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SYNPHYTOINDICATION MODELS OF THE ANTHROPOGENIC TRANSFORMATION OF ECOSYSTEMS

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Human activity related to the exploitation or protection of environmental elements requires the creation of forecasts of the consequences involved. Such forecasts are not possible without the construction of models of ecosystems and the processes occurring in them. One of the critical elements in modern forecasting of the dynamics of ecosystems is the modelling of their anthropogenic block. Our research aims to develop methods for assessing the anthropogenic transformation of ecosystems necessary for modelling their state and dynamics. In accordance with the goal, we set ourselves the following tasks: to determine the limits of anthropotolerance of plant species; to evaluate the hemeroby of plant groups by the methods of synphytoindication; to create models of mutual dependence between anthropogenic transformation and natural dynamics. To implement the tasks, we used standard geobotanical methods (creating a geobotanical description, classification of plant communities, and synphytoindication). Hemeroby of plant communities can be used as an indicator of the anthropogenic transformation of ecosystems. To do this, we measure the boundaries of anthropotolerance of the plant species that make up these groupings. The range of anthropotolerance of individual plant species can be determined by the 12 most common types of human activity. The strength of their impact on ecosystems was determined by the induced changes in above-ground phytomass. The transition from anthropotolerance of individual species to hemeroby of plant communities was carried out according to the classical synphytoindication technique. We created an 18-point scale by assigning three points to each classic type of hemoroby. The use of the synphytoindication scale allows modelling of the interdependence between anthropogenic transformation and the measurable characteristics of the ecosystem. An inverse linear relationship with a probability of approximation of 0.2 and a correlation coefficient of 0.45 is an indicator of natural dynamics and the level of anthropogenic transformation. The correlation coefficient is 0.29 for ecosystems that are not suitable for economic use, and 0.85 for the rest.

Key words: modelling, Ukrainian Polissia, hemeroby, plant communities, anthropotolerance

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Ljudska aktivnost povezana s iskorištavanjem ili zaštitom elemenata okoliša zahtijeva stvaranje prognoza potencijalnih posljedica. Takve prognoze nisu moguće bez izgradnje modela ekosustava i procesa koji se u njima odvijaju. Jedan od kritičnih elemenata u suvremenom predviđanju dinamike ekosustava je modeliranje njihovog antropogenog dijela. Naše istraživanje ima za cilj razviti metode za procjenu antropogene transformacije ekosustava potrebne za modeliranje njihovog stanja i dinamike. U skladu s ciljem, postavljeni su sljedeći zadaci: utvrditi granice antropotolerancije biljnih vrsta; metodom sinfitoindikacije vrednovati degradiranost biljnih skupina; stvoriti modele međusobne ovisnosti između antropogene transformacije i prirodne dinamike. Za realizaciju zadataka korištene su stand-

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ardne geobotaničke metode (izrada geobotaničkog opisa, klasifikacija biljnih zajednica i sinfitoindikacija). Degradiranost biljnih zajednica može se koristiti kao indikator antropogene transformacije ekosustava. Da bismo to učinili, mjerili smo granice antropotolerancije biljnih vrsta koje čine ove skupine. Raspon antropotolerancije pojedinih biljnih vrsta može se odrediti prema 12 najčešćih vrsta ljudske aktivnosti. Snaga njihovog utjecaja na ekosustave određena je izazvanim promjenama u nadzemnoj biljnoj masi. Prijelaz s antropotolerancije pojedinih vrsta na degradiranost biljnih zajednica proveden je klasičnom sinfitoindikacijskom tehnikom. Napravljena je ljestvica od 18 stupnjeva dodijelivši tri boda svakom klasičnom tipu degradiranosti. Korištenje sinfitoindikacijske ljestvice omogućuje modeliranje međuovisnosti između antropogene transformacije i mjerljivih karakteristika ekosustava. Inverzni linearni odnos s vjerojatnošću aproksimacije 0,2 i koeficijentom korelacije 0,45 pokazatelj je prirodne dinamike i razine antropogene transformacije. Koeficijent korelacije je 0,29 za ekosustave koji nisu pogodni za gospodarsko korištenje, a 0,85 za ostale.

Ključne riječi: modeliranje, ukrajinsko Polesje, antropogene promjene u staništu, degradiranost staništa, biljne zajednice, antropotolerancija

INTRODUCTION

Faced with the crisis in the environment, humanity has begun to look for various ways of solving the situation. Modelling and forecasting the state of the environment has become one of the most promising and knowledge-intensive approaches. The first attempts to create models at the global and local levels opened up a large number of theoretical and applied problems (Ellis *et al*., 2010). Ecosystems are complex self-organized and self-regulating open systems with a significant proportion of determined and stochastic processes. For such objects, it is difficult to determine the complexity of the model. On the one hand, oversimplification of the model leads to a sharp decrease in the accuracy of the forecasts built with its help. On the other hand, the excessive overloading of the model with details complicates work with them, requires excessive resources, and can lead to erroneous conclusions. Searching for the optimal number of elements and variables in models of ecosystems of different levels is one of the key issues of ecosystemology (Soetaert & Herman, 2009).

The most difficult block of the ecosystems for modelling and forecasting is a complex of anthropogenic factors. At first glance, it seems that human activities are diverse in terms of the type and strength of impact (Bowler *et al*., 2020). However, any other group of factors presents itself in the same way. The more narrowly we define the environmental factor, the more predictably it acts. This forces us to divide the anthropogenic factor into a large number of smaller factors. In this case, again we face the problem of balancing detail and efficiency (Gillman & Hails, 1997). This raises the problem of the possibility of identifying an integrated anthropogenic indicator to characterize human activity as a single system (Khomiak *et al*., 2018). This brings us closer to an analogy with the existence of a complex gradient along classical abiotic or biotic factors. We can find out whether such an analogy is acceptable through the answer to the question of how much the anthropogenic factor differs from other environmental factors.

Classical ecology separates human activity from other environmental factors. On the one hand,human beings, as representatives of the animal world, affect ecosystems like other representatives of the biota. This allows the anthropogenic factor to be added to the biotic group of environmental factors. On the other hand, there are a number of differences. We must remember the volume, globality, and novelty of human-generated environmental factors. No other organism can match our capability to combine these three parameters. At the same time, unlike other organisms, we are able to realize our role in the natural environment and limit ourselves to a reasonable limit (Burlaka & Khomiak, 2008).

When we start talking about environmental protection, we must realize that we are protecting the environment from ourselves and for ourselves. By environmental protection, we mean the preservation of a complex of environmental factors in the optimum zone, despite the global interconnection between local ecosystems. Trying to generalize all the influences of human activity on ecosystems through the law of optimum, we can divide them into two groups. The first group is an increase in the magnitude of individual factors (pollution). The second one is a decrease in indicators (depletion of resources) (Fig. 1).

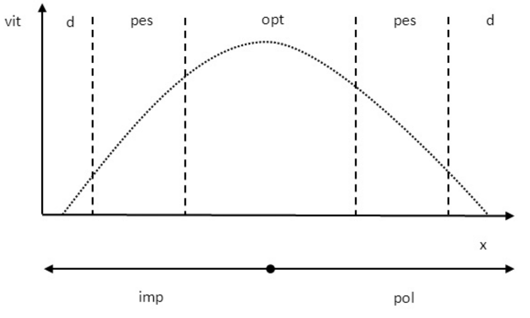

Fig. 1. Typing of anthropogenic impact on the environment. Explanation of Symbols: vit – vitality index of human populations, x – environmental factor, d – death zone, pes – pessimum zone, opt – optimum zone, imp – resource depletion, pol – pollution.

From the point of view of ecosystemology, ecosystem dynamics are specific changes associated with energy turnover (Khomiak *et al.*, 2019). First of all, this concerns the energy accumulated in the form of primary production. The evolution of ecosystems comprises the changes that lead to the formation of new ways of energy storage. They are more energy efficient or more resistant to specific environmental conditions. Fluctuations in ecosystems are minor fluctuations in energy circulation that do not entail reformatting ecosystem relationships. The succession is an alternation of different types of ecosystems with regular changes in the amount of accumulated energy. All processes occurring in the succession can be reduced to a balance between allogeneic changes leading to a decrease in primary production stocks and autogenic changes leading to their growth. At the stage of energy climax, the internal self-organization of the ecosystem reaches the maximum possible at a certain stage of evolution, the value of energy reserves. A catastrophic climax occurs under conditions of equal external and internal influences on energy reserves, the resistance of the edaphotope to endoecogenesis, or the action of invasive species of transformers, which prevents the formation of climax groups (Khomiak *et al.*, 2019).

An anthropogenic impact most often leads to the depletion of the energy resources of ecosystems, and most of the pollution caused by humans leads to the suppression of autogenic successions. An exception may be the introduction of mineral nutrients into poor soils or plantations of species from later stages of the autogenic succession (Didukh & Khomiak, 2007).

It is important to select a convenient and effective tool to determine these deviations from the optimal values. Since humans are integrated into local ecosystems, the changes they make in the environment also change the ecological spectrum of these ecosystems (Mammides, 2020). At the level of specific living organisms, we can observe changes in the signs of vitality under the influence of anthropogenic factors. More precisely, this will present itself at the level of plant communities. They respond to anthropogenic pressure by changing the species composition and relationships between individual groups of species. In other words, the ecosystem under the influence of human activity will change. We name this process the anthropogenic transformation of ecosystems (Burlaka & Khomiak, 2008).

Any plant communities can be indicators of anthropogenic transformation. For example, we carried out such studies on groups of earthworms (Khomiak *et al.*, 2016; Vlasenko *et al.*, 2020). The accuracy, efficiency, and convenience of bioindication of different groups of species are different. It is more convenient to use plant communities or the synphytoindication method for such studies (Khomiak *et al.*, 2018; 2019). Ecologists attempted to develop a general objective indicator of the anthropogenic factor in the 20th century. Researchers were successful when they determined the response of living systems to the action of an anthropogenic factor, rather than trying to measure the activity of the factor itself. They used a systemic approach and obtained a chain of influence of one subsystem on another: anthropotolerance of species → anthropotolerance of communities → anthropotolerance of ecosystems. The issue of anthropotolerance in ecology and other natural sciences has been studied since the middle of the 20th century. For example, J. Jalas uses the concept of hemeroby as a synonym for anthropotolerance (Jalas, 1953; 1955). Borrowing the classical definition, this is the ability of a plant to grow and spread in human-transformed habitats. Therefore, we can use hemeroby as an indicator of anthropogenic transformation. Hemeroby in this case is a tool for measuring the power of the anthropogenic factor.

We need to create a measurement scale to use as an indicator of the anthropogenic transformation of ecosystems. H.P. Blume, G. Sukopp, and E. Weinert started to create such a scale in the 70-80s (Blume, 1976; Blume, Sukopp, 1976; Weinert, 1985). They divided ecosystems into classes with different degrees of anthropogenic transformation. This was a rather general and inaccurate assessment. In the 90s. Polish scientists B. Yatskowiak and J. Khmil and Ukrainian scientists Y.P. Didukh and R.I. Burda consider a number of approaches to the further improvement of approaches to the creatin of a scale of anthropogenic transformation (Chmiel, 1993; Jackowiak, 1990; Burda 1991; Burda & Didukh, 2003). They consider the possibility of dividing the classes by a certain number of points and determining the average value using the ratio between species with different degrees of hemeroby (Khomiak *et al.*, 2018; Khomiak *et al.*, 2019).

MATERIALS AND METHODS

Study area

Total of 3126 standard geobotanical descriptions stored in the laboratory of the Theory of Ecosystems of Zhytomyr Ivan Franko State University were chosen as the research materials. The descriptions were made by route-expeditionary, semi-stationary, and stationary field methods on the territory of the Ukrainian Polissia (Myrkyn *et al.*, 2001) (Fig. 2). We have chosen this region as a testing ground for modelling anthropogenic dynamics through a number of its unique properties. Here we can find communities formed by t boreal, nemoral, mountain, and Mediterranean flora. All of them are located on several types of soil. Soddy-podzolic soils prevail in the north and grey forest soils in the south. In addition, the grey forest soils are located near the northern border of the Ukrainian Polissia in the form of loess hills. According to climatic conditions, the territory favours the development of communities of non-**boreal**??? flora, and according to soil conditions – boreal. The climate is temperate continental, with warm, humid summers and mild winters. Global climate changes lead to the xerophytization of Polissia and the degradation of complexes of wild nature. The anthropogenic transformation of natural ecosystems accelerates and intensifies this process. There are very different territories for the intensity of human activity here. There are areas that have been completely altered by man and areas of well-preserved wildlife. The main human impacts on wildlife in the territory of the Ukrainian Polissia are recreation (trampling), collection of wild organisms, grazing, felling, mowing, burning, planting, land reclamation, ploughing, mining, use of biocides, and construction. This creates a high diversity of ecosystems at different stages of natural dynamics and anthropogenic transformation.

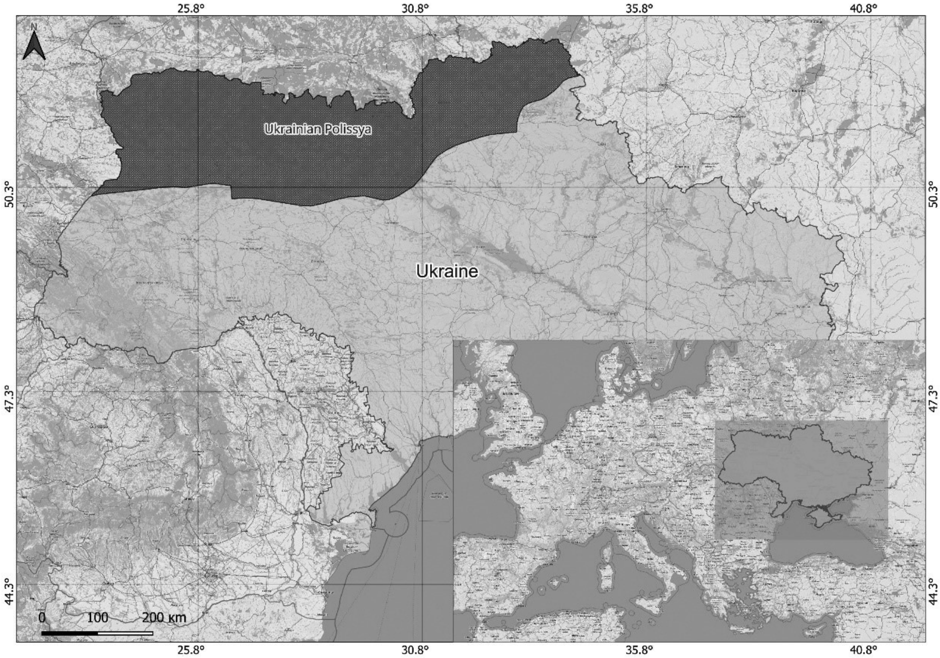

Fig. 2. Map-scheme of the territory of Ukrainian Polissia.

Methods of creating geobotanical descriptions

The coordinates of the geobotanical descriptions were set using a GPS navigator. The descriptions were processed and classified according to the principles of the Braun Blanquet School (Westhoff & Maarel, 1973). The geobotanical description included characterizing environmental conditions and projective coverings of higher vascular plants according to a modified Brown-Blanquet scale (Westhoff & Maarel, 1973). We converted the classic seven-point scale into a five-point scale in order to use it for synphytoindication. We assigned projective coverage above 75% – 5 points; from 50 to 75% – 4 points; from 25 to 50% – 3 points; from 5 to 25% – 2 points and less than 5% – 1 point. The Braun-Blanquet scale categories "1 point", "+" and "r" in the new modified scale received the value "1 point". The descriptions were stored and processed using the Simargl 1.12 software package with the EcoDBase 5f database (Khomiak & Khomiak, 2012). Also with its help, a synphytoindication analysis of the geobotanical description data was carried out.

Methods of classification of plant communities

We classified plant communities in accordance with the principles of the ecological and floristic school of J. Braun-Blanquet. Plant communities were determined by creating standard geobotanical descriptions and processing them using the TURBOVEG for Windows program. The descriptions were exported to JUICE 7.1.29 as XML table files. The created phytocenotic tables are saved in the WCT format (Table format WCT–JUICE). Later, similar descriptions were combined using colour coding. With the help of the TWINSPAN program integrated into JUICE, the descriptions were grouped into clusters according to their fidelity in the syntactic table. The names of plant communities were determined using Prodrome the vegetation of Ukraine for 2019 (Dubyna *et al*., 2019).

Synphytoindication methods

We determined indicators of environmental factors and indicators of dynamics (ST) using synphytoindication methods. We use the unified Didukh-Plyuta scale to indicate the magnitude of environmental factors (Didukh & Plyuta, 1994; Didukh, 2012). These factors are perennial moisture regime (HD), moisture variability (FH), edaphotope acidity (RC), total salinity or trophicity (SL), carbonate content (CA), and plant available nitrogen (NT).

RESULTS AND DISCUSSION

Modelling of anthropogenic transformation of ecosystems is carried out in several stages in two directions. The first is the integration of the diverse anthropogenic impacts on ecosystems into one indicator. The second is the search for diagnostic signs of changes in ecosystems that have occurred under anthropogenic pressure.

It is necessary to create a database of the diverse human activities and determine certain objective signs of their strength in order to integrate the anthropogenic factor. Based on the results of the common research with the M.G. Kholodny Institute of Botany, NAS of Ukraine, we identified 12 basic types of human activity and identified the integral changes that they cause (Didukh & Khomiak, 2007). These studies have shown that in most cases we are talking about the depletion of primary production stocks (Khomiak *et al*., 2019). The reduction of above-ground phytomass occurs due to recreation (trampling), collection of wild organisms, grazing, logging, mowing, burning, ploughing, mining, use of biocides, and construction.

The share of described observations on the types of human activity that accelerates the accumulation of biota energy reserves is insignificant. In most cases, this was a temporary effect associated with the introduction of some invasive species or early stages of overgrowing of fallow lands. Mineral and organic fertilizers that are used in the agricultural land continue to exert their influence for several years after the end of plooughing. Moreover, the combined accumulation of organic residues in river valleys or relief folds also had a temporary effect. It stopped any acceleration of the accumulation of aboveground phytomass during the transition to the stage of primary forests.

The construction of ditches in the area of oligotrophic swamps leads to the growth of above-ground phytomass because secondary and native forests are formed. Other processes are observed in the zone of eutrophic water bodies and wet eutrophic meadows. In the riparian zone and along the ditches, instead of the rare riparian willow forests and shrubs, trivial deciduous forests are formed. This partially accelerates the accumulation of phytomass. At the same time, outside the riparian zone, the growth of phytomass during the restoration of natural vegetation decreases. This is caused by global climate change. These changes in the territory of Polissia are accompanied by xerophytization of its ecosystems. Vegetation in the territory near meliorative ditches suffers from a lack of moisture and frequent changes in it.

A decrease in primary production stocks is accompanied by a decrease in phytomass value and age (Khomiak et al., 2019). Thus, we can make its assessment by observing various types of anthropogenic pressure and a decrease in the value of aboveground phytomass and its age.

The next step is to create a scale of the anthropogenic impact. The basis for this was the hemeroby class according to H.P. Blum and H. Sukop (Blume & Sukopp, 1976; Sukopp, 1969; Weinert, 1985). Since supraorganism biosystems show tolerance to the environmental factors in accordance with the law of the optimum, this gives us the right to speak about the correlation of the level of the anthropogenic transformation with the level of anthropotolerance of ecosystems (Jalas, 1953; 1955). Each of the classes of hemeroby was divided into three subclasses and an 18-point scale of the anthropogenic transformation of the ecosystems was obtained according to the characteristics of 12 main types of human activity. Thus, undisturbed natural ecosystems (ahemeroby) had a level of the anthropogenic transformation of 1-3, points for oligohemeroby – 4-6, mesohemeroby – 7-9 points, evhemeroby – 10-12 points, polyhemeroby – 13-15 points, and metahemeroby – 16-18 points (Didukh & Khomiak, 2007).

In the first stage, we chose the Slovechansko-Ovruch Ridge (Central Polissia) as a modular territory (Harbar *et al*., 2021). The highest species and syntaxonomic diversity within the studied area are observed here. At 852 sections of the ridge, we created standard geobotanical descriptions and determined indicators of hemeroby for 12 types of human activities using the formula:

$$He = \sum \frac{k_{(1-12)}}{12},$$

where He – the degree of hemeroby expressed in points, k(1-12) hemeroby in points for each type of activity.

As a result, we obtained a database where we could observe the condition of individual plant species in an ecotope with a certain level of hemeroby. The individual response of certain species that are within the studied area makes them the indicators of anthropogenic transformation. This allows us to move on to the second stage of modelling, which is the synphytoindication.

We used the standard Didukh-Plyuta formula to establish the indicators of the anthropogenic transformation in the presence of certain species in the geobotanical description of the plot and their projective cover (Khomiak *et al.*, ***2018***).

$$HE = \frac{k_1 Hm_1 + k_2 Hm_2 + \ldots + k_n Hm_n}{k_1 + k_2 + \ldots + k_n}$$

where HE – the level of the anthropogenic transformation of the ecosystem; Hm_1, Hm_2, Hmn – the middle of the amplitude of anthropotolerance of species; n – a number of informative views in the description; k_1, k_2, kn – the coefficient of the projective cover of the species in points according to J. Braun-Blanquet.

Using the Simargl software package, we obtained the indicators of the degree of the anthropogenic transformation for 3126 descriptions made on the territory of Ukrainian Polissia. These indicators can be used to build models of interactions between various factors and processes that occur in ecosystems. In addition, they can be generalized to different levels of classification in different types of the classification systems.

Synphytoindication models of the anthropogenic transformation of the ecosystems have all the advantages and problems of bioindicator methods. Their accuracy is reduced due to the lack of species in the created databases, the low number of species in descriptions, and the dominance of eurytopic species. Where there are less than 5 species per description, or if there are fewer than 5 of those present in the database, then we have an error that is too large for practical and theoretical conclusions to be drawn. This method shows good results only in the ecosystems with a large number of higher vascular plants in the database, their amplitude of tolerance to the anthropogenic factor having been well studied.

Modelling the anthropogenic transformation of the ecosystems, we can generalize the research result for any level of the classification. The main condition is that this classification correlates with the features of the autotrophic block of the ecosystems (Kuzemko *et al.*, 2018). This can be done by units allocated for the EUNIS system, Resolution 4 of the Berne Convention, the UkrBiotop, Appendix I of the Habitat Directive, dynamic and edaphic classification, and others (Khomiak *et al.*, 2018). Moreover, this can be made to classify ecosystems the autotrophic blocks of which are classified according to the method of J. Brown-Blanquet. For example, here we have summarized the data at the vegetation class level (Tab. 1).

There are 7 classes in oligohemeroby (4-6 points) according to the average values of indicators of the anthropogenic transformation. These are forest (with the classes Molinio-Betuletea pubescentis, Vaccinio-Piceetea, and Carpino-Fagetea), marsh (with the classes Scheuchzerio palustris-Caricetea and Oxycocco-Sphagnetea) and some rock (Asplenietea) and littoral ecosystems (Littorelleratea). Average ahemerobic values are not given here due to the lack of the required number of indicator species. However, some littoral ecosystems are included in the zone of the minimal anthropogenic transformation (1-3 points), having a value of the modelled indicator of 1.6 points.

The largest group of ecosystems identified in this way is located in the zone of mesohemeroby (7-9 points). This includes ecosystems with 24 classes of vegetation. Among them there are natural and partially transformed ecosystems. Seventeen of them have an oligohemerobic plot, and eleven have an evhemerobic plot.

The ecosystems with a high level ofanthropogenic transformation (ev hemeroby, 10-12 points) include 3 types – those that have autotrophic blocks in the form of vege-

Tab. 1. Indicators of the level of the anthropogenic transformation in points on the Didukh-Khomyak scale in the autotrophic blocks of the ecosystems at the class level according to the Braun-Blanquet classification.

Autotrophic block of the ecosystems	Statistical Factors			
	average	maximum	minimum	range
Charetea	6,6	7,41	5,85	1,56
Lemnetea	7,04	7,58	5,33	2,25
Potamogetea	7,31	9,5	5,5	4
Littorelletea uniflorae	3,67	6,74	1,86	4,88
Isoëto - Nanojuncetea	7,75	8,61	6,73	1,88
Phragmiti - Magnocaricetea	6,79	8,3	5,14	3,16
Scheuchzerio palustris - Caricetea	6,07	7,56	4,76	2,8
Oxycocco - Sphagnetea	5,36	7,82	4,8	3,02
Molinio - Arrhenatheretea	8,09	10,83	5,76	5,07
Calluno - Ulicetea	7,51	8,88	6,34	2,54
Nardetea strictae	7,12	8,78	5,61	3,17
Trifolio - Geranietea	8,02	9,6	6,68	2,92
Koelerio glaucae - Corynephoretea	8,28	9,05	5,57	3,48
Sedo - Scleranthetetea	7,83	9,71	5,66	4,05
Epilobietea angustifolii	8,15	9,56	6,25	3,31
Robinietea	7,8	9,84	5,78	4,06
Rhamno - Prunetea	7,84	9,09	6,94	2,15
Lonicero - Rubetea	7,61	9,61	6,36	3,25
Vaccinio - Piceetea	6,25	9,82	4,44	5,38
Carpino - Fagetea	6,46	8,78	5,64	3,14
Quercetea robori - petraeae	6,61	8,78	5,77	3,01
Quercetea pubescentis	6,83	7,15	6,23	0,92
Salicetea purpurea	8	9,57	7	2,57
Alnetea glutinosae	7,15	8,75	5,88	2,87
Molinio - Betuletea pubescentis	6,24	6,84	5,61	1,23
Pyrolo - Pinetea	7,26	7,81	6,67	1,14
Franguletea	6,93	8,27	5,18	3,09
Asplenietea	5,84	9,51	4,87	4,64
Stellarietea mediae	10,9	12	9,37	2,63
Artemisietea	9,66	11,3	7,43	3,87
Polygono arenastri - Poëtea annuae	9,62	10,4	8,93	1,47
Plantagenetea	9,13	10,5	7,81	2,69
Galio - Urticetea	7,98	9,58	6,41	3,17
Bidentetea tripartiti	8,13	9,71	6,63	3,08

tation classes Polygono arenastri-Poëtea annuae, Artemisietea, and Stellarietea mediae. The first two types have descriptions that are related to the less transformed mesohemerobic communities.

It was not possible to introduce polyhemerobic and metahemerobic ecosystems into the model using this method due to the absence here of multispecies communities of higher vascular plants described by the J. Braun-Blanquet method.

Determining the tolerance limits of species with respect to the anthropogenic factor is not a problem. The main thing is to objectively determine the magnitude of the anthropogenic factor and the manifestations of its influence. A. Borhidi suggests using naturalness values (NV), which are the opposite of hemeroby (Borhidi, 1995). This gives indicators of naturalness for 2.5 species of plants in Hungary. Their indicators range from -3 to +10. The author determines the vulnerability of the species using the naturalness index. This index consists of two classifications of species – life strategies (classification of social beshaviour types) plus rarity and vulnerability in relation to the anthropogenic factor. A. Borkhidi, in addition to hemeroby, uses other characteristics: urbanity, ruderality, xenicity, annuality.

However, all characteristics, with the exception of the share of annuals, are parts or individual cases of anthropogenic transformation of the environment, which determines anthropotolerance. In our opinion, the general value of anthropotolerance and its individual components should not be included in such a formula. On the other hand, the proportion of yearlings is not a universal factor. Ruderal and segetal ecosystems existed even before the appearance of human activity. They were pioneer ecosystems on naturally disturbed areas of land. These species react to disturbed natural and segetal territories in the same way. Therefore, their share is increasing both because of anthropogenic influence and due to natural violations of the integrity of the vegetation cover. That is why we only focused on the impact of human activity on the stocks of primary products and above-ground phytomass.

The resulting scales differ in the number of gradations. This is influenced not only by the author's approach but also by the number of described species. For example, the naturalness scale of A. Borhidi covers 2,591 species. To date, we have evaluated 3,547 objects. Considering the difference in the species diversity of Hungary and Ukraine, A. Borhidi's database better represents the level of anthropotolerance of ecosystems on this territory. However, in addition to higher vascular plants, we evaluated some common lichens, mosses, and algae. Also, we took into account different age communities for phanerophytes, as well as whether the plant is wild or cultivated. These characteristics have significant differences with respect to anthropotolerance.

Methods of using the anthropotolerance of individual species to determine the anthropotolerance of plant communities and ecosystems were developed in Poland, Germany, Hungary, and Ukraine. These methods are quite different from each other in terms of usage and mathematical models (Goncharenko, 2017). Usually, there is a transition from the classical types of hemeroby of Blume and Sukop to numerical scale points (Frank, 1990). Each previous type of hemeroby differs from the next one by 1 point. This approach leads to species with very different anthropotolerance within this score. We offer a more detailed system when each class is evaluated with three points.

Polish scientists B. Jackowiak and J. Chmiel suggest assigning 20 points to each class of hemeroby. However, there is no justification for such detailing. We know that there are typical representatives of a certain class, the optimum indicators of anthropotolerance of which are within its limits. Also, there are those that mostly belong to this class, but their ecological amplitude is shifted in one direction or another. This is proof that our three-point system is more effective than the one-point system of A. Borhidi and D. Frank or the 20-point system of B. Jackowiak and J. Chmiel.

B. Jackowiak and J. Chmiel propose calculating the anthropogenic impact within a certain plant communities by taking into account the ratio of the number of species of different classes of hemeroby. From these ratios, they determined the group's hemerophilia and hemerophobia, which indicated its general hemeroby. This method was criticized by R.I. Burda and J.P. Diduh (Burda & Diduh, 2003). On the one hand, this indicator depends on the number of species in the group. On the other hand, the species present in the group may have different meanings. The role and importance of the species in the grouping are best reflected by the projective coverage. That is why we use the classic synphytoindication formula, which takes into account the hemeroby of the species and its projective cover.

Based on further synphytoindication assessments of the hemeroby of the ecosystems, we can create a model of the mutual dependence between various environmental factors or dynamic processes with asn anthropogenic transformation. For example, it can be a model of the relationship between natural dynamics, determined through energy changes during autogenic successions with human activities. In other words, it is a model of a balance between the autogenic processes of the self-organization of the ecosystems and the allogeneic processes generated by humans (Fig. 3).

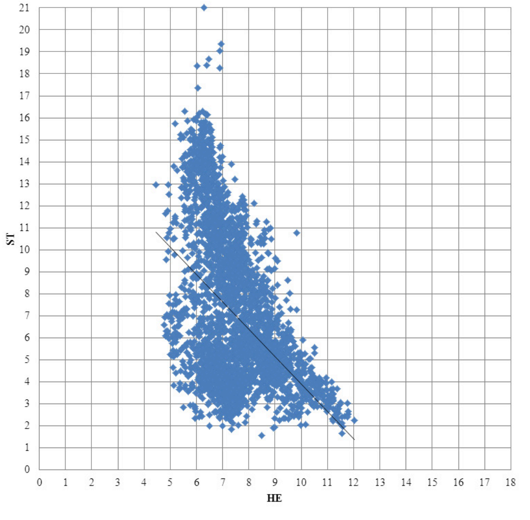

Fig. 3. The model of the influence of the anthropogenic pressure on the indicators of the natural dynamics of the ecosystems in Ukrainian Polissia. Explanation of Symbols: HE – the anthropogenic transformation indicator, ST – the natural dynamics indicator.

The model created on the basis of the empirical data points to the inverse linear relationship that we predicted in our initial hypothesis. This dependence can be described by the equation:

$$ST = -1{,}243HE + 16{,}33$$

where HE – the anthropogenic transformation indicator, ST – the natural dynamics indicator

The value of the reliability of the approximation of such a model is 0,2, and the correlation coefficient is 0.45. The allocation of individual parts of the ecosystems in relation to the trend line indicates the heterogeneity of the ordination field. It consists of two parts, which have visible differences. The first part has relatively low indicators of the natural dynamics and low indicators of the anthropogenic transformation. This is observed in the ecosystems of little use for economic activity: water bodies, swamps, sand dunes, rocks. The conditions that make such settlements unsuitable for their operation at the same time slow down the autogenic succession. For such ecosystems, the model has slightly lower coefficients:

$$ST = -0{,}5605HE + 8{,}519$$

The correlation coefficient for this group of ecosystems is 0,29.

For the main group of ecosystems, we can observe a stronger relationship between factors. The correlation coefficient is 0,85. Besides, the highest are the coefficients of the linear function describing this dependence:

$$ST = -2{,}1938HE + 25{,}694$$

CONCLUSION

Hemeroby of plant communities can be used as an indicator of anthropogenic transformation of ecosystems. To do this, we measure the boundaries of anthropotolerance of plant species, which make up these groupings.

The range of anthropotolerance of individual plant species can be determined by the 12 most common types of human activity. The strength of their impact on ecosystems was determined by the induced changes in above-ground phytomass. The transition from anthropotolerance of individual species to hemeroby of plant communities was carried out according to the classical synphytoindication technique using the formula

$$HE = \frac{k_1 Hm_1 + k_2 Hm_2 + \ldots + k_n Hm_n}{k_1 + k_2 + \ldots + k_n}$$

where HE – the level of the anthropogenic transformation of the ecosystem; Hm_1, Hm_2, Hmn – the middle of the amplitude of anthropotolerance of species; n – a number of informative views in the description; k_1, k_2, k_n – the coefficient of the projective cover of the species in points according to J. Braun-Blanquet.

We created an 18-point scale by assigning three points to each classic type of hemoroby. The use of the synphytoindication scale allows modelling the interdependence between anthropogenic transformation and measurable characteristics of the ecosystem

An inverse linear relationship with a probability of approximation of 0.2 and a correlation coefficient of 0.45 is an indicator of natural dynamics and the level of anthropogenic transformation. The correlation coefficient is 0.29 for ecosystems that are not suitable for economic use, and 0.85 for the rest.

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