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Hemeroby assessment of the flora of the north-western part of the Altai-Sayan province

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Abstract. Based on the regional flora studied by the authors (north-western part of the Altai-Sayan floristic province, subdivided into 13 operational botanical-geographical regions), an assessment of the degree of transformation of territories at the level of large units of the rank of botanical-geographical regions according to the structure of hemeroby tolerance of their floristic composition was made. This study revealed a rather close relationship between the distribution of species by ecological-coenotic groups and hemeroby classes. These indicators can be used for floristic zoning and assessing the level of anthropogenic transformation of flora.

1 Introduction

For territories that differ in population density, level of industrial and agricultural development, an important indicator of the impact on the plant world is a complex indicator – hemeroby [1], or the degree of disturbance, reflecting the integral effect of changes in the natural state of ecosystems as a result of anthropogenic impact. Since the values of this indicator cannot be obtained by direct measurements, ecological scales are used for its indirect assessment – a traditional tool for quantitative indicator value (IV) analysis, or phytoindication analysis [2]. Several similar scales have been published and effectively used to quantify the degree of disturbance, differing in geographic coverage, format of indicator statuses, and discreteness of the hemeroby gradient [3–6]. For the territory of southern Siberia, the authors developed a scale of plant hemeroby tolerance [7]; the same paper provides a methodology for constructing the scale and its detailed parameters. Here is a brief descriptive characteristic of the scale: type: amplitude-optimal; number of gradations: 9; number of indicator taxa: 2747, of which 846 have incomplete (preliminary) statuses; average amplitude of tolerance (in scale gradations) – 3.904 ± 0.041 (here and below, the arithmetic mean values are given with their standard errors).

Traditionally, the degree of disturbance is assessed at the level of individual phytocoenoses or coenofloras [8]. In comparative floristic works this type of analysis is

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rarely used. Thus, we exploited it in the mentioned work [7] as an index of integral disturbance of the catchment areas of the Tom River tributaries within the framework of the basin approach to the study of floras.

The aim of this work is to assess the level of transformation of territories at the level of large units at the rank of botanical-geographical regions according to the structure of hemeroby tolerance of their floristic composition, the use of these indicators for the purposes of zoning classification, as well as identifying the relationship between the distribution of species by categories of hemeroby tolerance and their distribution by ecological-coenotic groups (EC groups).

2 Materials and methods

2.1 Study area and Materials

As the object of our research we have chosen the flora of the north-western part of the Altai-Sayan floristic province (NWASP). This territory, located between the vast plains of Western Siberia, on one side, and the high mountains of Altai and Sayan, on the other, can be considered as a huge ecotone zone. This is a region with a rather complex relief, a very long history of vegetation development and very diverse vegetation. The boundary position of the studied territory, together with the uniqueness of individual landscapes and communities, determines the high taxonomic diversity and significant level of endemism of the region’s biota. Here, in a relatively small area (some 220 thousand square kilometers, which is just over 2.2% of the entire territory of Siberia), more than 2 thousand species of vascular plants grow (together with alien species, this is about 2.4 thousand species), which is approximately half of the species composition of the flora of Siberia. The territory of the NWASP has been experiencing diverse human influences for a very long time, and now it is one of the most populated and human-modified regions of Siberia. The steppe and forest-steppe regions of Altai and Khakassia are the territories from which the settlement of Southern Siberia by ancient people began hundreds of thousands of years ago. By now the plant cover of these regions has been greatly transformed as a result of centuries of agricultural development. Currently, the rural population density in a number of areas of the NWASP exceeds 10 people per 1 km^2, and these are the highest values within the whole of Siberia. The territory of modern Kemerovo Oblast is home to the Kuznetsk Coal Basin (‘Kuzbass’), and this region is currently one of the main coal-mining regions of Russia. The largest area of land disturbed by coal mining in Kuzbass is in the Kuznetsk intermountain basin [9]. Mining of gold, aluminum, manganese and other metals is carried out on a large scale in some areas of the Kuznetsk Alatau and Salair Ridge. Within the NWASP there are such large cities as Novosibirsk, Kemerovo, Novokuznetsk, Tomsk and others. The transport network is well developed mainly in the foothill and low-mountain areas, this is represented by roads (in particular, a section of the famous Chuysky tract is located here) and, to a lesser extent, railways (including a small section of the Trans-Siberian Railway). There are a number of tourist routes along the NWASP, and many areas are favorite places for unorganized recreation. In this regard, a special study of anthropogenic trends in changes in the flora of this territory seems very relevant.

The author’s scheme of operational botanical-geographical regions is used in the present work (Fig. 1). These regions, used for further comparative analysis, were identified on the basis of regional vegetation cover characteristics, taking into account geographical location and relief. At the same time, different regions, possessing specific territorial patterns of economic development, should theoretically be populated by groups of species with varying degrees of hemeroby tolerance. This gives rise to the idea that the spectra (or structures) of regions according to hemeroby can be used for their classification on a par with the floristic composition at the species level.

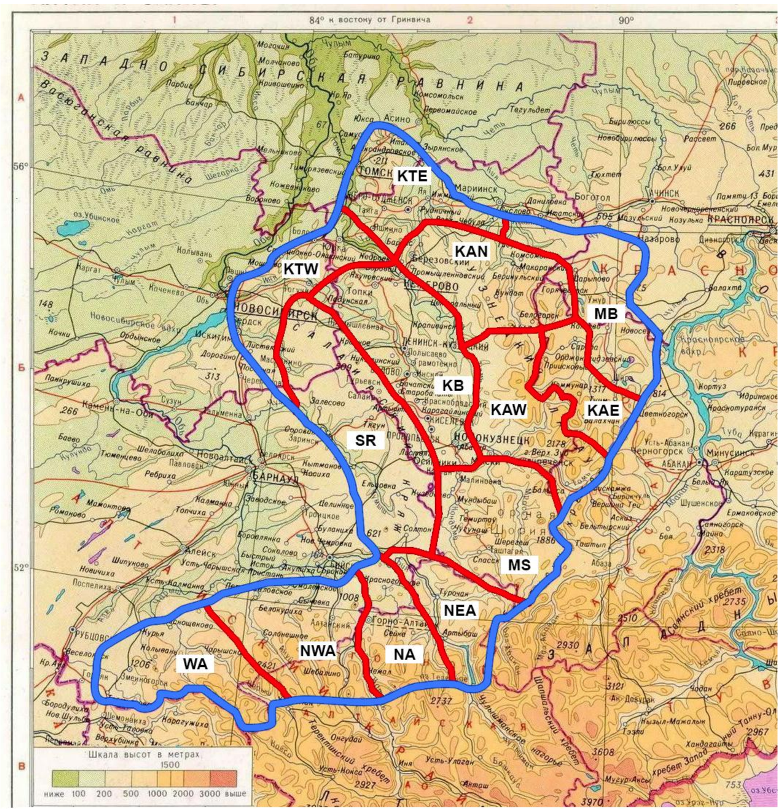


Fig. 1. A scheme of operational botanical-geographical regions of NWASP (for names of regions see Table 2)

2.2 Evaluation of hemeroby

Environmental information is used on all indicator taxa that are part of the taxonomic list of coenosis or flora to obtain a quantitative assessment of the synecological optimum of a plant community or flora of any rank and nature. The methods for obtaining average status described in details in our paper [2]. We used *Weighted averaging methods* for calculating average status in this research: *Weighted by frequency and tolerance averaging method* for floras of operational regions and *Weighted by tolerance averaging method* for lists of EC groups. An important condition for the application of IV scales is sufficient representation of indicator species in taxonomic lists. Another parameter is the index of ecological consensus, which shows the degree of consistency of the overlap of the ecological tolerance amplitudes of species in the taxonomic list – objective indicator of the degree of environmental homogeneity/heterogeneity of coenosis or flora.

For brevity, we present the taxonomic and hemeroby parameters of operational regions of NWASP in Table 1. Mean values for all included parameters are as follows in the same order: 1025.31 ± 48.75, 3.40821 ± 0.09719, 0.85728 ± 0.00834, 0.73160 ± 0.00331.

Table 1. Taxonomic and hemeroby parameters of operational regions of NWASP: *Abbrv* – abbreviated name of the region; *Name* – full name of the region; *Species* – total number of species; *Status* – average hemeroby status; *Indicators* – share of indicator-taxa of whole species list; *Consensus* – index of ecological consensus

Abbrv	Name	Species	Status	Indicators	Consensus
WA	Western Altai	1379	3.12057	0.80638	0.74154
NWA	North-Western Altai	1304	3.19492	0.81365	0.73927
NA	Northern Altai	1062	3.11112	0.85217	0.72196
NEA	North-Eastern (Priteletsky) Altai	1044	3.04486	0.82950	0.72232
MS	Mountain Shoria	950	3.56510	0.85053	0.71940
SR	Salair Ridge	949	3.70951	0.87777	0.73418
KB	Kuznetsk Basin	1031	3.80576	0.86227	0.74000
KAW	Kuznetsk Alatau (western region)	776	3.04687	0.88531	0.70546
KAE	Kuznetsk Alatau (eastern region)	1038	2.98372	0.86705	0.74316
KAN	Kuznetsk Alatau (northern region)	846	3.63679	0.90189	0.73231
MB	Nazarovo-Minusinsk Basin (northern part)	1164	3.29774	0.83247	0.74775
KTW	Kolyvan-Tomsk Plateau (western region)	948	3.85757	0.89451	0.73766
KTE	Kolyvan-Tomsk Plateau (eastern region)	838	3.93223	0.87112	0.72579

2.3 Brief description of EC groups

Since certain EC groups combine species with similar ecology, and therefore similar attitudes to habitat disturbance, we assume that the EC spectra of areas can be used for their classification along with the floristic composition and hemeroby spectra.

When identifying coenoelements and EC groups for the NWASP flora, we took into account the approaches used mainly in the works of Siberian botanists or scientists from other regions of the Russian Federation who have worked extensively and fruitfully in Siberia [10].

The basis for the ecological-coenotic analysis of the flora was the previously published conspectus of the NWASP flora [11], taking into account the latest additions and changes in the flora composition.

For brevity, we present the abbreviated and full names of EC groups of NWASP alongside with their taxonomic and hemeroby parameters in Table 2. Mean values for all included parameters are as follows in the same order: 186.91 ± 45.14, 3.12798 ± 0.48991, 0.64828 ± 0.04850, 0.81492 ± 0.02427.

Table 2. Taxonomic and hemeroby parameters of EC groups of NWASP: *Abbrv* – abbreviated name of the region; *Name* – full name of the region; *Species* – total number of species; *Status* – average hemeroby status; *Indicators* – share of indicator-taxa of whole species list; *Consensus* – index of ecological consensus

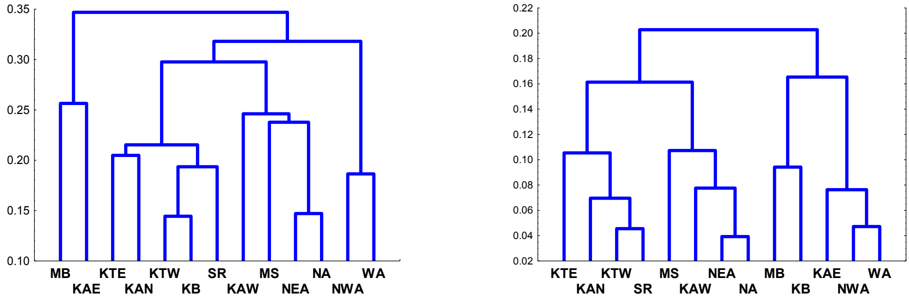
Abbrv	Name	Species	Status	Indicators	Consensus
SG	Steppe group	503	2.23386	0.77535	0.86653
FG	Forest group	412	2.78435	0.79369	0.82475
MG	Meadow group	165	4.37292	0.78182	0.74858
HMG	High-mountain group	248	1.16673	0.70565	0.94987
WG	Wetlands group	201	2.19092	0.83085	0.78948
AG	Aquatic group	122	3.34325	0.45082	0.79444
PG	Petrophytic group	121	1.46468	0.38843	0.91512
HG	Halophytic group	110	2.61971	0.66364	0.85559
ShG	Shallow group	43	4.55680	0.44186	0.74708
SyG	Synanthropic group	113	6.86872	0.74336	0.80605
UG	Uncertain group	18	2.80589	0.55556	0.66667

2.4 Data management and Statistical analysis

Statistical methods used in this work are as following: descriptive sample statistics, agglomerative hierarchical cluster analysis (WPGMA), contingency analysis for two-dimensional distribution tables. The set of model floristic lists was created in the form of a database of the integrated botanical information system IBIS v.7.2. [2, 12]. The IVA module of this software was used for all calculations of hemeroby status of regions and EC groups, and for creation of EC spectra and hemeroby profiles of regions; StatSoft Statistica v.12 and MS Excel 2010 were used for statistical processing, data transformation and visualization.

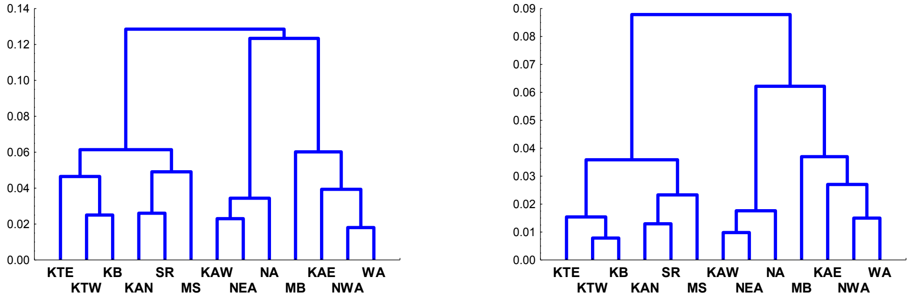
3 Results and discussion

1. After constructing ecological-coenotic spectra and spectra by hemeroby classes for the floras of the regions, we performed a series of classification constructions to determine the degree of similarity of the floras, using various bases and indices of similarity. A single linking method, WPGMA, was used to construct all dendrograms. Due to the limited space of the article, we present here only 4 topologies of the obtained similarity dendrograms as an illustration.



A. Bray–Curtis

B. EC groups spectrum



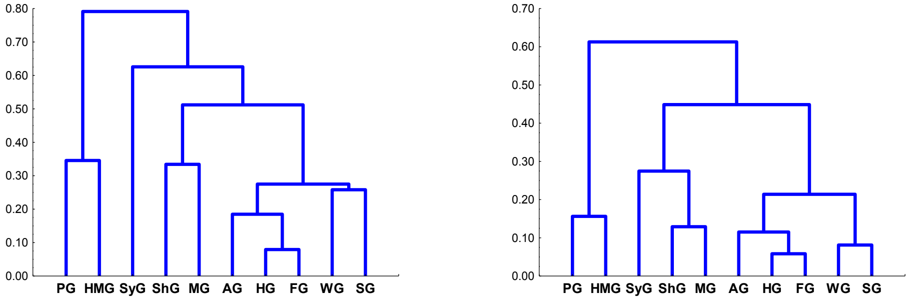
C. Hemeroby spectrum

D. Ecological hemeroby profile

Fig. 2. Dendrograms of similarity of 13 regions of NWASP on different bases

As a reference basis we used a dendrogram based on the quantitative Bray-Curtis similarity index for complete floristic lists (Fig. 2: A). Typological similarity of EC spectra of floras of the regions using Renkonen's percentage similarity index (Fig. 2: B). This coefficient was used for all other dendrograms based upon spectra and ecological profiles. The next step is to use the properties of hemeroby tolerance of species to determine the degree of similarity of the floras of regions. Hemeroby spectrum (distribution of species across 9 classes of disturbance scale) showed a different topology of the dendrogram from others (Fig. 2: C). Other features of the relationships between regions are shown in the following dendrogram (Fig. 2: D), reflecting the similarity of probabilistic ecological profiles according to the hemeroby factor using 18 intervals. See more about the approach in our previous work [13].

2. An interesting problem is to establish proximity relationships between EC groups. It is not possible to assess the similarity of EC groups based on their floristic composition using traditional binary or quantitative similarity indices, since there are no floristic intersections between the groups if we consider EC groups as factor sets. To solve this problem, we used the property of hemeroby tolerance of species: thus, even taxonomically unrelated species can exhibit a similar attitude to the disturbance factor. Thus, the hemeroby spectrum (Fig. 3: A) and ecological hemeroby profile for 36 intervals (Fig. 3: B), constructed for the floristic lists of different EC groups, were re-applied. The results were very similar but slightly different dendrogram topologies. The problem of classifying coenoelements to objectify their unification into EC groups is of interest, but this is beyond the scope of this work.



A. Hemeroby groups B. Ecological hemeroby profile

Fig. 3. Dendrograms of similarity of EC groups on different bases

3. To test the hypothesis that species within an EC group should, with some probability, show similar attitudes towards a disturbance factor, we performed a contingency analysis of the bivariate distribution of NWASP flora species across EC groups and hemeroby classes. Species that do not have hemeroby status in our IV scale and 17 species of the 11th Uncertain EC group were preliminarily excluded from the floristic list. We present a complete contingency table for the remaining 1730 taxa (Table 3).

Table 3. Contingency table of two-dimensional distribution of species by disturbance gradations and ECG. Reduced combined flora consists of 1730 species (14 species from the undefined EC groups, 276 species without hemerobic status and 3 species that had neither were excluded)

	H1	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**	**H9**	N(y)	Chi2(y)	p<0.05
SG	40	263	87	28	12	8	5	3	0	446	103.51	**
FG	9	154	125	30	24	12	6	8	0	368	99.465	**
MG	2	14	31	26	23	21	22	7	0	146	210.57	**
HMG	172	42	4	0	0	1	0	0	0	219	528.44	**
WG	49	71	28	16	9	7	6	1	0	187	13.581	
AG	2	26	23	16	4	4	2	2	0	79	33.71	**
PG	38	43	4	0	0	1	0	0	0	86	61.986	**
HG	8	38	30	8	7	0	0	0	0	91	24.431	**
ShG	2	3	3	1	8	6	2	1	0	26	64.01	**
SyG	0	4	3	3	8	8	12	39	5	82	641.41	**
N(x)	322	658	338	128	95	68	55	61	5	1730		
Chi2(x)	588	137	110	65.2	85.8	89.8	122	483	100		1781.1	**
p<0.05	**	**	**	**	**	**	**	**	**		**	

The contingency indices calculated from this table are: summary statistic $\chi2$: 1781.11 (p<0.001), contingency coefficient *Tau*: 19.79019, Pearson's φ: 1.01467, Pearson's contingency coefficient C: 0.71224, Tschuprow's measure of association T: 0.34833, and Cramér's contingency coefficient V: 0.35874.

Thus, we see a very high and statistically significant association between these two distributions, which justifies the use of hemeroby parameters of taxa for the purpose of classifying not only complete territorial floras, but also partial floras – floras of EC groups.

4 Conclusion

The conducted studies revealed a rather close relationship between the distribution of species by EC groups and hemeroby classes. In general, it can be concluded that hemeroby and EC groups are suitable for classifying floras. This approach may be promising for the purposes of comparative floristics, including floristic zoning and assessing the level of anthropogenic transformation of flora.

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