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ABOVE-GROUND PHYTOMASS DYNAMICS IN AUTOGENIC SUCCESSION OF AN ECOSYSTEM

Ivan Khomiak*, Oleksandr Harbar, Nataliia Demchuk,
Iryna Kotsiuba, and Iryna Onyshchuk

Ivan Franko Zhytomyr State University, 40 V. Berdychivska Str., 10008, Zhytomyr, Ukraine.
*E-mail: ecosystem_lab@ukr.net

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Abstract

It was found that a regular growth in the above-ground phytomass occurs during autogenic succession, which is approximated by logarithmic dependence with high reliability indices. External, including anthropogenic, effects on the process of succession lead to a decrease in the rate of phytomass growth. Besides, the rate of phytomass changes is influenced by endo-ecogenesis caused by various plant species, entering the ecosystem at certain stages of succession. The above-ground phytomass portioning behaviour makes it possible to use it to create a unified indicator of dynamics. Each plant species can be only within certain indicators of the phytomass of their plant communities. At the same time, there is a normal distribution of the projective cover value. This allows us to work out synphytoindication methods for determining the dynamics indicator.

Key words: anthropogenic transformation, ecosystem dynamics, synphitoindication analysis, Ukrainian Polissia.

Introduction

One of the key issues of the integration of environmental theories is to find out the basis for their unification. The great majority of scientists believe that the thermodynamics of ecosystems should be basic (Odum 1971; Didukh 2008; Jørgensen 2002, 2006–2007; Svirezhev and Jørgensen 2004). Odum (1971) called the energy an ‘ecological currency’. The energy can serve as a means for assessing individual elements of ecosystems, structures, and various processes occurring within, including dynamic ones. The basis for energy transformations within the ecosystem are the laws of thermodynamics (Didukh 2008). The ecosystem, according to classical thermodynamics, is an open system where a constant energy cycle occurs along with changes in the level of the entropy (Svirezhev 2000). Until today the ecosystemologists approach to assess energy content, energy flows and the problem of entropy is a measure of disorder. At this stage of the research the transition to use of thermodynamics to assess dynamic processes in ecosystems is pressing. It became possible to combine ecology with technical and economic sciences through energy factors. It gives an opportunity to simulate processes in ecosystems, to predict and to evaluate them by using engineering and economic methods. The simulation based on thermodynamic factors is the basis for modern systems and synergetic approaches to wild life study (Didukh

2008). However, an objective and accurate determination of the energy flow rate in real ecosystems is a difficult technological problem. The red hot task today is to find the objective indicators available for the study that allow the researcher to retrace the dynamics of energy flowin ecosystems (Didukh 2008).

The energy that moves within trophic chains enters the ecosystem through the producers. They transform its chemical and physical types into energy of organic compounds – that is phytomass. The exceptions are the types of energy used indirectly such as sun light besides photosynthetically active radiation, heat, ionizing radiation. These types of energy act as external environmental factors. They can limit the development of an ecosystem or influence its attractors, but it is the internal energy which is a key in determining all ecosystem processes. The problem of assessing the internal energy is difficult, but it will be definitely associated with those species that are able to move between elements of the ecosystem. Most energy varieties that act as external factors are specific with rare exceptions. Only the energy of phytomass moving by trophic chains and turning into other species unites the ecosystem into a single synergetic unit. Therefore, it is the dynamics of phytomass that can be an indicator for models of thermodynamic processes (Lindeman 1942, Didukh and Lysenko 2010). Numerous studies of phytomass changes at different stages of succession indicate the validity of this forecast (Khaurdinova 2014, Khomiak 2018, Khomiak et al. 2018).

We have chosen autogenic succession as a reference sample of ecosystem dynamics. The mechanisms of syngenesis and endocogenesis work during its course with a minimum external influence. During real observations, we do not find ecosystems where only self-organization processes exist and external effects are completely absent. A statistically reliable result can be obtained due to a large number of observations. The pattern of phytomass change in various types of autogenic succession allows us to make a hypothesis that can be an indicator of internal processes that occur in an ecosystem during successions.

Ukrainian Polissia was chosen as a model. It is characterized by a high diversity of flora, which had come from different zones of the Circumboreal Region. The ecosystems of the Ukrainian Polissia are in different edaphic, orographic and microclimatic conditions at different stages of succession under various external influences including anthropogenic ones.

Material and Methods

The research was carried out by expeditionary and stationary methods. Materials for research are 835 standard geobotanical descriptions during expeditions and 80 descriptions from stations in the territory of Ukrainian Polissia. The descriptions for the field research were carried out on square lots of 4 m^2 for grassy vegetation, 100 m^2 for shrubs and 200 m^2 for forestry. The vegetation located ribbon-like was investigated in rectangular areas with a length of 2 m for grassy vegetation, 5–10 m for shrubs and 10–20 m for forestry. The thickness of the rectangular area was determined by the visual homogeneity of the living cover. The above-ground phytomass value and its age were determined as a part of the descriptions. The sites were formed in strata within edaphic and microclimatic conditions and anthropogenic impact. Sites are rectangular open area of

8 by 20 m in size and located on upland lots (plakor) with an exposure close to 0 °. They are oriented in length to latitudinal direction. By origin all sites were fallow sod pod soils of the first year once the cultivation was stopped. According to preliminary synphitoindication analysis the deviation in the initial factors of environment did not exceed on average 4 %: from 2 % for the total salt regime and illumination up to 8 % of the content of available nitrogen according to the Didukh-Pliuta phytoindication scale (Didukh et al. 1994). Each station was divided into 10 strata. Every year the above-ground phytomass of one of the stratum was withdrawn for weighing during the period of maximum vegetation (Rodin et al. 1967). Beforehand its standard geobotanical description was created. The removal of phytomass occurred first in the southern areas and then in the north from west to east.

A similar definition of phytomass was carried out for strata with meadow, agrocoenosis, ruderal, and shrub vegetation outside the station. The above-ground phytomass for forest ecosystems was determined by standard forest engineering methods (Anuchin 1977) or the available forest inventory materials were used. The age of perennial plants was established experimentally for shrubs, and for trees – by using classical forest engineering methods or materials of forest inventory. In woody vegetation areas where there are no forestry taxation materials, the forest density was determined by volumetric tables and tables of growth for normal-growing stock. The method error was ±5 %. The height was determined by using an angle finder, and the diameter was defined by using a caliper. The phytomass of the undergrowth, the understory and shrubs was determined by using measurements on square lots of 4 m^2 with uniform allocation or by line-intercept method (band width 1 m) for staggering location. Ten sample lots of 1 m^2 were laid to measure the aboveground phytomass of grass and shrub vegetation. Phytomass removal was carried out using the cut-sample method (Rodin et al. 1967).

The age of plants was determined by species for one- and two-year-olds, by an experimental approach for shrubs (cut with ring counting for 10 model species), by the number of rows of knots for some trees, and according to tables of growth in the absence of materials for other trees.

The vegetation as a part of the descriptions made was classified using the principles of Braun-Blanquet (Braun-Blanquet 1965, Weber et al. 2000) in regards to the vegetation prodrome of Ukraine (Solomakha 2008). The syntaxonomic scheme included 165 associations, distributed into 66 unions, 6 orders, and 27 classes. The power of anthropogenic impact was determined using the original synphytoindication technique (Didukh and Khomiak 2007) using the program Simagrl 1.12 (Khomiak 2018).

Results and Discussion

Lindeman (1942) foresaw a regular growth of the accumulated energy in ecosystems during self-development. Since this energy accumulates in the form of organic compounds, such changes should also relate to the phytomass or its individual parts. Our studies confirmed the growth of above-ground phytomass during the restoration of natural vegetation on sod-fields (Table 1). This type of dynamics is close to secondary autogenic succession. Under natural conditions, it is almost impossible to organize a large-scale experiment where the ideal autogenic succession will be modeled, and where changes will occur only due to syngenesis and endo-ecogenesis caused by the influence of biota on the environment without extraneous influences. More often we can find a combination of autogenic and allogenic successions of nature, the balance of which is shifted in a certain direction or in equilibrium (a catastrophic climax according to Odum 1971). However, we can define the direction and the type of deviation from the model under the condition of external influence. First of all, it is about anthropogenic impact. Stations with minimal anthropogenic impact will be closer to it, and will be respectful distant with the maximum one.

The rates of accumulation of above-ground phytomass differ at different sites (Table 1). And this distinction depends on the time. The results of the analysis indicated heterogeneity of indicator dispersion of the above-ground phytomass (P=0.009). The LSD test (ANOVA) was taken to check the reliability of differences between the studied sites within the conditions of the elevated phytomass, and the results of which were estimated taking into account the Bonferoni correction. The results of the analysis indicated significant differences between stations No 1 and No 4, No 1 and 7, and also No 4 and No 6 (Table 2). Thus, these are areas that cause the heterogeneity of the dispersion of the above-ground phytomass.

Table 1. Above-ground phytomass indicators in the stations, t·ha^{-1}.

Section \ Years	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	8.30	9.97	13.80	15.60	18.90	20.25	20.63	21.17	21.36	21.51
2	5.65	9.09	15.16	18.13	25.93	33.65	37.50	44.29	46.69	48.00
3	9.19	11.17	18.08	18.83	20.27	20.36	24.84	28.00	28.41	31.70
4	8.73	11.17	20.23	21.53	40.52	42.72	45.39	46.59	53.43	55.25
5	6.18	15.47	19.95	20.60	26.83	27.95	29.22	36.04	36.17	36.53
6	8.22	14.77	18.00	19.83	19.93	21.52	21.52	21.55	21.80	21.48
7	12.87	16.48	23.05	23.76	33.33	41.02	45.12	48.01	48.02	48.28
8	5.47	15.59	16.80	19.26	21.39	38.81	42.58	45.38	47.30	50.89

Table 2. Estimates of differences in the above-ground phytomass taking into account the Bonferoni correction (ANOVA, LSD-test).

Station number	2	3	4	5	6	7	8
1	0.044336	0.476705	<u>0.002283</u>	0.133614	0.756575	<u>0.003095</u>	0.019049
2		0.187265	0.267753	0.598017	0.086919	0.313596	0.725953
3			0.016792	0.425322	0.687273	0.021723	0.096656
4				0.104020	<u>0.005659</u>	0.918971	0.446766
5					0.231780	0.126874	0.380988
6						0.007523	0.040387
7							0.509497

The differences in phytomass indicators at different stations are shown in the diagram (Fig. 1). As it can be seen, stations differ both in average values of phytomass and in the nature of variability (rates of growth in above-ground phytomass).

There are two most likely causes for the change in the rate of growth in the above-ground phytomass: endoecogenesis and anthropogenic impact (Fig. 2). The value of the anthropogenic impact on individual areas differed. It was overestimated in sites No 1 and No6. There were marks of live-stock grazing and poaching (recreation) here. Marks of live-stock grazing were noted in the site No 1, starting from 2-year observation, and in the site No 6 – since 5 years. At the same time, there is a significant positive correlation between the change in the above-ground phytomass and the power of anthropogenic pressure (r=0.77).

High correlation is for changes in above-ground phytomass and some indicators of edaphic factors. First of all, it concerns the general salt regime (0.83), the content of available nitrogen (0.83) and the aeration of the soil (0.85). In all these cases, the inverse linear relationship was observed – in due time, these indicators decreased, and the phytomass continued growing. This process is due to several reasons. First, the strata are former agroecosystems where overestimated salinity levels, including nitrates and ammonium salts, were artificially held up. High aeration was held up by regular cultivation.

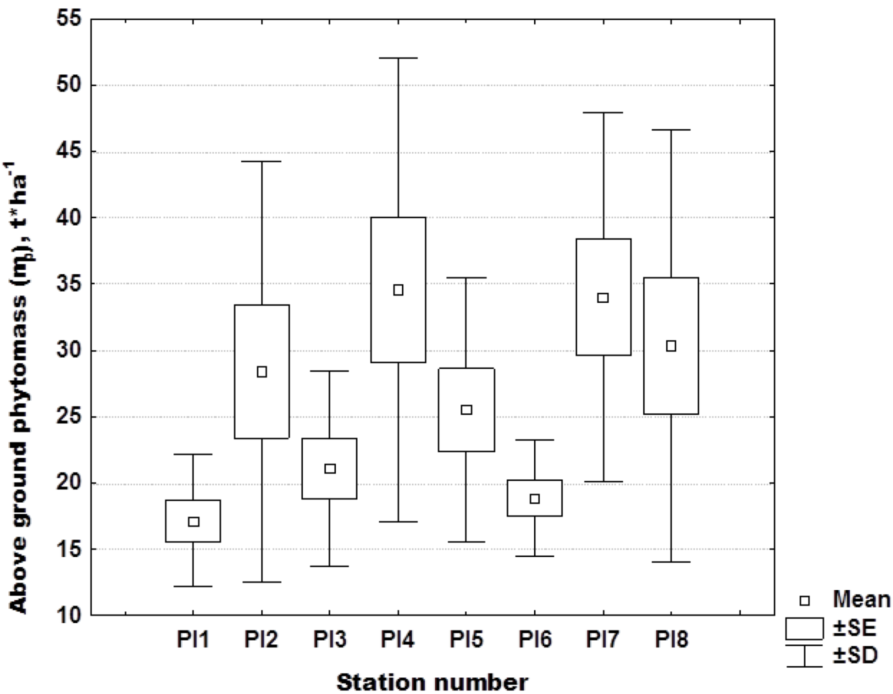

Fig. 1. Variability of phytomass indicators.

Legend: Mean – arithmetical mean; SE – standard error; SD – standard deviation, m_p – above-ground phytomass.

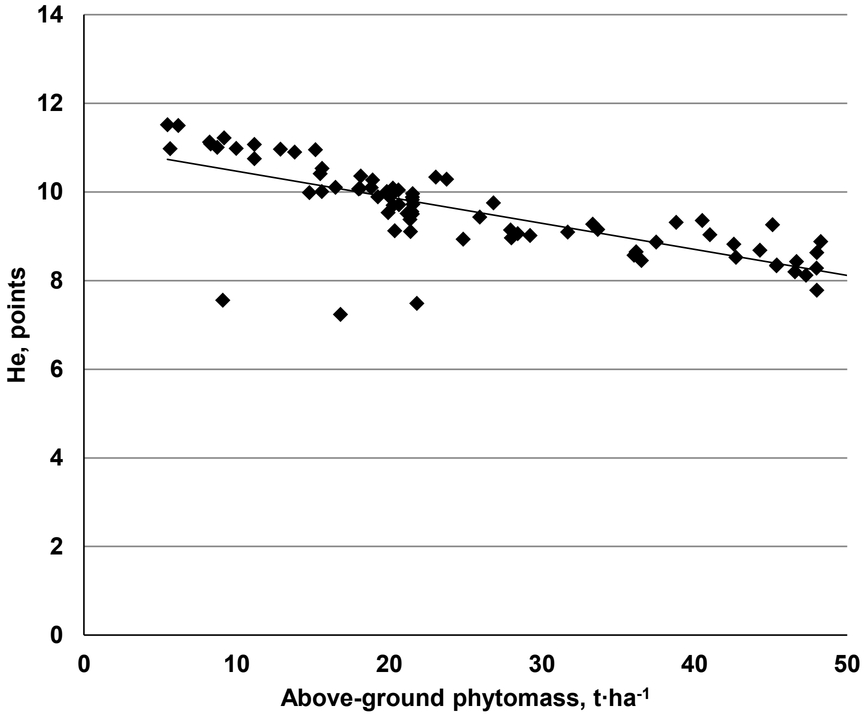

Fig. 2. Dependence of changes in the above-ground phytomass on the indicator of anthropogenic transformation (He).

Termination of crop growing started the natural processes of reducing of such indicators. They occurred faster than others at certain stations. This was facilitated by the healthy growth of phanophytes which absorbed the above-mentioned salts brought along. For example, this can be observed at the site No 4, where the decrease in the salt regime occurs most actively together with the high rates of phytomass growth. Since the fifth year the strata overgrowing, *Pinus sylvestris* L., that is an active transformer of the edaphotop, has been actively spreading here. Besides, in some sites, starting from the sixth year of the strata overgrowing, *Betula pendula* Roth appears, that is also capable to transform the edaphotop in the direction of the salt content decrease in due time. This is particularly shown on sod-podzolic soils with low humus content (Naumova et al. 2005, Sorokina and Sorokin 2006).

Syngenesis is associated with the formation of vegetative cover from seeds or vegetative parts of plants that were already in the soil or penetrated outside. In some cases, the growth rate of phytomass may vary depending on their species composition. This can be carried out both through active endo-ecogenesis caused by these species, and their allelopathic properties. For example, the appearance of *Hieracium pilosella* L. together with *P. sylvestris* in the fourth site led to the active suppression of meadow vegetation and the formation of a floristic block close to the class *Koelerio-Corynephoretea* Klika in Klika and Novák (1941).

Thus, both the anthropogenic pressure and the transformation of the edaphotop affect the dynamics of the above-ground phytomass value in various stations due to the appearance of certain types of edificators here.

The dynamics of the above-ground phytomass in regards to the logarithmic trend line has got the measure of the approximation reliability of 0.59. The correlation index for this pattern is quite high – 0.77. Despite the differences in time and environmental conditions, these results are very close to those obtained by Khaurdinova (2014) for the Kyiv Polissia strata (Fig. 3).

The equation (1) for our model is the logarithmic function:

$$y=4.1159+14.645\cdot \ln x \qquad (1),$$

where: y – stock of the above-ground phytomass, t·ha^{-1}; x – time from the beginning of the strata overgrowing, years.

It should be noted that there is a high similarity of the coefficient '*a*', obtained in our case (*a*=4.1159) and in the researches of Khaurdinova (*a*=3.8) (Khaurdinova 2014). Despite the ninety-year difference in the strata overgrowth, this index is very close, which may indicate the likely possibility of creating a universal mathematical model for the dynamics forecast.

Eighty descriptions made at stations during the first ten years of strata overgrowing are not enough to create a full-fledged model of the dynamics of ecosystems. To expand the selected amount of data from the entire data set of 835 descriptions, we chose 251, close to the conditions within stations according to the conditions of edaphic indices (Fig. 4).

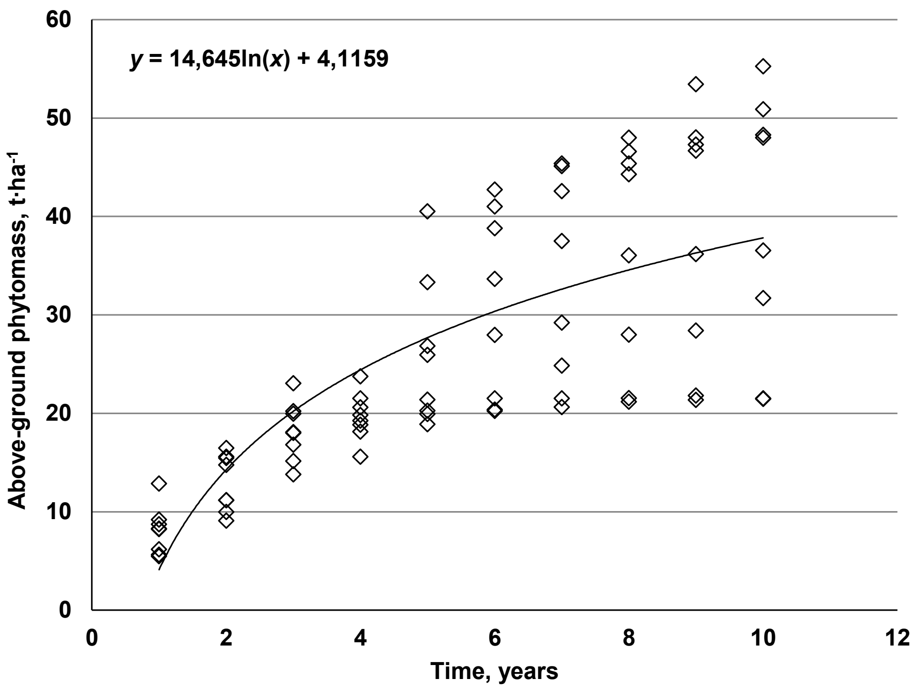

Fig. 3. The change in the above-ground phytomass at the stations in due time.

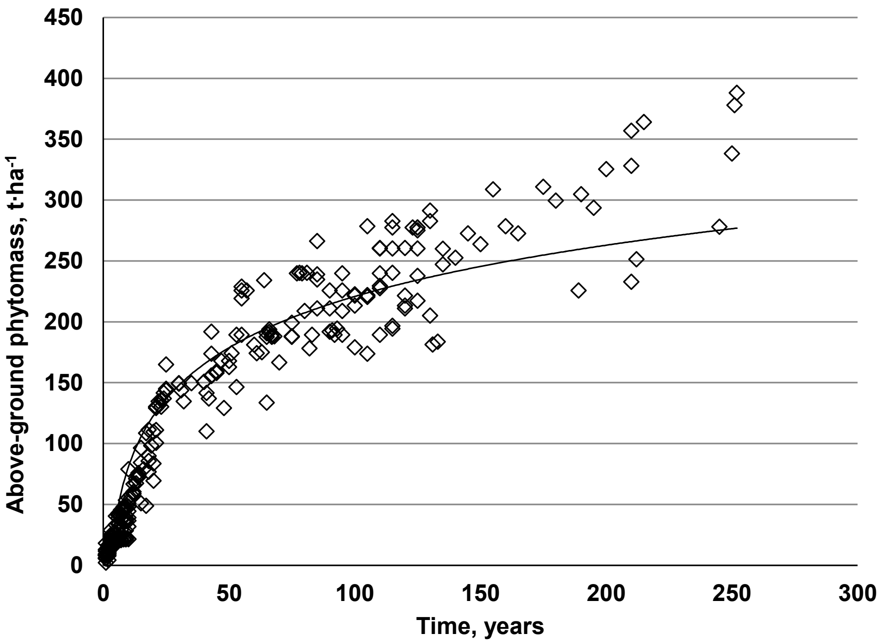

Fig. 4. The change in the above-ground phytomass in due time in the conditions of similar stations.

As a result of approximation of the logarithmic curve, we get the equation (2):

$$y=58.785+60.718\cdot\ln x \qquad (2),$$

A significant difference in the indicators is due to the difference in the age of plantings, their type. Our research at stations covers the strata overgrowth in the first ten years, while the studies of Khaurdinova (2014) cover the reproduction of pine forests on the strata for 100 years. Besides, our generalized research has already included all types of plantings in similar edaphic conditions. In addition, plantings over the age of 120–130 years are very little described. Therefore, the exact location of the set of points in this zone is unknown to us. Most of the age plantings came under influence of the anthropogenic effects of various types (recreation, salvage cutting, etc.). To exclude cases of allogenic successions from our model, we applied a filter that excluded all ecosystems elder than 10 years with a level of anthropogenic transformation above 9 points according to Didukh-Khomiak scale (according to Blume and Sukopp 1976).

This allows us to define the problem of the existence of a single mathematical model for all variants of the dynamics of ecosystems. In other words, does it lead to the expansion of the range of studies in a universal formula or whether there is its own mathematical pattern for each variant of successions? To solve this problem, it is necessary to integrate all possible measurements of phytomass reserves in plantings with the known age. If we advance the hypothesis that any deviation from autogenic succession towards allogenic leads to a decrease in phytomass, then we can take the maximum values for each age group and build a model based on the patterns of their location. An exception to the above case may be the penetration of species with high efficiency of photosynthesis (type C4 instead of C3); anthropogenic activity is associated with artificial plantings of fast-growing phanerophytes or with growth in soil fertility with mineral fertilizers or organic waste. These cases are not common enough. Their influence can be reduced if the model is applied only for a separate environmental zone or a geobotanical sub-province, and also a significant number of measurements is used under controlled conditions (objects of the nature reserve fund).

High correlation rates were observed between the planting age and their above-ground phytomass – 0.77 and 0.94, respectively in both cases studied. This shows the possibility of using the value of the stock of above-ground phytomass as a basis for deriving the dynamics indicator. This value will allow not only to assess the state of ecosystems as a link of succession series, but also to become the basis for predicting their future development.

We suggested a hypothesis that species can exist only with certain values of the above-ground phytomass that reserve in the ecosystem. To this end, it was established how the projective cover of certain plant species changes with a change in the above-ground phytomass of the groups to which they belonged (Fig. 5). These changes can be described by the

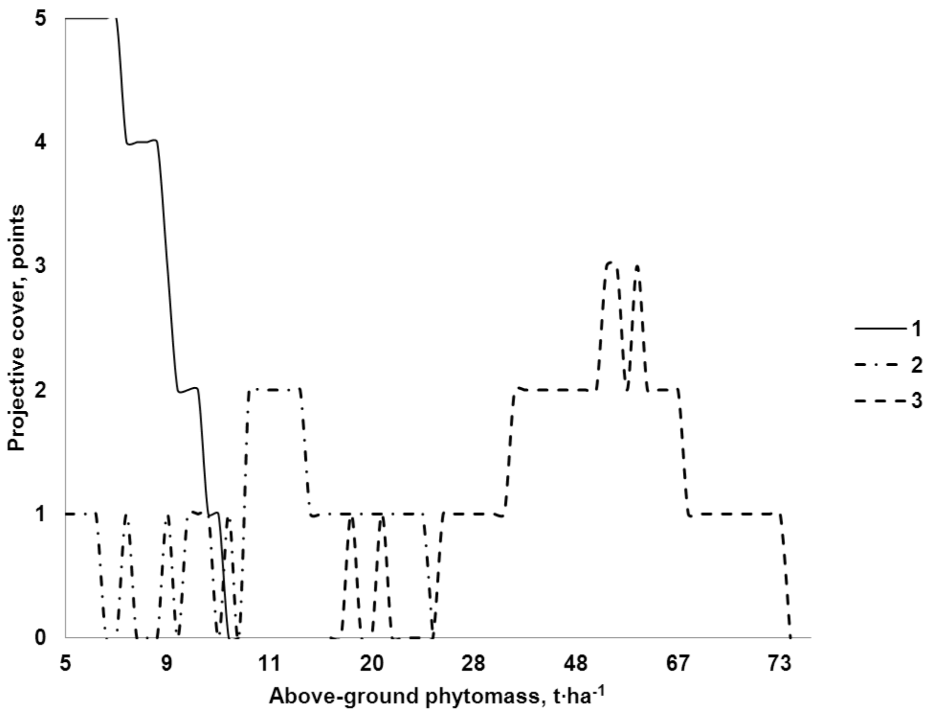

Fig. 5. Change of the complex factors of projective cover *Echinochloa crusgalli* (L.) P. Beauv. (1), *Convulvulus arvense* L. (2) and *Salix caprea* L. (3) in groups with various indices of the above-ground phytomass.

normal distribution (Gauss curve) according to the Shelford tolerance law. Each of the species can only be in certain limits of endurance. The deviation from the optimum is accompanied by a decrease in the projective cover of the species. This opens up the possibility of using of synphyteindicative methods for determining the dynamics indicator.

Conclusions

During the process of autogenic succession, a regular growth in the above-ground phytomass occurs, which is approximated with a high reliability index by logarithmic dependence.

Anthropogenic factors and endoecogenesis, caused by various plant species that penetrate the ecosystem at certain stages of succession, affect the dispersion growth of the above-ground phytomass indices.

The regularities of the distribution of the above-ground phytomass value allow using it to create a unified indicator of dynamics.

Each plant species can be only within the certain indicators of the phytomass of their plant communities. At the same time, there is a regular distribution of the projective cover value. This allows us to develop synphytoindication methods for determining the dynamics indicator.

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