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On the Formal and Informal Estimates of Floristic Diversity: An Example of Pine Forests of the Southern Urals

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Abstract—Advantages of the informal assessment of biodiversity based on the phytosociological spectrum (the ratio of species associated with different higher units of ecological-floristic classification in the cenoflora) are demonstrated in a study of pine forests of the Southern Urals (classes Vaccinio-Piceetea, Brachypodio-Betuletea, and Querco-Fagetea). The phytosociological spectrum reflects environmental conditions better than formal estimations of α, β, and γ-diversity.

Key words: biodiversity, formal and informal criteria, the Southern Urals, pine forests, phytosociological spectrum.

The problem of revealing trends in floristic diversity becomes more pressing in the periods of increasing anthropogenic influences on biosphere, because the diversity of heterotrophic biota is connected with the diversity of plant species. Hence, monitoring the floristic diversity of some areas or plant communities is becoming the most important component of general biological monitoring, which allows the assessment and optimization of such influences on ecosystems (Gorchakovskii, 1984, 1999).

The system of formal estimations of biodiversity (Mirkin and Naumova, 1998) is widely used in ecology presently. This system includes α-diversity (species diversity in the community), β-diversity (diversity of communities), and γ-diversity (species diversity in the landscape or region). Many works are devoted to the nature of α-diversity (Palmer, 1994; Mirkin and Naumova, 1998). Malyshev (1991, 1993; Malyshev *et al.*, 1994) demonstrated the dependence of γ-diversity on the area, specific features of vegetation, and geographic conditions of different regions. In our opinion, however, such formal estimations of biodiversity can often be of low information content, because the resultant indices may conceal basic differences in the patterns of formation and dynamics of floristic composition.

MATERIAL AND METHODS

The comparison of formal and informal estimations of biodiversity was performed using an example of pine forests of the Southern Urals (for completeness, including pine forests of adjoining plains). Pine forests are among the most widespread formations of forest vegetation. Their geographic range extends from Great Britain to the Far East, and habitats are most diverse: from moss bogs to sands and rock outcrops. Studies on pine forests of Russia and the Urals provided a basis for special generalizations made in the works of Russian scientists (Kolesnikov, 1961; Rysin, 1975; Sannikov and Sannikova, 1985; Fil'roze *et al.*, 1990). The high ecological and syntaxonomic diversity of pine forests has been emphasized by other European researchers (Kelly and Connolly, 2000).

In Bashkortostan, pine forests are much more diverse than forests of any other formation. This can be explained by extended geographic gradients (vertical zonation accounted for by the Ural Mountains) and specific biogeographic position of Bashkortostan at the Europe–Asia interface, where the floristic combinations of European and Siberian floras "collide" with each other.

For the analysis of floristic diversity, all pine forests studied by our team have been combined into five ecological–physiognomic types, which correspond by volume to the unions of ecological–floristic classification:[1]

(1) Steppificated pine forests—union Caragano fruticis-Pinion sylvestris.

(2) Steppificated-herbaceous pine forests—union Veronico teucrii-Pinion.

(3) Moist-herbage pine forests—union Trollio europaeae-Pinion.

(4) Nemoral-herbage pine forests—union Aconito septentrionalis-Tilion.

(5) Green-moss pine forests—Dicrano-Pinion.

[1] Since the syntaxonomy of pine forests is not discussed in this work, the authorship of syntaxa is omitted.

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The main diagnostic species providing an idea of specific ecological and floristic features of these types are listed in Table 1.

Both formal and informal criteria were used to assess floristic diversity. The formal criteria were as follows: (a) α-diversity, or the number of species in one description of a 1000-m^2 test plot; we determined the average number of species and the range of variation in this parameter in the communities of every union; (b) β-diversity, or community diversity; we determined the number of associations and the number of lower syntaxa of the system (i.e., variants or subassociations, depending on the degree of development of intraassociation syntaxonomy); and (c) γ-diversity, or cenoflora of the union (Yurtsev and Kamelin, 1991; Yurtsev, 1994); we considered both the entire cenoflora and its individual fractions comprising higher vascular plants (herbaceous plants, trees, and shrubs), mosses, and lichens.

As an informal criterion, we used the phytosociological spectrum of a community (Mirkin and Naumova, 1998), i.e., the proportions of different species groups associated with different higher units of ecological–floristic classification in the cenofloras of different pine forests. The phytosociological spectrum was assessed at the level of classes:

(1) Brachypodio-Betuletea: hemiboreal herbaceous mesophytic pine, larch, and birch forests of Western and Central Siberia.

(2) Querco-Fagetea: mesophytic and mesoxerophytic broad-leaved deciduous forests on rich soils in the temperate zone.

(3) Vaccinio-Piceetea: boreal coniferous forests on pure acid soils with well-developed moss cover.

(4) Festuco-Brometea: steppes, xerothermic and semixerothermic herbaceous communities.

(5) Trifolio-Geranietea: meadow communities of forest margins and open forests.

(6) Molinio-Arrhenatheretea: secondary postforest meadows of the Eurasian temperate zone. Taking into account the broad ecological range of this class, the assessment was made by two orders, Arrhenatheretalia (true meadows) and Molinietalia (moist meadows), because these orders sharply differ in both ecological characteristics and floristic composition.

The species connected with other classes and the species of indefinite syntaxonomic position were included in the group "others."

The term "species of the class (order)" was used in a broad sense; i.e., it referred not only to the diagnostic combination of the corresponding syntaxon, but also to the species included in syntaxa of lower rank. In order to reflect the contributions of species to the composition of a community, we constructed the spectrum with regard to species constancy, rather than mere presence in the community. Thus, instead of the list of cenoflora, the sum of constancy classes of these species was taken as 100%, and the list was reduced by omitting the species that failed to reach a constancy of 20% in any union.

RESULTS AND DISCUSSION

The results of assessing floristic diversity by formal criteria are presented in Table 2. Such a quantitative assessment does not reveal differences in species richness (α-diversity) between different ecological types of pine forest communities: the average values of this parameter in different unions vary from 53 to 59 species, whereas the ranges of its variation within these unions are significantly broader and overlap.

The indices of β-diversity are more informative. In this case, two peaks are distinguished, which provide evidence for the diversity of communities under the conditions characteristic of the unions. The first peak corresponds to the union Trollio-Pinion. These are pine forests growing on well-developed soils in the mountains, where soil fertility and moistening can differ significantly depending on slope exposure, steepness, and other local conditions. The second peak of β-diversity is observed in boreal forests, where a great number of associations and units of lower class have been revealed.

The highest γ-diversity, i.e., the volume of cenoflora in the union, was observed in steppificated and moist-herbage pine forests. The proportion of mosses is minimal in the communities of nemoral-herbage pine forests but is relatively high in other unions, although the species composition and cenotic role of mosses differs from union to union. In herbaceous forests, mosses occur mainly as isolated patches on the bases of trunks and decaying wood (epixylous mosses); In green-moss forests, they are dominants of the ground vegetation layer (epigeal mosses) and play an important environment-forming role largely determining the species composition of vascular plants.

Table 3 shows the results of the informal assessment of floristic diversity based on phytosociological spectrum. It is seen that the cenofloras of the unions differ significantly. Species of the class Brachypodio-Betuletea and the order Arrhenatheretalia are represented in all unions more or less equally, whereas the proportion of steppe species of the class Festuco-Brometea sharply increases in the union Caragano-Pinion, and that of species of the class Trifolio-Geranietea, in the union Veronico-Pinion. The proportion of species characteristic of moist meadows (order Molinietalia) becomes greater in the union Trollio-Pinion, the role of nemoral species of the class Querco-Fagetea sharply increases in the union Aconito-Tilion, and that of boreal species of the class Vaccinio-Piceetea, in the union Dicrano-Pinion. Thus, similar formal estimations of floristic diversity can refer to the cenofloras that strikingly differ in ecological structure, and these differences can be revealed by constructing their phytosociological spectra.

Table 1. Abridged diagnostic table for five types of pine forest in Bashkortostan

Species	Vegetation layer	Pine forest type and number of descriptions				
		1	2	3	4	5
		70	72	230	31	101
Pinus sylvestris	-t1	V	IV	V	V	V
Larix sibirica	-t1	III	IV	II	r	III
Betula pendula	-t3	IV	IV	IV	II	V
Calamagrostis arundinacea	-hl	V	V	V	V	V
Rubus saxatilis	-hl	V	V	V	V	V
Brachypodium pinnatum	-hl	V	IV	V	III	V
Lilium pilosiusculum	-hl	II	III	IV	II	IV
Vicia sepium	-hl	+	II	V	II	III
Chamaecytisus ruthenicus	-s1	IV	IV	III	II	V
Adenophora lilifolia	-hl	III	III	IV	I	V
Primula macrocalyx	-hl	II	IV	IV	+	II
Caragana frutex	-s1	V	II	r	II	r
Centaurea sibirica	-hl	V	r	r	.	+
Artemisia sericea	-hl	IV	II	r	+	r
Viola rupestris	-hl	IV	r	+	+	II
Poa transbaicalica	-hl	IV	r	r	.	r
Cerasus fruticosa	-s1	IV	I	r	II	.
Rosa majalis	-s1	III	V	II	I	II
Filipendula vulgaris	-hl	III	IV	I	I	II
Vicia cracca	-hl	I	IV	I	I	I
Seseli libanotis	-hl	V	IV	I	II	II
Origanum vulgare	-hl	V	IV	II	II	I
Luzula pilosa	-hl	I	r	IV	III	V
Aegopodium podagraria	-hl	+	II	IV	IV	II
Trollius europaeus	-hl	.	II	IV	r	II
Aconitum septentrionalis	-hl	r	I	IV	I	I
Trientalis europaea	-hl	.	r	IV	I	IV
Cirsium heterophyllum	-hl	r	r	IV	r	II
Euonymus verrucosa	-s1	+	.	.	V	r
Lonicera xylosteum	-s1	I	r	r	IV	+
Tilia cordata	-t2	II	II	+	IV	+
Picea obovata	-t3	.	.	r	III	+
Asarum europaeum	-hl	r	.	r	III	r
Quercus robur	-t3	III	II	r	III	+
Pleurozium schreberi	-ml	IV	II	IV	II	V
Hylocomium splendens	-ml	II	+	II	r	V
Ptilium crista-castrensis	-ml	II	I	II	.	V
Rhytidiadelphys triquetrus	-ml	I	II	III	+	V
Vaccinium myrtillus	-hl	r	.	II	I	V
Orthilia secunda	-hl	II	I	III	IV	V

Note: The numbers of syntaxa correspond to their sequence in the text. Vegetation layers: (t1, t2, t3) the first, second, and third tree layers, (s1) shrub layer, (h1) herbaceous layer, and (m1) moss layer.

Table 2. Main indices of floristic diversity of pine forests in Bashkortostan

Criteria	Forest type				
	1	2	3	4	5
Alfa-diversity					
average	58	58	59	53	54
ranges of variation in different subassociations	52–64	36–66	48–78	31–62	40–66
Beta-diversity					
at the level of associations	2	4	6	2	6
at the level of lower syntaxa	4	5	14	4	11
Gamma-diversity					
total	373	476	494	274	380
herbaceous plants	232	340	339	204	258
trees	13	16	20	21	16
shrubs	17	15	17	19	14
mosses	84	60	82	30	66
lichens	27	45	36	?	16

Table 3. Phytosociological spectrum of pine forest in Bashkortostan

Floristic combination of syntaxa	Forest type				
	1	2	3	4	5
Brachypodio-Betuletea	21.5	24.5	26.4	19.4	27.2
Festuco-Brometea	30.2	15.6	1.9	4.5	6.0
Trifolio-Geranietea	7.2	12.2	9.6	8.7	7.5
Molinietalia	0.3	3.1	4.7	–	1.9
Querco-Fagetea	11.8	14.0	22.0	39.7	15.0
Vaccinio-Piceetea	10.0	9.2	14.3	12.0	25.1
Arrhenatheretalia	12.1	14.3	13.0	8.3	11.3
Others	6.9	7.1	8.1	7.4	6.0

Both formal and informal estimations of floristic diversity are important for biological monitoring; i.e., it is important to take into account both how many species or communities grow in a certain area and what are these species and communities. Informal criteria, compared to formal, can be more informative in some cases, because the phytosociological spectrum better reflects the nature of ecological factors governing the formation of a forest community and allows indirect estimation of environmental changes.

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