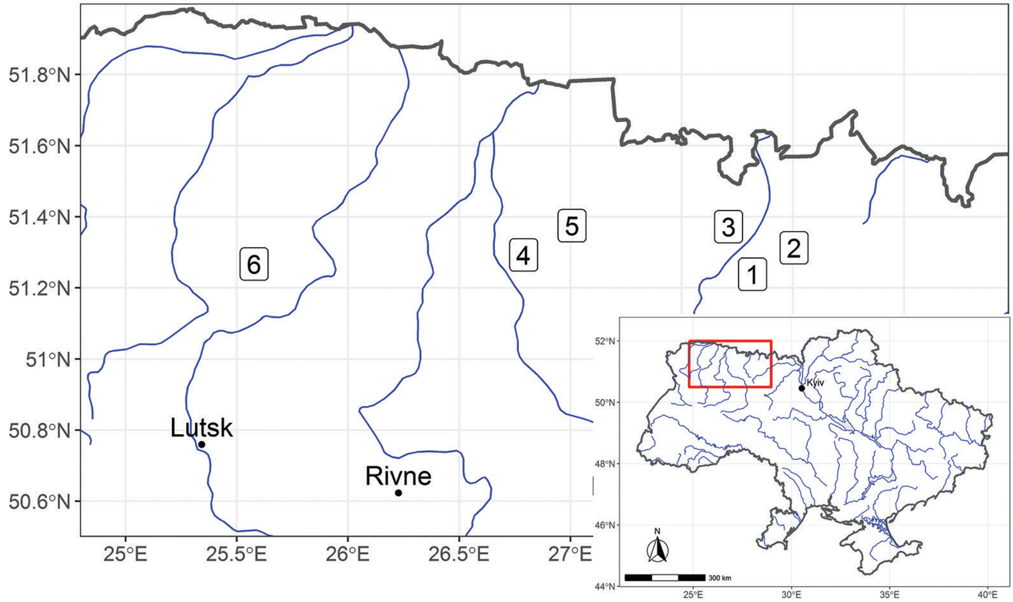

Fig. 1. Location of amber mining sites on the map of Ukraine studied in this research.

Table 1. Localities of the Western part of Ukrainian Polissya damaged by illegal amber mining.

No	Name of forestry (forest square/ allotment)	Type of EUNIS habitats prior disturbance*	Estimated area of disturbance, ha	Year of startingof field work	Preferred mining method**
		Olevsk district, Zhytomyr region			
1	Poiaskivske (21/5,7,18)	G3.4	27,2	2014	1
2	Poiaskivske (20/17,20,32)	G3.4	6,5	2014–2016	1
3	Yuriivske (65/14)	G3.4	0,6	2015	2
		Klesiv district, Rivne region			
4	Klesivske (40/8)	G3.E	2,8	2014	1
5	Liubonske (7/14)	G3.4	2,1	2014	2
		Manevychy district, Volyn region			
6	Vovchetske(42/28)	G3.E	5,9	2014	2

Note: * – following Onyshchenko (2017); ** 1 – underground water washing (hydromechanical method), 2 – manual digging of amber (after Volnenko et al. 2017).

Depending on the method of amber production, the nature of transformation of edaphotopes at the sites studied differs (Malanchuk et al. 2016, Volnenko et al. 2017). The main soil-forming layers are the re-deposited fluvio-glacial deposits (moraines), on which podzolic and sod-podzolic weak- and medium-podzolic soils of light (sandy), rarely sandy loam, mechanical composition were formed. Most often, after the hydro-fluid, a secondary wetland is formed, with the upper horizons of the soil profile being washed away, overlapping with a slurry solution. In the case of amber mining, the site has an uneven micro-relief, covered with pits; the upper horizons of the soil profile are mixed with clay layers and siltstones, fluvio-glacial deposits, moraine.

The vegetation is dominated by fresh pineta (pure Scots pine forests) and subors (Scots pine forests with an additional tree stratum), as well as dry (lichen) pinetum sand oligotrophic and mesotrophic marshes. The main forest-forming species is *Pinus sylvestris* L. with an admixture of *Betula pendula* Roth. Such species as *Betula pubescens* Ehrh., *Quercus robur* L., *Populus tremula* L., and *Alnus glutinosa* (L.) Gaertn, tend to occur in relief depressions.

Materials and Methods

In amber mining sites, vegetation studies were carried out using phytosociological methods (Mueller-Dombois and Ellenberg 2002).

Vegetation was studied on 100 m^2 sample plots. The cover abundance score of all vascular plants was recorded using a 6-point Braun-Blanquet's scale (Braun-Blanquet 1964). The adopted taxonomic concept of species corresponds to the checklist of species of Ukraine (Mosyakin and Fedoronchuk 1999). Classification of species relative to Braun-Blanquet's classes follows the EuroVegChecklist (Mucina et al. 2016).

Further analysis of phytosociological data was carried out in two main directions – with the combined species composition, i.e. partial flora (here in after referred to as 'flora'), and considering the individual relevés and their clusters, similar in terms of habitat and type of vegetation.

Additional list of species of relevés was analyzed in order to establish the structure of the partial flora. Species composition of relevés was mainly used for phytoindicational assessment of habitats (Ellenberg et al. 1991, Didukh 2011).

The floristic composition was analyzed using the ratio of the species groups under various classification systems of species – taxonomical, biomorphological, phytosociological etc. It led to a derivation of different structures, including taxonomic groups of a higher rank (systematic structure of partial flora); considering plant life forms (Raunkiaer 1937); by the proportions of diagnostic species of different classes of vegetation (Braun-Blanquet 1964).

The calculations of the ratios of species (spectra) were performed by two quantitative approaches: an unweighted and a weighted one. In the unweighted case, the calculation is based only on frequencies of species without taking into account their different coenotical role (cover and abundances). In a weighted approach of calculations by formula (1), the ratios were accounted using the phytocoenotic activity index of species (*PAI* for short), which is an arithmetic mean of the relative occurrences of species and its average abundance in relevés where species are present.

$$PAI = \frac{\frac{\sum freq}{N} + \frac{\sum \log_2(abund)}{N_p}}{2}, \qquad (1)$$

where: *PAI* – the index of phytocoenotic activity, *freq* – frequency of species, *N* – total number of relevés, *abund* – abundance of species, expressed in percentages, N_p – number of relevés in which species occurs.

The index of *PAI* takes into account two main indicators that characterize the behaviour of the species–frequency and abundance. The latter characterizes the environment-forming ability of species and depends on population and coenotic characteristics. Most important of them are the degree of matching the amplitude (optimum) of species and habitat conditions, the reproductive efficiency of species, type of its renewal, the biotic interfering potential, the adaptive strategy. Thus, the *PAI* is a combined (integrating) indicator of species success in real conditions.

Assessment of habitats was carried out using a well-proved phytoindication approach (Ramensky et al. 1956, Ellenberg et al. 1991, Didukh 2011). The choice of this method was motivated, firstly, by the need for a quick screening assessment of habitats of a significant area, as well as the need to generalize and scope the 'long-term' changes in vegetation. Phytoindication does not replace, but supplements the direct instrumental methods, and provides an integral measurement tool since vegetation reflects environmental conditions as a years-averaged generalized trend (Goncharenko 2017).

Ecological scales of 9 factors were used for phytoindicational calculations: *Hd* (soil moisture), *Rc* (soil acidity), *Tr* (total salt regime of soils), *Nt* (content of nitrogen compounds), *Lc* (general light regime), *Tm* (climate), *Kn* (continentality), *fH* (variability of moisture), *Ca* (calcium content) (Didukh 2011). In addition, to quantify the anthropogenic transformation, we used the scales related to anthropogenic impact measuring: *Hm* (hemeroby) (Frank and Klotz 1990) and *Nv* (naturalness index) (Borhidi 1995). For comparability of scores on various factors, the values in phytoindicational scales were standardized to a single 100-point scale before calculations.

The results of phytoindication were used for the numerical classification of habitats. To achieve this, the hierarchical cluster analysis was carried out with the distance matrix based on the Euclidean distance using standardized data and the Ward's agglomeration method, which is often used due to the formation of compact clusters and the insusceptibility of a chaining phenomenon (Granato and Ares 2013). The use of phytoindication scores for cluster analysis was motivated by the main task of classifying the habitats, not the vegetation itself. The optimal number of clusters was determined by the maximization of the Calinski-Harabasz criterion (Halkidi et al. 2001).

To understand the interrelations between environmental parameters the phytoindication results matrix was subjected to principal component analysis. Although environmental factors in phytoindication are postulated as orthogonal (independent) from each other, correlations between them are usually found (Didukh and Plyuta 1994). It is explained by two reasons – an integrating nature of the reaction of plants to environment and the mutual conjugation from hidden factors, for example anthropogenic pressure.

The degree of anthropogenic transformation of vegetation was assessed based on several criteria: share of therophytes, ratio of diagnostic species of synanthropic classes, as well as number of adventive species. Measuring anthropogenic transformation of vegetation using phytoindication techniques have been discussed in detail (Goncharenko 2017). To determine environmental factors by which differences in the stated group of relevés were the most significant, we applied the Student's t-test of comparing means.

All calculations were processed in R software (CRAN 2019). The following libraries were used: tmap (Tennekes 2018) – for mapping, fpc (Hennig 2019) – for cluster validation, vegan (Oksanen et al. 2018) – for pre-transforming data, dendextend (Galili 2015) – when working with dendrograms, as well as popular universal libraries (reshape2 (Wickham 2007), ggplot2 (Wickham 2016) and packages built into the R (hclust – hierarchical cluster analysis, prcomp – principal component analysis).

Results and Discussions

Taxonomic structure of the partial flora

The total species composition of relevés consists of 111 species belonging to 80 genera and 30 families, so the ratio between them equals 1/1.39/2.67. Figure 2 presents the taxonomical relations taking into account the first most numerous 10 families. Two histogram columns are given for each family – the first column based

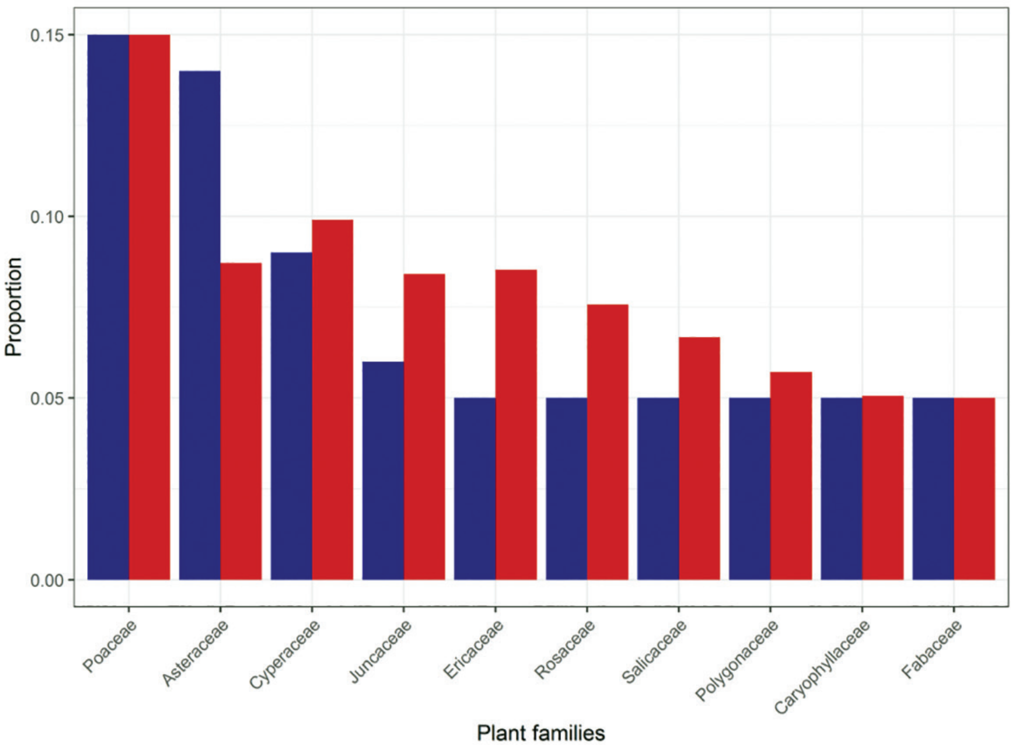

Fig. 2. Taxonomic ratios of species of 10 leading families in the joint species composition of relevés.

only on the number of species, the second one takes into account the *PAI* index (see Materials and methods).

As can be seen, the leading positions belong to the families of Poaceae and Asteraceae. When comparing the obtained ratios with those typical for the flora of Ukraine, the fact draws attention that Poaceae comes first; while in the flora of Ukraine (Zaveruha 1985, Mosyakin and Fedoronchuk 1999), as in most floras of temperate regions, Asteraceae is usually leading. This is connected with the restoration of the vegetation, which starts with a stage of intense sodding in the given climatic conditions with grasses playing a major role. High positions of the families Cyperaceae and Juncaceae (3rd and 4th, respectively) and Salicaceae (7th) are characteristic for northern floras with most of their species being meso-hydrophytes. On the contrary, the lowering of Fabaceae to the 10th place also characterizes the studied flora as being of northern type because Fabaceae is more typical for southern floras, for example, flora of Pivnichne Prychornomoria (Moysiyenko 2013).

If we take into account the *PAI* index of species, the differences in taxonomic rations are considered to be significant for some families. For example, although Asteraceae is represented by numerous species, their phytocoenotic role is not quite high. Conversely, both indicators equal to 0.15 and are maximal for Poaceae. In six families (Cyperaceae – Polygonaceae, see Fig. 2), the opposite trend is observed. Distribution when *PAI* index is considered gives higher scores than when based only on the species diversity. The phytocenotic activity of members of Cyperaceae and Juncaceae species is also high due to favourable hydrophilic and acidophilic condition prevail. It was also found that the distribution of frequency classes of species is skewed. For example, only 4.5 % of species occur in more than half of relevés (Table 2), among them, the tree species (*Pinus sylvestris*, *Betula pendula*) and perennial herbaceous species (*Chamerion angustifolium* (L.) Holub, *Juncus effusus* L., *Molinia caerulea* (L.) Moench).

Table 2. Distribution of frequency classes of species in the plant communities studied.

Frequency of occurrence	Number of species	Percentage, %
High (≥50 %)	5	4.5
Medium (25–49 %)	13	11.7
Low (10–24 %)	45	40.5
Very low (<10 %)	48	43.2
Total:	111	100.0

Species that are widespread (recorded in 25–49 % of relevés) belong to different plant life forms, including trees – *Populus tremula*, shrubs – *Frangula alnus* Mill., *Rubus caesius* L., *Sorbus aucuparia* L., bushes – *Vaccinium myrtillus* L., perennial herbs – *Calamagrostis arundinacea* (L.) Roth, *Carex echinata* Murr., *C. leporina* L., *C. nigra* (L.) Reichard, *Phragmites australis* (Cav.) Trin. ex Steud., *Pteridium aquilinum* (L.) Kuhn, *Rumex acetosella* L., *Veronica officinalis* L.

Biomorphological structure of the partial flora

Figure 3 shows the relationships between the quantities of species of different Raunkiaer's life forms. Two indicators are presented (in columns): the first one is calculated only by number of species of each life form class, and the second one reflects the phytocoenotical role of species of various life forms.

As can be seen, the prevailing life form according to both criteria is that of hemic-

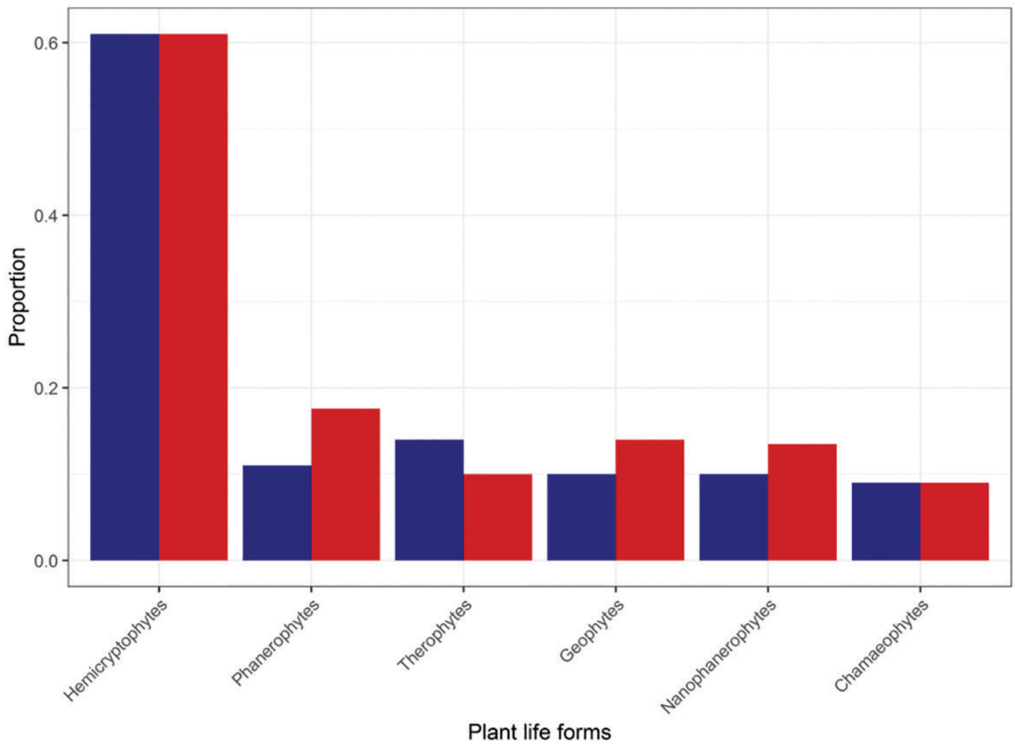

Fig. 3. The ratio of species of different life forms (according to the Raunkiaer's classification) of the partial flora investigated.

ryptophytes. This can be explained by the fact that this life form combines species with a relatively high degree of tolerance to anthropogenic impact of medium intensity. Most hemicryptophytes are stable unless the soil profile is completely destroyed, and they are more plastic than phanerophytes under such conditions. The phanerophytes keep second position. With the *PAI* index taken into account, their role is higher, which is explained by the intensive environment-forming ability of species of this life form.

Therophytes occupy the 3rd place (Fig. 3) and this is of diagnostic importance in relation to anthropogenic transformation of the studied communities. They express explerent reproductive strategy (Whittaker 1980, Zlobin 2009), having low competitive ability in undisturbed conditions, but quickly capture the vacated territories. This is an obvious consequence and an indicator of the degree of anthropogenic transformation of the studied plant communities. The ranks in the spectrum of other life forms (geophytes, nanophanerophytes, and chamaephytes) correspond to their role in forest vegetation. In general, the biomorphological structure is of 'forest' type, but enriched with hemicryptophytes, which is the result of meadow-type succession, and with therophytes due to anthropogenic disturbances.

Phytosociological structure

Figure 4 presents the ratios of diagnostic species of different vegetation classes.

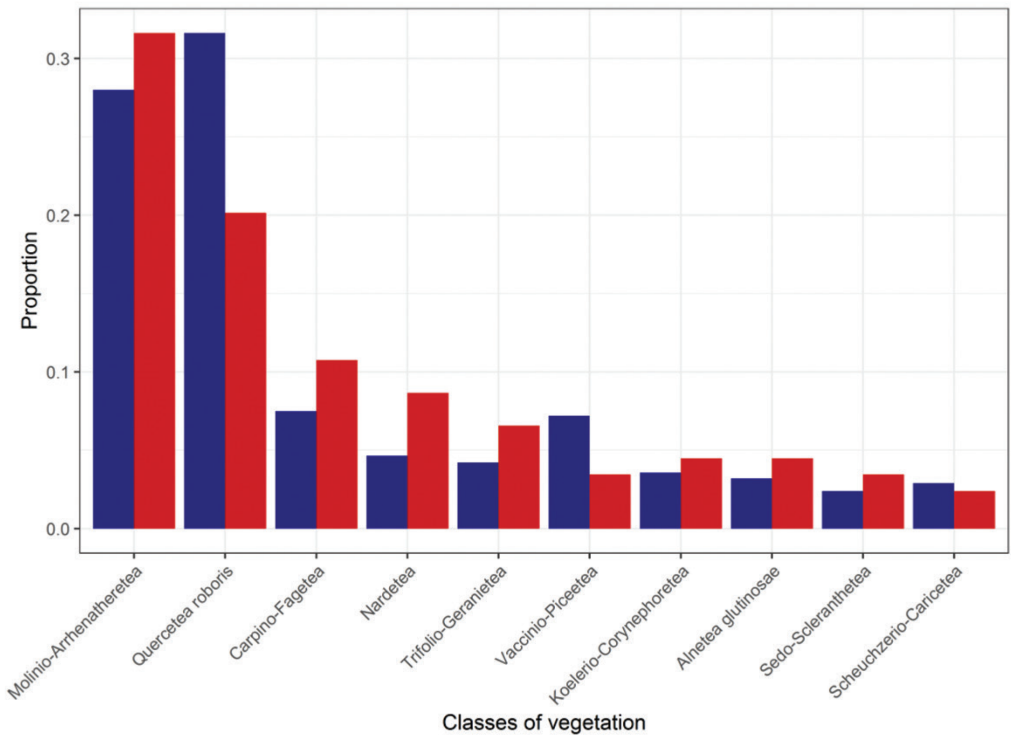

Fig. 4. Distribution of species belonging to different classes of vegetation.

Since most species are not confined to the only class of vegetation, they were accounted for each class for which they are considered to be diagnostic.

As can be seen, two classes *Molinio-Arrhenatheretea* and *Quercetea robori-petraeae* occupy leading positions in the phytosociological spectrum. *Quercetea robori-petraeae* dominates in the number of species, but *Molinio-Arrhenatheretea* is in first place taken into account the *PAI* index of species. At the current stage of restoration, meadow species predominate in abundance over the forest species. *Molinio-Arrhenatheretea* species are light-demanding and benefit also due to their plasticity and speed of growth. The occurrence of *Quercetea robori-petraeae, Carpino-Fagetea* and *Vaccinio-Piceetea* species is related to the pattern of surrounding vegetation. A significant number of species of acidophilic classes, including *Quercetea robori-petraeae*, *Nardetea*, *Scheuchzerio-Caricetea*, are explained by acidic and nutrient-poor soils. The positions of *Koelerio-Corynephoretea* and *Sedo-Scleranthetea* classes are associated with a light soil textures, which is favorable for the growth of psammophytes and form the core of these classes. In general, the distribution of species of different classes of vegetationis in good agreement with the type of primary vegetation which grew prior the start of disturbances.

Numerical classification of habitats

Figure 5 shows a dendrogram demonstrating the degree of similarity of habitats according to their assessment from the phy-

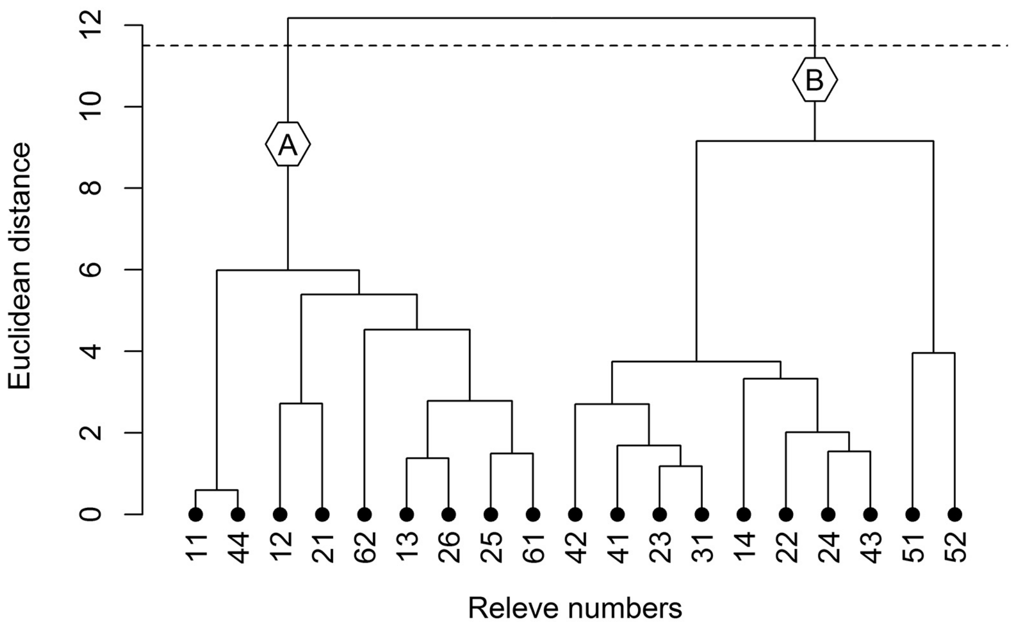

Fig. 5. Cluster analysis of habitats according to phytoindication scores of relevés.

Note: The first digit in relevé numbers indicate the geographic location of relevés and corresponds to the locality id (see map on Fig. 1).

toindication. Partitioning into two groups (clusters A and B) is considered optimal according to the Calinski-Harabasz criterion (see Materials and methods).

Table 3 presents the diagnostic (constant and differentiating) species of the vegetation studied. Species with a relative frequency in each of the clusters of at least 50 % were considered constant. Such species are common to both types of habitats. The list of differentiating species includes species with an affinity calculated by the Ochiai's coefficient of higher than 50 %.

Table 3. Constant and differentiating species of the two main types of habitats (see Fig. 5).

Cluster A	ClusterB
Betula pendula, *Chamerion angustifolium*, *Juncus effusus*, *Molinia caerulea, Pinus sylvest*ris	
Calamagrostis arundinacea, *Calluna vulgaris*, *Frangula alnus*, *Pteridium aquilinum*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Veronica officinalis*	*Calamagrostis epigeios*, *Carex echinata*, *Carex leporina*, *Corynephorus canescens*, *Oenothera biennis*, *Phragmites australis*, *Rubus caesius*

For example, cluster A comprises the sites which are related to pine and mixed forests on fresh podzolic soils, mainly with the dominance of *Vaccinium myrtillus*. Cluster B combines psammophytic communities with the dominance of *Corynephorus canescens*. Other species, for example, *Chamerion angustifolium,* *Oenothera biennis* are considered to be secondary and a consequence of fellings. Such species as *Juncus effusus, Calamagrostis epigeios, Phragmites australis* are components of surrounding natural vegetation but their abundances increased significantly after anthropogenic impact. The forest species, which are associated with the primary vegetation, prevail in the group of diagnostic species. Conversely, meadow, meadow-bog, and psammophytic species have appeared or changed their phytocoenotical role as a result of anthropogenic impact.

PCA structure of correlations of ecological factors

Figure 6 summarizes results of the principal component analysis based on the correlation matrix of phytoindication scores of relevés. Environmental factors are shown by arrows with the angles between them and the lengths indicating the contribution of individual factors to the first and second components (axes). Only the first two main components are shown because considering the remaining components is not relevant since the first two main axes

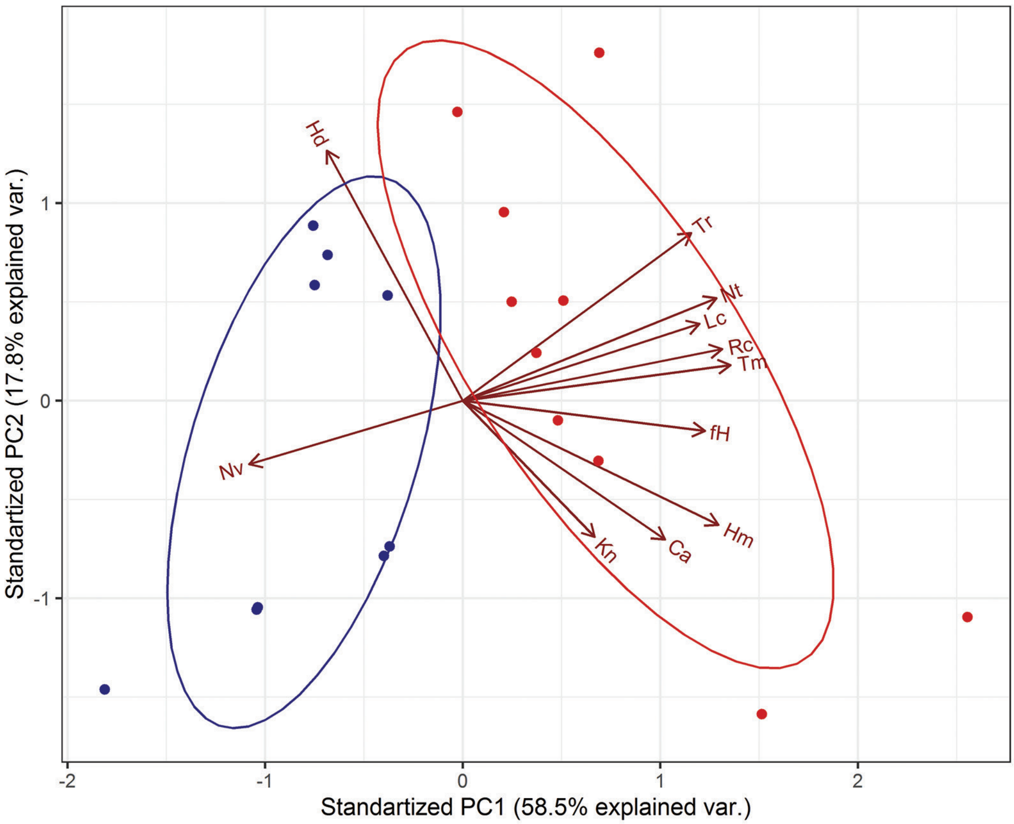

Fig. 6. Principal component analysis (PCA) of environmental factors based on the results of the phytoindicational assessment.

Note: Ellipses indicate two clusters of habitats: cluster A (left) and cluster B (right).

explain about ¾ (58.5 % + 17.8 %) of the total variation.

The first axis reflects more than half (58.5 %) of the total variation, and the second one contributes more than 3 times smaller (17.8 %). This indicates the significant multicollinearity, which is confirmed by the co-directionality of some vectors (*Tr*–*Kn*). It can be explained by two reasons. Firstly, the phytoindication data are derived from the one source – the phytocoenotical dataset. Secondly, large number of inter-correlations among the environmental factors that have been discovered is associated with the existence of a strong (limiting) factor to which vegetation mainly responds.

The factors related mainly to the first component belong to two major groups – edaphic (*Tr*, *Nt*, *Rc*) and anthropogenic (*Hm*, *Nv*). As for the second component, a connection with the humidity (*Hd*) is mainly manifested. The direction of vectors suggests that the habitats in cluster A should be interpreted as oligotrophic and acidophytic. Cluster B combines habitats of acidic and poor soils too, which is typical for Polissya as a whole, but inferior to cluster A in these indicators. The difference in the group means is significant, which will be shown further in the text.

Significant contribution to the PCA model of the anthropogenic factors (*Hm*, *Nv*) is confirmed by a large amount of variation explained by the first axis. In addition to a direct effect on vegetation, the anthropogenic factors also modulate other factors, for example, edaphic ones. Anthropogenic impact, direct (as a result of mining activity) or indirect (through the disturbance of vegetation), potentiates changes in the water and mineral regimes of soils, the intensity of the podzolic process, the rate of decomposition (mineralization) of the litter.

In general, the revealed strong correlations characterize the studied habitats as a marginal (evasive) type. Taking into account the worse ability of vegetation to recover in rather discouraging conditions, a prediction for possibility of demutational succession of studied plant communities is unfavorable.

Phytoindicational comparing of two types of habitats of amber mining sites

Figure 7 shows the distributions of main phytoindication variables, including edaphic (*Hd*, *Tr*, *Rc*, *Nt*), light value (*Lc*), and naturalness index (*Nv*), between two types of habitats (see Fig. 5, clusters A and B).When choosing factors for the analysis, we focused on the selection of factors of different nature, describing soil, light and anthropogenic conditions.

As can be seen, the differences for most factors, except humidity (*Hd*), are significant at $p<0.05$. The largest difference is observed for the nitrogen (*Nt*) (p=2.1e-05), with the cluster A corresponding to soils poor in nitrogen compounds. At the same time, the habitats are acidophytic and oligotrophic, with significant differences in these indicators from the cluster B. Cluster A relates to the primarily forested sites which results in lower *Lc* values and the preservation of many forest species as *Pteridium aquilinum*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Veronica officinalis* (see Table 3). And the naturalness index (*Nv*) of relevés of cluster A is higher and significantly different from the cluster B. The cluster B is quite heterogeneous phytocoenotically. It combines secondary vegetation types, which were formed after at least two different types of primary natural vegetation types. They are the psamophytic and xe-

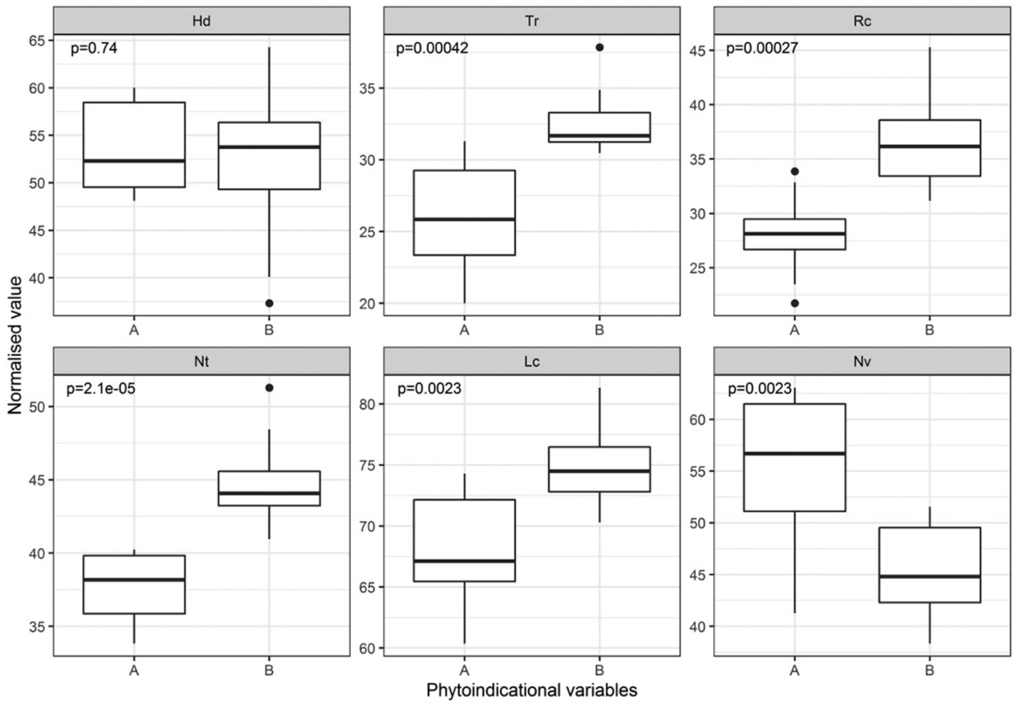

Fig. 7. Distribution of phytoindicational scores in two groups of habitats (clusters A and B, see Fig. 5).

Note: The t-test significance level is denoted bythe *p*-value (abbreviated *p*).

rophytic communities with the dominance of *Corynephorus canescens* and the pine and pine-birch forests with *Molinia caerulea* dominating in the herbaceous layer as well.

Anthropogenic transformation of vegetation

Amber mining activity started in 2014 in all studied localities, i.e. there is reason to measure and observe the anthropogenic changes in vegetation over a 5-year period. Some of the manifestations of anthropogenic impact, such as an increase in the proportion of therophyte sand others, were also mentioned. The relation of the anthropogenic-mediated factors (*Hm*, *Nv*) to the first PCA axis testifies their significant influence on the studied vegetation. The taxonomic structure of the flora as a whole is one of the most conservative indicators, so we did not find any anthropogenic-associated changes in it. Phytosociological structure is also similar to surrounding natural vegetation. However, estimates of anthropogenic transformation will not be optimistic if we take into account the share of synanthropic species with 30 species out of 111 being synanthropic. Therefore, the background synanthropization is 27 % which is quite high. The share of adventitious species equals 10 %, which is also a high level of anthropogenic transformation. Among adventitious species, there is a significant number of kenophytes (*Robinia pseudoacacia*, *Bidens frondosa*, *Phalacroloma* *annuum*, *Oenothera biennis*, *Kochia scoparia*, *Conyza canadensis*) (Protopopova 1991, Mosyakin and Yavorska 2002), and their presence can be explained only by anthropogenic influence. Archaeophytes (*Xanthium strumarium*, *Scleranthus annuus*, *Lactuca serriola*, *Fallopia convolvulus*, *Ballota nigra*) are also found, but in pine forests, they are alien sand also secondary.

We also stated a relative enrichment the species compositions of relevés with nitrophilous species. In particular, such species as *Fallopia convolvulus*, *Ballota nigra*, etc., are characteristic of richer soils and their occurrence on poor sandy soils in the study area can be explained by the relative enrichment of soils with this important nutrient not caused by of the external flow, but due to the accelerated mineralization in case of disturbance of the forest ecosystems. This promotes the growth of nitrophilous species in such poor-sandy conditions (Goncharenko 2017).

In the vegetation we studied, the enhanced growth of *Juncus effusus* is obviously associated with its nitrogen fixing ability (Stewart 1977, Halda-Alija 2003). This species has a dense root system, favorable for the settlement of nitrogen-fixing bacteria. This specific feature in combination with humid conditions in the studied sitesisone of the main reasons for the formation of communities where *Juncus effusus* is dominating in amber mining sites. Such species as *Carex echinata* and *C. leporina*, having similar ecological requirements are usually co-growing with *Juncus effusus.*

In case of grazing conditions or the formation of tall-meadow communities, the undergrowth of trees will have competitive relations with herbaceous species. They last with higher level of plasticity and speed of growth are likely to have advantages in comparison with trees. Therefore, the current intensive growth of meadow and meadow-bog species in amber-mining abandoned territories will most likely negatively affect the ability of tree species to recover naturally.

Conclusions

In the present study, we examined the structure of vegetation and habitats after amber mining works.

The phytoindicational description of habitats was given and two principal groups of them that are now prevalent in the abandoned areas were established.

Multiparametric analysis of anthropogenic changes in vegetation showed that different features of the habitat are transformed at different speeds and are at different stages of restoration processes currently. For example, the taxonomic structure of the studied flora has preserved its natural features and is typical for most northern floras. Biomorphological structure is also preserved and has natural features, but we noted an increase in the share of therophytes, which is a definite sign of anthropogenic changes. The phytosociological structure is also ambivalent in terms of anthropogenic changes. On the one hand, synanthropic classes of vegetation were not found among the top 10 classes of the phytosociological spectrum. On the other hand, the total number of synanthropic species (not taking into account vegetation classes) was 27% and the share of adventitious species was 10%, both of which are quite high in terms of anthropogenic transformation. The correlative structure of the phytoindicational scores matrix, as well as the subdivision habitats into two types, is more relevant to natural features, as the two clusters of habitat types and their differentiating species are in a stronger agreement with the natural vegetation types that existed prior to illegal amber mining activity.

In general, given that, the ability of vegetation to recover under conditions far from optimal decreases (especially when moving to the north), this worsens the prognosis of the potential recoverability of the vegetation examined in this study and arising in the place and as a result of amber mining. However, among the factors favoring the natural course of restoration, one can name the remoteness from large settlements and the relatively high preservation of the surrounding forests, which creates the potential for the secondary resettlement of forest species from adjacent territories. In any case, remediation measures and monitoring of succession changes in the longer term are appropriate.

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References

Alkama R., Cescatti A. 2016. Biophysical climate impacts of recent changes in global forest cover. Science 351(6273): 600–604.

Alekseyevsky V. (Ed.), Bakhmachuk Yu. 1992. Environmental aspects of land reclamation in Volyn. Lutsk–Kiev: Lybid. 235 p.

Beresford N.A., Fesenko S., Konoplev A., Skuterud L., Smith J.T., Voigt G. 2016. Thirty years after the Chernobyl accident: What lessons have we learnt? Journal of Environmental Radioactivity 157: 77–89. Available at: http://dx.doi.org/10.1016/j.jenvrad.2016.02.003

Borhidi A. 1995. Social behaviour types, the naturalness and relative ecological indicator values of the higher plants in the Hungarian flora. Acta Botanica Hungarica 39(1–2): 97–181.

Bozhok P. 1976. Development of works on drainage of land in Zhytomyr region. Scientific works of the Ukraine Agricultural Academy 173: 3–12.

Braun-Blanquet J. 1964. Pflanzen soziologie. Grundzuge der Vegetationskunde. New York, Springer-Verlag, Wien. 865 p.

CRAN 2019. The Comprehensive R Archive Network. Available at: https://cran.r-project.org/

Didukh Ya.P. 2011. The ecological scales for the species of Ukrainian flora and their use in synphytoindication. Kyiv, Phytosociocentre. 176 p.

Didukh Ya.P., Plyuta P.G. 1994. Phytoindication of ecological factors. Kyiv, Naukova dumka. 280 p. (in Ukrainian).

Ellenberg H., Weber H.E., Dull R., Wirth V., Werner W., Paulisen D. 1991. Zeigerwerte von Pflanzen in Mitteleuropa. In: Scripta Geobotanica, Verlag Erich Goltze KG, Göttingen: 248.

Frank D., Klotz S. 1990. Biologisch-Ökologische Daten Zur Flora der DDR. 2 Edn. Martin-Luther-Universität Halle-Wittenberg, Halle. 167 p. (in German).

Filipovich V.E. 2015. Satellite monitoring for the areas of illegal extraction of amber. Ukrainian journal of remote sensing 6: 4–7 (in Ukrainian with English summary).

Filipovich V.E., Shevchuk R.M. 2016. The methodology and technology assessment of damage caused by ukrainian government as a result of illegal extraction of amber. Ukrainian journal of remote sensing 11: 15–21 (in Ukrainian with English summary).

Galili T. 2015. dendextend: an R package for visualizing, adjusting and comparing trees of hierarchical clustering. Bioinformatics 31(22): 3718–3720. DOI: 10.1093/bioinformatics/btv428 URL: Available at: https://academic.oup.com/bioinformatics/article-lookup/doi/10.1093/bioinformatics/btv428 (Accessed January 16, 2020).

Goncharenko I.V. 2017. Phytoindication of anthropogenic factor. Dnipro. 127 p. (in Ukrainian).

Gordeychuk M.V. 2013. Effect of extraction of the natural landscape of amber Rivne. Physical Geography and Geomorphology 2(70): 259–262 (in Ukrainian).

Granato D., Ares G. 2013. Mathematical and statistical methods in food science and technology. Wiley Blackwell, Chichester, West Sussex, UK ; Hoboken, NJ. 536 p.

Halda-Alija L. 2003. Identification of indole-3-acetic acid producing freshwater wetland rhizosphere bacteria associated with *Juncus effusus* L. Canadian journal of microbiology 49(12): 781–787.

Halkidi M., Batistskis Y.,Vazirgiannis M. 2001. On clustering validation techniques. Journal of Intelligent Information Systems 17(3): 107–145.

Hennig C. 2019. fpc: Flexible Procedures for Clustering. R package version 2.2-3.

Kazymyr M.M., Bedernichek T.Y. 2017. Reclamation of land violated due to extraction of amber in Polissia: problems and prospects. Environmental Economics: State, Problems, Prospects / EPA-2017 13 – March 20, 2017, UFSU, Irpin: 90–94 (in Ukrainian).

Khomyak I., Demchuk N., Vasylenko O. 2018. Phytoindication anthropogenic transformation of ecosystems on the example of Ukrainian Polissya. Biodiversity conservation research journal 3(22): 113–118 (in Ukrainian).

Kovalevsky S.B., Marchuk Yu.M., Mayevsky K.V., Kurdyuk O.M. 2017. The Scope and Consequences of Illegal Amber Extraction on Lands of Zhytomyr RDFH. Scientific Bulletin of UNFU 27(10): 69–72 (in Ukrainian with English summary). Available at: https://doi.org/10.15421/40271011

Kovalevsky S.B., Marchuk Yu.M., Mayevsky K.V., Kurdyuk O.M. 2019. Succession processes on the territories disrupted due to illegal amber mining of Zhytomyr Regional Forestry and Hunting administration. Ukrainian Journal of Forest and Wood Science 10(2): 26–40 (in Ukrainian with English summary).

Kovalevskyi S.B., Kovalevskyi S.S. 2019. Amber fossils: history of study, methods of getting and effect on forest ecosystems. Scientific Bulletin of UNFU 29(3): 56–59 (in Ukrainian with English summary). Available at: https://doi.org/10.15421/40290312

Krasovskyi H.Ya., Shumeiko V.O., Klochko T.O., Sementsova N.I. 2018. Information technologies for monitoring the environmental consequences of amber production in Ukraine. Scientific and technical journal 'Ecological Safety and Balanced Use of Resources' 2(18): 107–117 (in Ukrainian with English summary). DOI: 10.31471/2415-3184-2018-2(18)-107-117

Lehkyi V.V., Kovalevskii S.B. 2018. Typological estimation of forest massif of Dubrovytskyi forestry disturbed by unauthorised extraction of amber. Scientific Bulletin of UNFU 28(8): 61–64 (in Ukrainian with English summary). Available at: https://doi.org/10.15421/40280812

Malanchuk Z., Korniyenko V., Malanchuk Ye., Khrystyuk A. 2016. Results of experimental studies of amber extraction by hydromechanical method in Ukraine. Eastern-European Journal of Enterprise Technologies 3/10(81): 24–28. DOI: 10.15587/1729-4061.2016.72404

Masley V.M., Mozgovoy D.K., Bilousov K.G., Horoshilov V.S., Bushanska O.S., Galich N.G. 2016. Methods of the impact evaluation of amber mining by multispectral satellite images. Space Science & Technol 22(6): 26–36 (in Russian with English summary). DOI: https://doi.org/10.15407/knit2016.06.026

McGrath M.J., Luyssaert S., Meyfroidt P., Kaplan J.O., Bürgi M., Chen Y., Otto J. 2015. Reconstructing European forest management from 1600 to 2010. Biogeosciences 12(14): 4291–4316.

Melnychuk V.H., Krynytska M.V. 2018. Amber of Polissya (Handbook). Rivne, NUVHP. 236 p. (in Ukrainian).

Mosyakin S.L., Fedoronchuk M.M. 1999. Vascular plants of Ukraine. A nomenclatural checklist. M. S.L. (Ed.). Kyiv, M.G. Kholodny Institute of Botany. 345 p.

Mosyakin S.L.,Yavorska O.G. 2002. The non native flora of the Kiev (Kyiv) urban area, Ukraine: a checklist and brief analysis. Urban habitats 1(1): 45–65.

Moysiyenko I.I. 2013. Floristic richness and taxonomic structure of the flora of Pivnichne Prychornomoria (Northern Black Sea Coastal Plain). Chornomorskyi Botanichnyi Zhurnal 9(1): 41–56 (in Ukrainian with English summary).

Mucina L., Bültmann H., Dierssen K., Theurillat J.-P., Raus T., Čarni A., Šumberová K., Willner W., Dengler J., García R.G., Chytrý M., Hájek M., Di Pietro R., Iakushenko D., Pallas J., Daniëls F.J.A., Bergmeier E., Santos Guerra A., Ermakov N., Valachovič M., Schaminée J.H.J., Lysenko T., Didukh Y.P., Pignatti S., Rodwell J.S., Capelo J., Weber H.E., Solomeshch A., Dimopoulos P., Aguiar C., Hennekens S.M., Tichý L. 2016. Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities R. Peet (Ed.). Applied Vegetation Science 19(S1): 3–264. DOI: 10.1111/avsc.12257

Mueller-Dombois D., Ellenberg H. 2002. Aims and methods of vegetation ecology. Reprint. New Yersey, The Blackburn Press. 547 p.

Oksanen J., Blanchet F.G., Friendly M., Kindt R., Legendre P., McGlinn D., Minchin P.R., O'Hara R.B., Simpson G.L., Solymos P., Stevens M.H.H., Szoecs E., Wagner H. 2018. Vegan: Community Ecology Package. R package version 2.4-6. Available at: https://CRAN.R-project.org/package=vegan (Accessed September 21, 2018).

Onyshchenko V. 2017. Habitats of Ukraine according to the EUNIS classification. Kyiv, Phytosociocentre. 56 p. (in Ukrainian).

Protopopova V.V. 1991. The synanthropic flora of Ukraine and its ways of development. Kyiv, Naukova dumka. 202 p. (in Ukrainian).

Ramensky L.G., Tsatsenkin I.A., Chizhikov O.N., Antipin N.A. 1956. Ecological assessment of forage land by vegetation. Moskva, Selhozgiz. 472 p. (in Russian).

Raunkiaer C. 1937. Plant life forms. Oxford, Clarendon Press. 104 p.

Shevchuk R.M. 2017. Verification of results of satellite monitoring of territories of illegal amber mining. Environmental safety and natural resources 3–4(24): 133–137 (in Ukrainian).

Stewart W.D. 1977. Present-day nitrogen-fixing plants. Ambio: 166–173.

Tennekes M. 2018. tmap: Thematic Maps in R. Journal of Statistical Software 84(6) DOI: 10.18637/jss.v084.i06 URL: http://www.jstatsoft.org/v84/i06/ (Accessed January 16, 2020).

Volnenko S., Mel'nichuk G., Kurepa Y., Mamchur S. 2017. Extra stocking methods of amber in the Ukrainian Polesie. Journal of Donetsk Mining Institute 1(40): 118–122 (in Ukrainian with English summary).

Whittaker R.H. 1980. Communities and ecosystems. Russian translation ed. Moskva, Progress. 327 p.

Wickham H. 2007. Reshaping Data with the reshape Package. Journal of Statistical Software 21(12): 1–20.

Wickham H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. 216 p.

Yablokov A.V., Nesterenko V.B., Nesterenko A.V., Sherman-Nevinger J.D. 2010. Chernobyl: Consequences of the Catastrophe for People and the Environment. New York: John Wiley and Sons. 400 p.

Yanchuk R., Prokopchuk A., Trohimets S. 2017. Identification and definition of the areas disturbed by mining amber lands based on multispectral satellite imagery Sentinel–2. Suchasni dosiahnennia heodezychnoi nauky ta vyrobnytstva 1(33): 120–124 (in Ukrainian with English summary).

Zanon M., Davis B.A.S., Marquer L., Brewer S., Kaplan J.O. 2018. European forest cover during the past 12,000 years: a palynological reconstruction based on modern analogs and remote sensing. Frontiers in plant science 9: 253:1–25. DOI: org/10.3389/

fpls.2018.00253
Zaveruha B.V. 1985. Flora of Volino-Podolii and its genesis. Kyiv, Naukova dumka. 190 p. (in Ukrainian).
Zlobin Yu.A. 2009. Population ecology of plants: the current state, the points of growth. Universitetskaia Kniga. Sumy. 263 p. (in Russian).