
ECOLOGICAL-COENOTIC DIFFERENTIATION OF SYNTAXA OF THE CLASS *CARPINO-FAGETEA SYLVATICAE* OF THE LEFT-BANK FOREST-STEPPE OF UKRAINE ACCORDING TO PHYTOINDICATION PARAMETERS

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INTRODUCTION

Forest vegetation of the *Carpino-Fagetea sylvaticae* class is one of the leading components of the natural ecosystems of the Left-Bank Forest-Steppe of Ukraine¹. This class unites groups of moderately humid and humid broad-leaved and mixed forests, which are formed under conditions of sufficient moisture, developed soil cover and relatively stable microclimate. Within the region, such forests are confined mainly to well-drained floodplain terraces and elevated relief elements, where natural conditions contribute to the development of nemoral woody vegetation². They play an important role in shaping the landscape structure and ensuring ecosystem functions, in particular regulating the water regime, maintaining soil fertility and stabilizing microclimatic conditions³.

At the same time, long-term anthropogenic impact has significantly transformed most of the forest communities of the *Carpino-Fagetea sylvaticae* class in the Left-Bank Forest-Steppe. Forest use, changes in the hydrological regime, development of territories and recreational load have led to the fragmentation of phytocenoses and disruption of their species-coenotic organization. Under such conditions, the study of ecological factors that determine the conditions for the formation, differentiation and stability of forest syntaxa of the region becomes particularly relevant.

¹ Фельбаба-Клушина Л. М. Прогномус рослинності України : монографія. Київ : Наук. думка, 2019. 782 с.

² Гончаренко І. В. Аналіз рослинного покриву північно-східного Лісостепу України. *Укр. фітоценол. зб. Сер. А.* 2003. Вип. 1 (19). С. 1–203.

³ Оптимізація екологічних функцій, територіального розподілу, використання та охорони пользахисних лісових смуг агросфери України (стан, структура, репрезентативність, фітострома) : метод. рек. / В. В. Коніщук та ін. Київ : Agroecology and Environmental Management NAAN, 2024. 82 с. DOI: <https://doi.org/10.33730/978-617-7785-61-2>

In addition to their high cenotic and floristic diversity, forest communities of the *Carpino-Fagetea sylvaticae* class are characterized by pronounced ecological heterogeneity, which is reflected in the variability of edaphic, hydrological and microclimatic conditions within the Left-Bank Forest-Steppe. Gradients of soil moisture, trophicity and aeration, combined with differences in relief position and groundwater depth, determine a wide spectrum of habitat conditions and, consequently, a significant differentiation of forest syntaxa. This ecological variability creates preconditions for the coexistence of forest communities with different ecological strategies and levels of tolerance to environmental factors, making the class a convenient model for studying patterns of ecological differentiation and stability of nemoral forest vegetation.

Phytoindication methods are an effective tool for analyzing the ecological conditions for the formation of vegetation and have been widely used in geobotanical studies of the Left-Bank Forest-Steppe since the early 1990s. The development of this direction in Ukraine is associated with the works of Ya.P. Didukh⁴ and his scientific school, within which the theoretical and methodological foundations of synphytoindicative research of forest vegetation were laid^{5,6}. Further work has demonstrated the informativeness of phytoindication scales for assessing the role of edaphic and climatic factors in the differentiation of forest communities of both natural and anthropogenically transformed origin^{7,8}.

Modern research has significantly expanded the range of phytoindication analysis objects, covering various types of forest stands, including artificial and secondary groups characteristic of the forest-steppe zone^{9, 10, 11}.

⁴ Дідух Я. П., Пліота П. Г. Фітоіндикація екологічних факторів. Київ : Наук. думка, 1994. 280 с.

⁵ Дідух Я. П. Методологічні підходи до проблем фітоіндикації екологічних факторів. *Укр. ботан. журн.* 1990. Т. 47, № 6. С. 5–12.

⁶ Дідух Я. П., Єшманов Д. Г., Школьніков Ю. А. Використання фітоіндикаційних оцінок при вивченні структури лісових екосистем. *Укр. ботан. журн.* 1997. Т. 54, № 1. С. 47–56.

⁷ Вакал А. П., Дідух Я. П. Фітоіндикаційна характеристика природних умов околиць міста Суми. *Укр. ботан. журн.* 1991. Т. 48, № 5. С. 57–61.

⁸ Гончаренко І. В. Рослинність заказника «Підліснівський» (Сумська область) та її фітоіндикаційний аналіз. *Укр. фітоценол. зб. Сер. С : Фітоєкологія.* 2003. Вип. 1 (20). С. 98–102.

⁹ Голик Г. М., Гончаренко І. В. Синтаксономія деревної рослинності м. Києва, її синфітоіндикаційний аналіз та антропогенна трансформація. *Екологія та ноосферологія.* 2017. Т. 28, № 1–2. С. 49–63.

¹⁰ Goncharenko I. V., Solomakha I. V., Shevchuk V. L. et al. A phytoindicational assessment of the vegetation of afforestation belts in the Middle Dnipro Region, Ukraine. *Environmental & Socio-economic Studies.* 2022. Vol. 10 (2). P. 30–39. DOI: <https://doi.org/10.2478/enviro-2022-0009>

¹¹ Бондарук М. А., Целіщев О. Г. Фітоіндикація едафічних режимів екотопів лісових екосистем Лівобережно-Дніпровського лісостепового округу України. *Лісівництво і агролісомеліорація.* 2018. Вип. 132. С. 94–104. DOI: <https://doi.org/10.33220/1026-3365.132.2018.94>

The results obtained indicate the decisive influence of soil and climatic regimes on the ecological differentiation of forest syntaxa, however, most of the available works are focused on individual local territories or narrow groups of phytocenoses.

In this regard, it is relevant to conduct a comprehensive ecological-coenotic analysis of syntaxa of forest vegetation of the *Carpino-Fagetea sylvaticae* class within the Left-Bank Forest-Steppe of Ukraine using phytoindication approaches. Such studies contribute to the clarification of the ecological amplitudes of forest communities, deepening the understanding of their spatial-ecological differentiation and creating scientific prerequisites for substantiating measures for the conservation and rational management of forest ecosystems in the region.

The aim of this study is to perform hierarchical clustering of syntaxa of the *Carpino-Fagetea sylvaticae* class of the Left-Bank Forest-Steppe of Ukraine based on phytoindication parameters and further analysis of the obtained dendrogram in order to identify the structure of their ecological differentiation. The main attention is paid to the interpretation of the dendrogram as an integral reflection of the similarity of syntaxa according to the set of soil-hydrological and climatic factors, to determine the optimal number of generalized ecological clusters, as well as to analyze the position of individual syntaxa (№ 1–50) within the formed groups. This approach allows us to deepen the understanding of the ecological relationships between syntaxa, characterize their relative ecological niches and assess the degree of ecological homogeneity and delimitation of forest groups reflected in the structure of the dendrogram.

1. Materials and methods of research

1.1. Characteristics of the conditions of the research region

The Left-Bank Forest-Steppe of Ukraine is one of the key physical-geographical and geobotanical components of the forest-steppe zone of Eastern Europe. Territorially, it is located within the left-bank part of the Dnieper basin and extends from north to south between Polissya and the steppe zone, forming a transitional zone with a high level of natural diversity. Within this region, elements of different natural zones are combined, which determines the complex spatial organization of landscapes and a significant variety of ecological conditions^{12, 13}.

¹² Національний атлас України / редкол.: Л. Г. Руденко (голова) та ін. Київ : ДНВП «Картографія», 2007. 440 с.

¹³ Іваненко Є. І. Комплексне природне районування України : історико-картографічний огляд. *Фізична географія та геоморфологія*. 2015. Вип. 1. С. 12–22.

The geomorphological structure of the Left-Bank Forest-Steppe is characterized by a combination of watershed plains, undulating loess plateaus, terraced valleys of large and small rivers, as well as the remains of ancient accumulative landforms. Such a variety of orographic conditions determines the heterogeneity of soil cover, hydrological regime and microclimatic characteristics, which directly affects the formation of plant cover and spatial differentiation of forest groups^{14, 15}. In geobotanical terms, the region encompasses several districts that differ in floristic composition, structure of plant communities, and degree of participation of zonal and intrazonal vegetation types¹⁶.

The climate of the Left-Bank Forest-Steppe belongs to the moderately continental type and is characterized by pronounced seasonality, which is manifested in clear annual fluctuations in air temperature and the amount of atmospheric precipitation. Winters are usually moderately cold, with unstable snow cover, while the summer period is marked by fairly high temperatures and uneven distribution of precipitation. Within the region, a gradient of climatic conditions is observed in the direction from north to south, which causes a gradual increase in the continentality of the climate, a decrease in humidity and an increase in the duration of the warm period. Such climate features create diverse ecological prerequisites for the formation of broad-leaved and mixed forests, and also determine their sensitivity to changes in thermal and water regimes¹⁷.

The soil cover of the Left-Bank Forest-Steppe has a pronounced mosaic structure, reflecting the complex history of soil formation under conditions of variable climate, relief and vegetation cover. On the watershed plains and gentle slopes, typical and degraded black soils are most common, which were formed under meadow-steppe and forest-steppe vegetation. In the southern part of the region, a significant area is occupied by dark-gray forest soils associated with the spread of broad-leaved forests and characterized by relatively higher acidity and a different ratio of humus horizons^{18, 19}.

¹⁴ Географічна енциклопедія України : у 3 т. / редкол.: О. М. Маринич (відп. ред.) та ін. Київ : УРЕ ім. М. П. Бажана, 1993. Т. 3 : П–Я. 480 с.

¹⁵ Національний атлас України / редкол.: Л. Г. Руденко (голова) та ін. Київ : ДНВП «Картографія», 2007. 440 с.

¹⁶ Геоботанічне районування Української РСР / Г. І. Білик, Є. М. Брадїс, М. А. Голубець та ін. Київ : Наук. думка, 1977. 304 с.

¹⁷ Географічна енциклопедія України : у 3 т. / редкол.: О. М. Маринич (відп. ред.) та ін. Київ : УРЕ ім. М. П. Бажана, 1990. Т. 2 : З–О. 480 с.

¹⁸ Крупский Н. К., Полупан Н. И. Атлас почв Украинской ССР. Киев : Урожай, 1979. 160 с.

¹⁹ Географічна енциклопедія України : у 3 т. / редкол.: О. М. Маринич (відп. ред.) та ін. Київ : УРЕ ім. М. П. Бажана, 1989. Т. 1 : А–Ж. 416 с.

1.2. Research materials

The material basis of the study was synoptic and complete phytocenotic description tables published in works devoted to the study of the vegetation of broad-leaved forests of the Left-Bank Forest-Steppe of Ukraine. A representative array of literary sources covering different parts of the region and reflecting the current state of syntaxonomic studies of forest vegetation was involved in the analysis.

In particular, materials published by O. M. Bayrak^{20, 21}, I. V. Solomakha et al.²², V. L. Shevchyk and O. D. Polishko²³, I. V. Goncharenko^{24, 25}, Ye. O. Vorobyov²⁶, L. M. Gomlya²⁷, V. A. Onyshchenko²⁸, D. A. Davydov²⁹, O. Yu. Smagliuk, N. O. Smoliar and V. A. Solomakha^{30, 31, 32} were used. The mentioned works contain detailed descriptions of the floristic composition, community structure, and ecological conditions of their formation.

From the above list of sources, data on the full species composition and ecological characteristics of 50 syntaxa of the *Carpino-Fagetea* class were

²⁰ Байрак О. М. Синтаксономія широколистяних лісів Лівобережного Придніпров'я. *Укр. фітоценол. зб. Сер. А.* 1996. Вип. 3 (3). С. 51–63.

²¹ Байрак О. М. Фітоценотична характеристика заплавних лісів Лівобережного Придніпров'я. *Укр. фітоценол. зб. Сер. А.* 1997. Вип. 1 (6). С. 45–51.

²² Соломаха І. В., Сенчило О. О., Колот О. М., Войтюк Б. Ю. Лісова рослинність Чорнухівщини (Полтавська область). *Укр. фітоценол. зб. Сер. А.* 1997. Вип. 2 (7). С. 80–88.

²³ Шевчик В. Л., Полішко О. Д. Синтаксономія рослинності ділянки борової тераси (Ліплявське лісництво Черкаської області). *Укр. фітоценол. зб. Сер. А.* 2000. Вип. 16 (1). С. 67–89.

²⁴ Гончаренко І. В. Аналіз рослинного покриву північно-східного Лісостепу України. *Укр. фітоценол. зб. Сер. А.* 2003. Вип. 1 (19). С. 1–203.

²⁵ Гончаренко І. В. Флористична класифікація лісів лісостепової Сумщини. *Укр. фітоценол. зб. Сер. А.* 2001. Вип. 1 (17). С. 3–17.

²⁶ Воробйов Є. О. Попередній продромус суходольних лісів та рідколісь природного та штучного походження з переважанням або помітною участю *Pinus sylvestris* L. s.l. рівнинної частини України. Рослинність хвойних лісів України. Київ : Фітосоціоцентр, 2003. С. 13–42.

²⁷ Гомля Л. М. Рослинність долини річки Хорол. *Укр. фітоценол. зб.* Київ, 2005. С. 3–186.

²⁸ Onyshchenko V. A. Forests of order *Fagetalia sylvaticae* in Ukraine. Kyiv : Alterpress, 2009. 212 p.

²⁹ Давидов Д. А. Лісова рослинність Роменсько-Полтавського геоботанічного округу (Україна): синтаксономія, антропогенні зміни та охорона : дис. ... канд. біол. наук : 03.00.05 / Ін-т ботаніки ім. М. Г. Холодного НАН України. Київ, 2012. 408 с.

³⁰ Смаглюк О. Ю., Соломаха В. А. Флористична класифікація мезофільних широколистяних лісів союзу *Carpinion betuli* Issl. em. Oberd. 1953 у басейні нижньої течії річки Сули. *Вісник Черкаського університету. Сер.: Біологічні науки.* 2015. № 19. С. 98–109.

³¹ Solomakha V., Smoliar N., Smagliuk O. Floristic classification of the floodplain alder, willow and poplar forests in the basin of the lower Sula (Ukraine). *Вісник Київського національного університету імені Тараса Шевченка. Сер.: Біологія.* 2016. Вип. 2. С. 33–44.

³² Смаглюк О. Ю., Смоляр Н. М., Соломаха В. А. Флористична класифікація мезофільних кленово-липово-дубових лісів у басейні нижньої Сули (Україна). *Вісник Львівського університету. Сер.: Біологічна.* 2017. Вип. 75. С. 23–34.

selected for further analysis. Among them, 27 syntaxa correspond to the rank of associations, while 23 are represented by subassociations and variants that reflect the internal differentiation of forest communities within the region. In the combined list of species formed on the basis of the analyzed syntaxa, there are a total of 3115 species of vascular plants, which indicates a high level of floristic diversity of the studied vegetation.

1.3. Research methodology

At the initial stage of the study, data on the occurrence of species within individual syntaxa were aggregated and unified. In order to ensure correct comparison between syntaxa, the initial indicators were converted into a percentage format, which allowed to level the influence of a different number of descriptions within individual phytocenotic tables. This approach ensured statistical consistency of the data and created the basis for further calculations of ecological characteristics.

Further analysis was performed using the phytoindication method³³, which is based on the use of ecological scales that reflect the reaction of plant species to the leading abiotic factors of the environment. The study took into account 12 ecological indicators that cover the key parameters of the plant habitat: soil moisture, moisture variability, soil acidity, total salt regime, nitrogen content, air humidity, soil aeration, thermal regime, illumination, climate continentality, cryoclimatic conditions and soil carbonate content. The set of these indicators allows for a comprehensive characterization of the ecological niches of syntaxa and the identification of patterns of their spatial differentiation. To identify similarities between syntaxa by a set of ecological characteristics, the hierarchical clustering method was used. Previously, only numerical ecological variables were selected from the original table, after which the data were standardized by z-transformation in order to eliminate the influence of different dimensionality of the indicators. The matrix of distances between syntaxa was calculated using the Euclidean metric, which is generally accepted in multidimensional ecological analysis. Clustering was carried out using the Ward method (Ward.D2), which minimizes intracluster dispersion and ensures the formation of statistically justified and ecologically interpreted groups. The results of hierarchical clustering are presented in the form of a dendrogram, on which the branches are signed with the corresponding syntaxon numbers. The optimal number of clusters was determined based on the analysis of the dendrogram structure, taking into account the levels of merger and sharp changes in the intercluster distance. Cutting the dendrogram allowed us to identify four

³³ Didukh Y. P. The ecological scales for the species of Ukrainian flora and their use in synphytoindication. Kyiv : Phytosociocentre, 2011. 176 p.

generalized clusters that reflect the main types of ecological differentiation of syntaxa of the *Carpino-Fagetea* class within the Left-Bank Forest-Steppe of Ukraine. All statistical calculations and graphical visualization of the results were performed in the R environment using standard packages for processing tabular data and multivariate statistical analysis, which ensured the reproducibility and transparency of the results obtained.

2. Results and their discussion

Hierarchical clustering of syntaxa according to the complex of phytoindication parameters, performed by the Ward method using Euclidean distance, revealed a clear ecological differentiation of forest communities. The dendrogram reflects the grouping of syntaxa according to the gradients of moisture, trophicity and climatic conditions, while syntaxa of one syntaxonomic union mainly form compact clusters, which indicates the ecological integrity of the corresponding phytocenotic types (Fig. 1.).

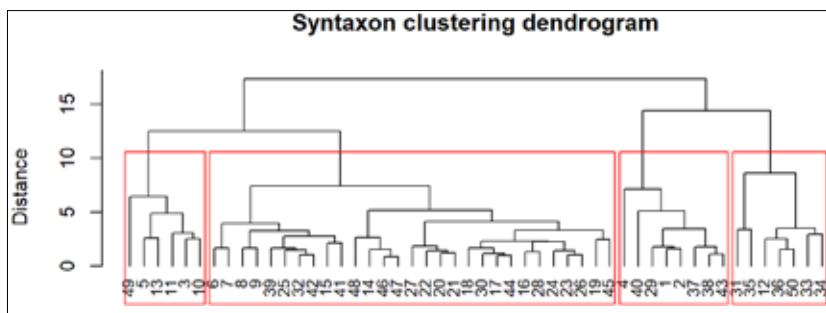


Fig. 1. Dendrogram of hierarchical clustering of syntaxa of the *Carpino-Fagetea sylvaticae* class by the complex of phytoindication parameters

Syntaxon designation: 1. *Aegonychon-Quercetum roboris*³⁴; 2. *Melica picta-Quercetum roboris*³⁵; 3. *Aceri negundi-Alnetum glutinosae*³⁶; 4. *Rubo*

³⁴ Давидов Д. А. Лісова рослинність Роменсько-Полтавського геоботанічного округу (Україна): синтаксономія, антропогенні зміни та охорона : дис. ... канд. біол. наук : 03.00.05 / Ін-т ботаніки ім. М. Г. Холодного НАН України. Київ, 2012. 408 с.

³⁵ Ibid.

³⁶ Solomakha V., Smoliar N., Smagliuk O. Floristic classification of the floodplain alder, willow and poplar forests in the basin of the lower Sula (Ukraine). *Вісник Київського національного університету імені Тараса Шевченка. Сер. : Біологія.* 2016. Вип. 2. С. 33-44.

*caesii-Alnetum*³⁷; 5. *Ficario-Ulmetum*³⁸; 6. *Luzulo-Quercetum* subass. *dryopteridetosum*³⁹; 7. *L.-Q.* subass. *alliariosum*⁴⁰; 8. *Ficario-Ulmetum*⁴¹; 9. *F.-U.* subass. *typicum*⁴²; 10. *F.-U.* subass. *chrysosplenietosum*⁴³; 11. *Rubocaesii-Alnetum*⁴⁴; 12. *Melico nutantis-Quercetum roboris*⁴⁵; 13. *Ficario-Ulmetum*⁴⁶; 14. *Luzulo-Quercetum* subass. *dryopteridetosum*⁴⁷; 15. *L.-Q.* subass. *alliariosum*⁴⁸; 16. *Tulipo biebersteinianae-Carpinetum betuli*⁴⁹; 17. *Galeobdoloni luteae-Carpinetum betuli* subass. *sambucetosum nigrae*⁵⁰; 18. *G. L.-C. b*⁵¹; 19. *Carici pilosae-Carpinetum*⁵²; 20. *C. p.-C.*⁵³; 21. *Galeobdoloni luteae-Carpinetum* subass. *typicum* var. *Viola reichenbachiana*⁵⁴; 22. *G. l.-C.*⁵⁵; 23. *Tilio-Carpinetum*⁵⁶; 24. *Galeobdoloni luteae-Carpinetum betuli* subass. *betuletosum pendulae*⁵⁷; 25. *G. l.-C. b.* subass.

³⁷ Байрак О. М. Фітоценотична характеристика заплавлених лісів Лівобережного Придніпров'я. *Укр. фітоценол. зб. Сер. А.* 1997. Вип. 1 (6). С. 45–51.

³⁸ Гончаренко І. В. Аналіз рослинного покриву північно-східного Лісостепу України. *Укр. фітоценол. зб. Сер. А.* 2003. Вип. 1 (19). С. 1–203.

³⁹ Ibid.

⁴⁰ Ibid.

⁴¹ Шевчик В. Л., Полішко О. Д. Синтаксономія рослинності ділянки борової тераси (Ліплявське лісництво Черкаської області). *Укр. фітоценол. зб. Сер. А.* 2000. Вип. 16 (1). С. 67–89.

⁴² Давидов Д. А. Лісова рослинність Роменсько-Полтавського геоботанічного округу (Україна): синтаксономія, антропогенні зміни та охорона : дис. ... канд. біол. наук : 03.00.05 / Ін-т ботаніки ім. М. Г. Холодного НАН України. Київ, 2012. 408 с.

⁴³ Ibid.

⁴⁴ Гомля Л. М. Рослинність долини річки Хорол. *Укр. фітоценол. зб.* Київ, 2005. С. 3–186.

⁴⁵ Гончаренко І. В. Аналіз рослинного покриву північно-східного Лісостепу України. *Укр. фітоценол. зб. Сер. А.* 2003. Вип. 1 (19). С. 1–203.

⁴⁶ Гончаренко І. В. Флористична класифікація лісів лісостепової Сумщини. *Укр. фітоценол. зб. Сер. А.* 2001. Вип. 1 (17). С. 3–17.

⁴⁷ Ibid.

⁴⁸ Ibid.

⁴⁹ Смаглюк О. Ю., Соломаха В. А. Флористична класифікація мезофільних широколистяних лісів союзу *Carpinion betuli* Issl. em. Oberd. 1953 у басейні нижньої течії річки Сули. *Вісник Черкаського університету. Сер.: Біологічні науки.* 2015. № 19. С. 98–109.

⁵⁰ Ibid.

⁵¹ Байрак О. М. Синтаксономія широколистяних лісів Лівобережного Придніпров'я. *Укр. фітоценол. зб. Сер. А.* 1996. Вип. 3 (3). С. 51–63.

⁵² Ibid.

⁵³ Соломаха І. В., Сенчило О. О., Колот О. М., Войтюк Б. Ю. Лісова рослинність Чорнухівщини (Полтавська область). *Укр. фітоценол. зб. Сер. А.* 1997. Вип. 2 (7). С. 80–88.

⁵⁴ Ibid.

⁵⁵ Ibid.

⁵⁶ Шевчик В. Л., Полішко О. Д. Синтаксономія рослинності ділянки борової тераси (Ліплявське лісництво Черкаської області). *Укр. фітоценол. зб. Сер. А.* 2000. Вип. 16 (1). С. 67–89.

⁵⁷ Onyshchenko V. A. Forests of order *Fagetalia sylvaticae* in Ukraine. Kyiv : Alterpress, 2009. 212 p.

*sambucetosum nigrae*⁵⁸; 26. *G. l.-C. b. subass. typicum*⁵⁹; 27. *G. l.-C. b. subass. betuletosum pendulae*⁶⁰; 28. *G. l.-C. b. subass. melampyretosum nemorosum*⁶¹; 29. *Galio-Carpinetum subass. poetosum nemoralis*⁶²; 30. *G.-C. subass. typicum*⁶³; 31. *Convallario-Pinetum*⁶⁴; 32. *Melico-Quercetum*⁶⁵; 33. *Melico nutantis-Quercetum*⁶⁶; 34. *Convallario majalis-Quercetum roboris*⁶⁷; 35. *Pteridio-Quercetum*⁶⁸; 36. *Melico nutantis-Quercetum roboris subass. typicum*⁶⁹; 37. *Stellario holosteaе-Aceretum platanoidis subass. typicum*⁷⁰; 38. *S. h.-A. p. subass. caricetosum pilosae*⁷¹; 39. *S. h.-A. p. subass. parietosum quadrifoliae*⁷²; 40. *S. h.-A. p.*⁷³; 41. *S. h.-A. p.*⁷⁴; 42. *S. h.-A. p.*⁷⁵; 43. *S. h.-A. p. subass. caricetosum pilosae*⁷⁶; 44. *S. h.-A. p. subass. parietosum quadrifoliae*⁷⁷;

⁵⁸ Onyshchenko V. A. Forests of order Fagetalia sylvaticae in Ukraine. Kyiv : Alterpress, 2009. 212 p.

⁵⁹ Давидов Д. А. Лісова рослинність Роменсько-Полтавського геоботанічного округу (Україна): синтаксономія, антропогенні зміни та охорона : дис. ... канд. біол. наук : 03.00.05 / Ін-т ботаніки ім. М. Г. Холодного НАН України. Київ, 2012. 408 с.

⁶⁰ Ibid.

⁶¹ Ibid.

⁶² Гомля Л. М. Рослинність долини річки Хорол. *Укр. фітоценол. зб.* Київ, 2005. С. 3–186.

⁶³ Ibid.

⁶⁴ Воробйов Є. О. Попередній продромус суходольних лісів та рідколісь природного та штучного походження з переважанням або помітною участю *Pinus sylvestris* L. s.l. рівнинної частини України. Рослинність хвойних лісів України. Київ : Фітосоціоцентр, 2003. С. 13–42.

⁶⁵ Смаглюк О. Ю., Смоляр Н. М., Соломаха В. А. Флористична класифікація мезофільних кленово-липово-дубових лісів у басейні нижньої Сули (Україна). *Вісник Львівського університету. Сер.: Біологічна.* 2017. Вип. 75. С. 23–34.

⁶⁶ Шевчик В. Л., Полішко О. Д. Синтаксономія рослинності ділянки борової тераси (Ліпнявське лісництво Черкаської області). *Укр. фітоценол. зб. Сер. А.* 2000. Вип. 16 (1). С. 67–89.

⁶⁷ Ibid.

⁶⁸ Давидов Д. А. Лісова рослинність Роменсько-Полтавського геоботанічного округу (Україна): синтаксономія, антропогенні зміни та охорона : дис. ... канд. біол. наук : 03.00.05 / Ін-т ботаніки ім. М. Г. Холодного НАН України. Київ, 2012. 408 с.

⁶⁹ Ibid.

⁷⁰ Ibid.

⁷¹ Ibid.

⁷² Ibid.

⁷³ Гончаренко І. В. Аналіз рослинного покриву північно-східного Лісостепу України. *Укр. фітоценол. зб. Сер. А.* 2003. Вип. 1 (19). С. 1–203.

⁷⁴ Гончаренко І. В. Флористична класифікація лісів лісостепової Сумщини. *Укр. фітоценол. зб. Сер. А.* 2001. Вип. 1 (17). С. 3–17.

⁷⁵ Смаглюк О. Ю., Смоляр Н. М., Соломаха В. А. Флористична класифікація мезофільних кленово-липово-дубових лісів у басейні нижньої Сули (Україна). *Вісник Львівського університету. Сер.: Біологічна.* 2017. Вип. 75. С. 23–34.

⁷⁶ Onyshchenko V. A. Forests of order Fagetalia sylvaticae in Ukraine. Kyiv : Alterpress, 2009. 212 p.

⁷⁷ Onyshchenko V. A. Forests of order Fagetalia sylvaticae in Ukraine. Kyiv : Alterpress, 2009. 212 p.

45. *Aegonychon-Quercetum roboris*⁷⁸; 46. *Mercuriali perennis-Fraxinetum excelsioris*⁷⁹; 47. *Stellario holosteae-Aceretum platanoidis*⁸⁰; 48. *Convallario-Padietum*⁸¹; 49. *C.-P. subass. equisetosum hyemali*⁸²; 50. *Pteridio aquilini-Quercetum roboris*⁸³.

The optimal number of clusters was determined based on a comprehensive analysis of the hierarchical clustering dendrogram, constructed using the Ward method, which minimizes intragroup variance and ensures the formation of the most ecologically consistent clusters. The key criterion for cluster selection was the sharp increases in the height of the merger, which are interpreted as a significant increase in the intercluster distance and, accordingly, as the boundary between qualitatively different ecological groups. Cutting the dendrogram at the level preceding the maximum jump in this indicator made it possible to reasonably distinguish four generalized ecological groups of syntaxa. These clusters reflect the leading ecological gradients of moisture and trophicity of the environment, which are decisive for the spatial differentiation of forest vegetation of the Left-Bank Forest-Steppe.

Further detailing of the dendrogram structure by deeper branching of clusters did not lead to the identification of new, ecologically independent types of groups, but only reflected the internal variability of syntaxa within one ecological regime. This indicates the adequacy of the selected level of clustering and confirms that it is the four clusters that most fully represent the main directions of ecological differentiation of the studied groups.

The syntaxa of cluster I are characterized by close values of phytoindication parameters of moisture, soil aeration and thermal regime, which indicates the formation of the corresponding groups in relatively humid, well-drained habitats under moderately warm climatic conditions. The majority of syntaxa of this group are characterized by increased values of soil and air moisture in combination with average indicators of acidity and mineral nitrogen supply. This set of ecological features is consistent with their localization to lowered relief elements, talwegs of ravines, river floodplains, and transitional forms between floodplain and supra-floodplain terraces. The small number of syntaxa

⁷⁸ Байрак О. М. Синтаксономія широколистяних лісів Лівобережного Придніпров'я. *Укр. фітоценол. зб. Сер. А.* 1996. Вип. 3 (3). С. 51–63.

⁷⁹ Ibid.

⁸⁰ Ibid.

⁸¹ Ibid.

⁸² Байрак О. М. Фітоценотична характеристика заплавної лісової екосистеми Лівобережного Придніпров'я. *Укр. фітоценол. зб. Сер. А.* 1997. Вип. 1 (6). С. 45–51.

⁸³ Байрак О. М. Синтаксономія широколистяних лісів Лівобережного Придніпров'я. *Укр. фітоценол. зб. Сер. А.* 1996. Вип. 3 (3). С. 51–63.

within the cluster and their compact grouping on the dendrogram indicate the relative ecological homogeneity of this group, despite certain differences in the floristic composition of individual associations.

Cluster II is the most numerous and unites syntaxa that are formed mainly in mesophilic conditions with average or moderately elevated moisture and trophic indices. Phytoindicative values within this cluster vary in a relatively narrow range, which determines their unification into one generalized ecological group. At the same time, the internal structural heterogeneity of the cluster reflects the different position of syntaxa along the gradients of soil moisture and mineral nutrition. It includes groups of different genesis, floodplain, ravine ecotopes, terrace and plateau, which determines the breadth of the ecological amplitude of this group. Despite this, the dendrogram records common features of their ecological organization, primarily in terms of mineral nitrogen content, acidity and soil aeration regime.

Syntaxa of cluster III are characterized by relatively lower values of moisture and trophicity indicators than in clusters I and II, as well as slightly reduced thermal values. This indicates their confinement to better drained ecotopes, mainly associated with the upper and middle parts of slopes, as well as plateau areas. The compactness of this cluster on the dendrogram indicates the proximity of the ecological niches of the syntaxa, even if they belong to different syntaxonomic units of higher rank. The internal structure of the cluster reflects a gradual transition from more mesophilic to relatively xerophilic conditions without clearly defined ecological boundaries, which is characteristic of slope and plateau forest ecotopes of the Forest-Steppe.

Cluster IV unites syntaxa, which are characterized by a combination of moderate or reduced moisture with relatively poorer soils and increased continentality of conditions. The indicators of acidity, mineral nitrogen content and air humidity within this cluster are generally lower compared to clusters I–II, which is consistent with the localization of the groups to floodplain terraces, sandy and sandy loam soils, as well as pine complexes. At the same time, the thermal parameters remain within the limits typical for the forest-steppe zone, which determines a clear, but not marginal separation of the cluster on the dendrogram. In general, this group is characterized by sufficient internal ecological coherence and represents a specific type of forest groups adapted to relatively drier and oligotrophic conditions.

Further detailed analysis of each cluster taking into account the specific composition of syntaxa confirms the consistency of the clustering with the ecotopic and phytoindication characteristics of the groups.

Cluster I unites syntaxa № 3, 5, 10, 11, 13 and 49, which are characterized by similar ecological and coenotic parameters and are confined to low-lying, well-moistened elements of the forest landscape. According to the soil moisture index, these groups cover the interval from mesophytic to hygro-mesophytic conditions, which corresponds to formation on fresh and moist soils with full or periodically excessive moisture. This characteristic is consistent with the ecotopic confinement of syntaxa № 3, 10 and 11 to river floodplains, low-lying areas and thalwegs of deep forest gullies with close groundwater levels.

The indicators of moisture variability reflect the predominance of hemihydrocontrastphobic conditions, characteristic of floodplain and lowland ecotopes with moderately uneven water regime. The aeration regime of the soils corresponds to hemiaerophobic conditions, which indicates the development of communities on moderately aerated, often moistened substrates. The acidity of the soil environment is characterized by subacidophilic values, typical of weakly acidic sod-podzolic and gray forest soils.

According to the general salt regime, the syntaxa of the cluster correspond to mesotrophic and semi-eutrophic conditions, which is consistent with well-moistened, but not saline soils. Mineral nitrogen availability varies from heminitrophilic to nitrophilic conditions and is most pronounced in syntaxa № 3 and 49, confined to floodplain forests. The carbonate regime indicates the formation of communities mainly on non-or weakly carbonate substrates.

Climatic indicators within the cluster are relatively homogeneous: the thermal regime corresponds to submicrothermal conditions, the continentality of the climate, to the hemioceanic type, and the cryo-regime, to subcryophytic conditions with moderate severity of winters. Atmospheric humidification is characterized by subaridophytic values with relatively high air humidity, which is consistent with the location in floodplains and lowlands. The light regime corresponds to hemisciophytic conditions, typical of closed or semi-closed deciduous and alder forests.

Thus, cluster I represents a group of floodplain and lowlands broadleaf and alder forest communities, united by conditions of increased moisture, moderate trophicity, and a relatively stable microclimate, which is clearly reflected both in phytoindication parameters and in the ecotopic characteristics of syntaxa № 3, 5, 10, 11, 13, and 49.

Cluster II includes syntaxa № 6, 7, 8, 9, 14–28, 30, 32, 39, 41, 42, 44–48 and represents mesophilic broad-leaved and mixed forests of various ecological and coenotic positions—from floodplain and terrace to plateau and ravine-gully ecotopes. According to the soil moisture index, all cluster groups are confined to mesophytic conditions, which corresponds to the formation

on fresh soils with full moistening of the root-containing layer. The highest moisture values are characteristic of floodplain and terrace syntaxa № 8, 9 and 48, while somewhat lower ones are characteristic of the plateau and upper slope groups (№ 16, 19, 28, 45).

The variability of soil moisture reflects the predominance of hydrocontrast-phobic and hemihydrocontrast-phobic conditions, which indicates a relatively uniform water regime in most ecotopes. Soil aeration corresponds to subaerophilic and hemiaerophobic conditions, characteristic of gray and dark gray forest loams. Soil acidity is subacidophilic, which is typical of sod-podzolic and gray forest soils of the Forest-Steppe.

According to the general salt regime, the cluster groups belong mainly to mesotrophic ones. At the same time, increased values of the content of mineral elements are characteristic of individual floodplain and terrace syntaxa (№ 7, 8, 9, 32, 42, 48), which is consistent with their confinement to richer and better moistened substrates. The carbonation of the soils corresponds to hemicarbonatophobic conditions and reflects the formation of communities on weakly carbonated or non-carbonated soils.

Climatic indicators within the cluster are quite homogeneous: the thermal regime corresponds to submicrothermal conditions, the continentality of the climate is of the hemioceanic type, and the cryoregime to subcryophytic conditions. Atmospheric humidification is characterized by subaridophytic values, typical of the Left-Bank Forest-Steppe. The light regime is mainly sciophytic and hemisciophytic, which corresponds to closed or semi-closed stands.

Overall, cluster II represents an ecologically relatively homogeneous group of mesophilic broadleaf forests that form under conditions of moderate moisture, mesotrophic soils, and a stable microclimate, while covering a wide range of ecotopes – from floodplains and terraces to plateaus and ravine-gully systems, which causes internal differentiation without going beyond the mesophilic ecological optimum.

Cluster III includes syntaxa № 1, 2, 4, 29, 37, 38, 40 and 43, united by similar phytoindication characteristics and confinement to well-drained, relatively dry ecotopes of slopes, plateaus and ravine-gully systems. According to the soil moisture index, most of the groups belong to submesophytic conditions, which corresponds to development in relatively dry forest habitats with moderate moisture of the root-containing layer. Syntaxon № 4 (*Rubocaesii-Alnetum*) is distinguished by mesophytic moisture values, however, its inclusion in the cluster is due to its proximity in other soil and climatic indicators.

The variability of moisture reflects hydrocontrastphobic and hemihydrocontrastphobic conditions, which reflects a relatively stable or moderately

uneven water regime, typical of slope and plateau ecotopes. The aeration regime of soils varies from subaerophilic to hemiaerophobic, which is consistent with the distribution of communities on well-aerated gray and dark gray forest soils, as well as on eroded substrates of slopes (№ 1, 2, 29).

Soil acidity within the cluster is relatively homogeneous: the values indicate subacidophilic conditions typical of gray forest soils of the Forest-Steppe. According to the general salt regime, the syntaxa correspond to mesotrophic conditions without signs of salinity. The carbonate regime is characterized by hemicarbonatophobic values, which reflects the formation of communities on weakly carbonated or almost non-carbonated soils. The mineral nitrogen supply is heminitrophilic, without pronounced enrichment.

Climatic indicators within the cluster are consistent: the thermal regime is submicrothermal, the continentality of the climate varies from suboceanic to hemioceanic, the cryo-regime from cryophytic to subcryophytic. Atmospheric humidification corresponds to mesoaridophytic and subaridophytic conditions, which is consistent with the confinement of the groups to elevated and well-drained relief elements. The light regime is sciophytic or hemisciophytic, characteristic of closed and moderately closed stands of oak and mixed forests.

In general, cluster III represents a group of forest syntaxa of drier and warmer habitats of the Left-Bank Forest-Steppe, united by submesophytic moisture conditions, mesotrophic soils, and relatively stable soil and climatic parameters.

Cluster IV includes syntaxa № 12, 31, 33, 34, 35, 36 and 50, confined mainly to floodplain and pine terraces of rivers and leveled interfluvial areas with sandy and sandy loam, mostly podzolized soils. According to the soil moisture index, the cluster groups are formed in conditions from submesophytic to mesophytic. The driest habitats are characteristic of syntaxa № 31 and 35, while № 12, 34 and 50 are confined to somewhat wetter terrace ecotopes. The variability of moisture corresponds to hemihydrocontrastophic conditions and reflects the moderately uneven water regime of well-drained sandy and sandy loam soils. The aeration regime is mainly subaerophilic, which is due to the light granulometric composition of the substrates. The acidity of the soil solution ranges from acidophilic to subacidophilic values, with the maximum values in syntaxa № 33 and 34.

According to the general salt regime, the groups belong to mesotrophic conditions. The carbonate regime is characterized by hemicarbonatophobic values, typical of podzolized sandy and sandy loam soils. The supply of mineral nitrogen varies from subanitrophilic to heminitrophilic conditions, with the lowest values in syntaxon № 35.

Climatic indicators within the cluster are relatively homogeneous: the thermal regime is submicrothermal, atmospheric humidification is subaridophytic, the continentality of the climate is hemioceanic, the cryoregime is subcryophytic. The light regime is predominantly hemisciophytic, which corresponds to oak, oak-pine and pine-oak forests with moderately closed stands.

In general, cluster IV represents a group of terraced and interfluvial forest communities of the Left-Bank Forest-Steppe, formed under conditions of moderate moisture, good drainage and mesotrophic slightly acidic podzolized soils, which is clearly reflected in the agreed phytoindication characteristics of syntaxa № 12, 31, 33, 34, 35, 36 and 50.

CONCLUSIONS

A comprehensive phytoindication analysis of 50 syntaxa of the *Carpino-Fagetea sylvaticae* class of the Left-Bank Forest-Steppe of Ukraine was carried out using hierarchical clustering according to 12 ecological indicators. The results obtained demonstrated a clear ecological differentiation of forest communities and allowed us to generalize their spatial-ecological organization. The allocation of four generalized clusters is statistically justified and reflects the leading gradients of moisture, trophicity and drainage of habitats, while further detailing only clarifies intracluster differences.

Cluster I combines floodplain and ravine-gully communities confined to lowered relief elements with increased moisture, moderate or increased trophicity and limited soil aeration. Cluster II, the most numerous, is represented by mesophilic broad-leaved and mixed forests formed under conditions of moderate moisture and mesotrophic soils and covers a wide range of ecotopes while maintaining similar phytoindication characteristics. Cluster III includes a group of well-drained, relatively drier habitats of slopes and plateaus with submesophytic moisture conditions and stable soil and climatic indicators. Cluster IV represents terraced and interfluvial forests on sandy and sandy loamy, mainly podzolized soils, which are characterized by good drainage, a weakly acidic environment and reduced mineral nitrogen supply. We established that edaphic factors in the intraclass differentiation of groups play a leading role, primarily soil moisture, its acidity and nitrogen content, while climatic indicators within the region remain relatively stable and are of secondary importance. Overall, the results indicate high ecological plasticity of the *Carpino-Fagetea sylvaticae* class, whose groups cover a wide range of ecotopes. The determined ecological amplitudes of syntaxa can be used to predict changes in forest vegetation and scientifically based planning of measures to preserve the biodiversity of the Left-Bank Forest-Steppe of Ukraine.

Studies of this type are of particular importance for the development of an evidence-based approach to the assessment, conservation and management of forest vegetation under conditions of increasing anthropogenic pressure and climate change. The use of phytoindication and multivariate statistical methods makes it possible to identify latent ecological gradients that are not always evident from floristic composition alone, to objectively delimit syntaxa and to assess their ecological similarity and vulnerability. The obtained results form a methodological basis for comparative analyses at the regional and interregional levels, contribute to the improvement of forest typology and syntaxonomic schemes, and can be applied in monitoring programs aimed at detecting early signs of ecological shifts and degradation processes in nemoral forest ecosystems.

SUMMARY

The paper presents the results of a comprehensive phytoindication analysis of 50 syntaxa of the *Carpino-Fagetea sylvaticae* class of the Left-Bank Forest-Steppe of Ukraine. The aim of the study was to identify patterns of ecological differentiation of forest communities in the region. Hierarchical clustering methods (Ward's method) based on 12 ecological scales of Ya.P. Didukh were applied. It was established that the leading factors of differentiation are soil moisture and trophicity (nitrogen content, acidity), while climatic indicators are relatively stable. Four generalized ecological clusters of syntaxa are distinguished: hygro-mesophytic floodplain and lowland forests; mesophilic forests of a wide ecotopic spectrum; submesophytic groups of slopes and plateaus; submesophytic forests of pine terraces on sandy soils. The results obtained demonstrate significant ecological plasticity of the *Carpino-Fagetea* class and provide a basis for predicting vegetation changes under anthropogenic load.

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