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The regularities of biotic taxa distribution on the territory of the West Siberian plain

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Abstract. Quantitative regularities of the biotic taxa distribution on the territory of the West Siberian Plain within Tyumen and Omsk regions are analyzed in the article. The article shows their relation with the climate through dryness index, which controls heat-moisture rate on Earth surface. The nature of distribution of species, genera, families and groups of biota by geographical zones and subzones of the specified region was observed: all ranks of taxa maximum values are observed in the taiga to steppe zone transition area, where dryness index values are 0,95–1,2 (≈1). Formula of geographical and hierarchical dependence of quantity of taxa of plants and animals of any rank were determined. The article demonstrates their self-similarity, integrity and common (sole) climate dependence.

Keywords: West Siberian Plain, Tyumen and Omsk region, biota, system, dryness index, climate, self-similarity

1. Introduction (objective and methods)

The most thorough description of vegetation cover and wildlife of the West Siberian Plain (WSP) is provided in the studies [2, 3, 5] which mostly include the description of qualitative characteristics of plant and animal complexes in various natural zones and subzones. In the current article quantitative biota taxa distribution and hierarchy regulations are studied within Tyumen and Omsk region which occupies northern and western parts of the West Siberian Plain including ten natural and climatic regions and subzones [3, 5, 7, 9] from northern tundra to steppe.

Spatial distribution of biota is mainly determined by climate. The objective of this research is to identify quantitative regulations of taxa and climatic indices relation as well as their distribution within geographic zones and ranking levels.

Research subject was the quantity of taxa (T) which were introduced into calculations as logarithms (W=1nT) which allowed to considerably lessen the uneven function patterns and to easily determine the correlations between systems and their components.

2. Results and discussion

2.1. Heat provision and water availability indices. All climate elements (CE) are interconnected. There were found quantifications of these correlations for the conditions of Tyumen and Omsk region [6-9], which allowed determining all the elements based on any known CE, for instance, dryness index. Dryness index is calculated according to the formula $J = B/qU$ where B is radiation balance, U stands for annual precipitation, and q is latent heat vaporization. This index is the most important integrated climate element answerable for heat and moisture distribution near Earth surface. Its values ranges from 0 in the arctic desert zone to 3-5 and more in deserts of subtropical and tropical belts [1]. To determine heat provision and water availability of the territory in agro-climatic studies they also use Selyaninov hydrothermic index [10] which is calculated according to the following formula $Kc = Uo/\sum o$ where Uo and $\sum o$ represent annual precipitation (cm) and sum of air temperatures over warm time of the year. Comparative calculations of J and Kc based on data from meteorological observing stations showed their correlation by a formula:

$$Kc = 1{,}85J^{-0{,}98} \approx 1{,}85 / J \qquad (1)$$

According to J values, phytosphere can be classified as northern Jn (cool and humid) and southern Js (hot and droughty). The border between them coincides approximately with isoline J=1. The conditions of heat and moisture exchange defined by J in the northern and southern phytospheres are logarithmically antisymmetrical. For example, the territory of persistent vegetation existence is restricted in the north by isolines Jn≈ 0,2...0,33 (northern tundra), in the south Js≈ 5... 3 (southern semidesert) [1], from which it is derived Jn≈ 1/ Js или ln Jn≈ ln/(1/ Js) ≈ - ln(Js).

The other indices are also antisymmetrical since expressed in correspondence with J, in particular annual precipitation, group pollen spectra, and phytoproductivity [6, 7]. Curves of these correlations are cycloids, with their maximum (peak) at J≈1 1,2. For example, on Diagram 1 there is shown the correlation of annual precipitation U (cm) and phytoproductivity or annual vegetation cover output Pr (t/ha*year) with J.

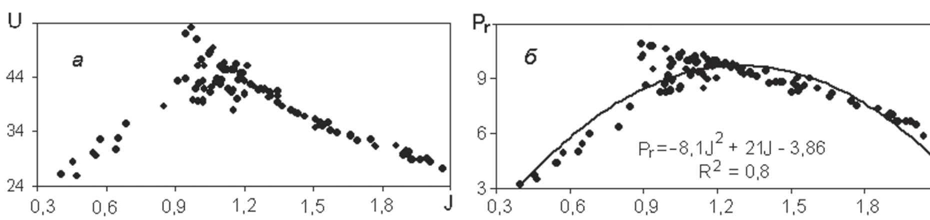

Diagram 1 Correlation of U (a) and Pr (б) with J

2.2 Geographical and hierarchical dependence of biotic taxa distribution.

Biotic taxa and J average values distribution within natural zones and subzones of the West Siberian Plain is shown in Table 1 [2, 3, 5]. Graphs on Diagram 2 show correlation of species wealth and phytoproductivity with J (lower horizontal axis) or Kn (higher horizontal axis). Both characteristics are on a logarithmic scale: $Wi = \ln Tp$, where Tp is the quantity of plant species in subzone i (according to Table 1), and $WPr = \ln Pr$.

It can be concluded from Table 1 and Diagram 2 that the quantity of taxa under research both floristic and faunal ones change similarly: from north to south at first they increase and then decrease. The vector change happens in sub-boreal forest which is northern forest-steppe which means that all biota habitation conditions are the most favourable in the transition zone from taiga to forest-steppe where dryness index J vacillates in the range 1÷1,2 [6-9].

There is the same regularity observed for certain flora types, in particular for herbs and ligneous plants. Most of herbs on the territory of the West Siberian Plain belong to families Cyperaceae (sedge family, 297 species) and Poaceae (gramineous family, 285 species); most of ligneous plants belong to Salicaceae (willow family, 73 species), Pinaceae (coniferous family, 38 species), and Betulaceae (birch family, 30 species) [5]. In Table 2 there are summarized species quantity of herbs and ligneous plants which refer to these families. As seen from Table 2, their zone distribution is subject to the same law as vegetation in whole (Table 1).

Table 1. Quantity of animal (birds + mammals) and tracheophyte taxa and average values of J in subzones of the West Siberian Plain

№	Subzone	J	Animals				Plants		
			species	genera	families	orders	species	genera	families
1	Northern tundra	0,35	73+18	46+15	20+9	7+5	57	35	17
2	Southern tundra	0,6	148+32	79+22	30+11	11+5	126	67	31
3	Forest tundra	0,75	194+42	107+27	39+12	15+5	99	58	28
4	Northern taiga	0,87	207+51	115+33	41+15	16+6	174	86	43
5	Middle taiga	0,96	257+59	136+38	48+17	18+6	247	147	50
6	Southern taiga	1,0	246+60	130+38	47+17	16+6	380	203	73
7	Sub-boreal forest	1,1	271+67	141+41	54+18	18+6	493	260	74
8	Northern Forest-steppe	1,3	259+63	139+43	50+19	19+6	540	267	64
9	Southern Forest-steppe	1,5	252+67	135+42	48+18	18+6	449	226	54
10	Steppe	1,9	208+58	115+40	45+16	19+6	215	131	36

Table 2. Distribution of herbs (Tp) and ligneous plants (D) of the most widespread on the territory of the West Siberian Plain (subzones are numbered according to Table 1; numerator is species quantity; denominator is their logarithms)

i	D	Tp	i	D	Tp
1	5 / 1,61	22 / 3,09	6	27 / 3,27	68 / 4,22
2	12 / 2,48	40 / 3,5	7	28 / 3,37	95 / 4,55
3	15 / 2,71	30 / 3,4	8	16 / 2,78	101/ 4,62
4	17 / 2,83	47 / 3,85	9	4 / 1,38	85 / 4,44
5	23 / 3,14	59 / 4,08	10	–	33 / 3,6

Peculiarity of geographic subzones in Table 1 is reflected by their sequential numbers.

There was found general formula for the dependence of taxa quantity on the sequential number of the zone:

$$W_i = Ai^2 + Bi + C, \qquad (2)$$

where $W_i = \ln(T_i)$, T_i stands for the biotic taxa quantity of this rank in the range: order (o) – family (f) – genus (g) – species (s) in geographic subzone i, while A, B and C are empirical constants which are defined by Table 3.

Table 3. Constants in the formula (2); formula fidelity (R2) for different biota groups: I – tracheophytes, II – birds, III – mammals, IV – birds and mammals

Group	Taxa	A	B	C	R^2
I	species	–0,042	0,57	2,27	0,87
	genera	–0,042	0,45	2,82	0,89
	families	–0,047	0,72	3,28	0,9
II	species	–0,024	0,393	4,01	0,97
	genera	–0,021	0,346	3,54	0,98
	families	–0,016	0,274	2,76	0,98
	orders	–0,014	0,25	1,81	0,93
III	species	–0,021	0,377	2,52	0,99
	genera	–0,015	0,29	2,38	0,99
	families	–0,012	0,222	1,88	0,96
	orders	–0,003	0,058	1,51	0,8
IV	species	–0,024	0,389	4,21	0,98
	genera	–0,02	0,332	3,82	0,99
	families	–0,015	0,259	3,11	0,99
	orders	–0,01	0,187	2,35	0,95

Using correspondence among i, J and K_n according to Table 1 and formula (1), value of i in (2) can be changed at once to climatic indices. For the example on **Diagram 3** there are graphs of dependence of W_i on i and its approximation for taxa of plants (I) and birds (II). On the lower horizontal scale of the graph there are singled out i values, while on the higher one the corresponding J values from Table 1; marks represent the quantity of plant and bird species in subzones on a logarithmic scale.

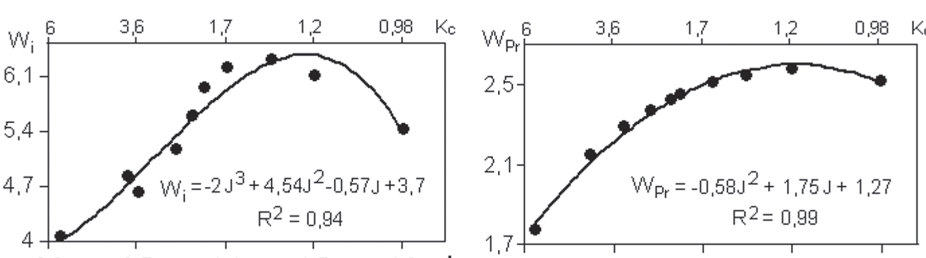

Diagram 2. Correlations of Wi and WPr on J or Kc and their formulas (signs represent the plant species quantity in subzones)

Analysis has shown that biotic taxa of different ranks in all climatic subzones can be interconnected with W_1 (species quantity logarithm):

$$W_j = kW_1 \quad (3)$$

where j =1...4 is the sequential number of taxa logarithm ($W_{1...}$ W_4) in series *species-genus-family-order*, k –empirical coefficient which is defined according to Table 4 as function of j.

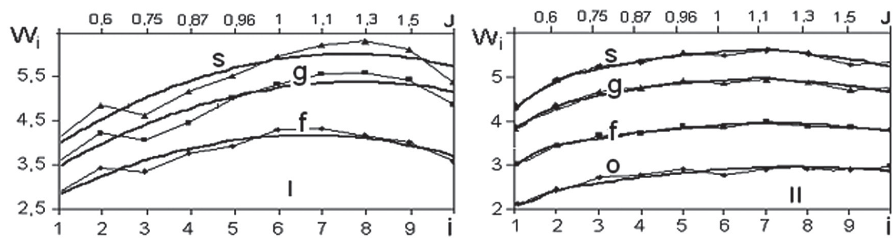

Diagram 3. Dependence of Wi on i or J and its approximation for plants (I) and birds (II) of the following ranks: species (s), genus (g), family (f), and order (o).

Table 4 as well as other introduced data indicate that there is nearly utmost unity of biotic taxa system and their relations expressed in terms of k. Thus, the difference of taxa ratio of floristic to faunal groups on levels species-genus-family does not exceed 5%.

If we put in formula (3) $W_j = \ln T_j$ and $W_1 = \ln T_1$, then after its rearranging there is a formula which correlates the quantity of genera (T_2), families (T_3) and orders (T_4) of biota with its species (T_1) on a common (not logarithmic) scale:

$$T_j = (T_1)^k \quad (4)$$

For example, for southern tundra k equals 0,89; quantity of species: mammals $T_в = 32$ (look at Table 1), mammals + birds - $T_в = 180$; the same of genera: mammals $T_р = \underline{22}$, mammals + birds $T_р = 101$. Calculation according to the formula (4) gives the following results: Tp = 23 and Tp = 106, which nearly coincides with factual data.

Table 4. Values of Wj and k in formula (3) for plants (I) and birds (II), mammals (III) and birds + mammals (IV)

№	j	W_j	k	№	j	W_j	k
I	1	5,4	1	III	1	4	1
	2	4,7	0, 88		2	3,6	0,9
	3	3,8	0,7		3	2,8	0,69
	4	-	-		4	1,8	0,45
II	1	5,3	1	IV	1	5,7	1
	2	4,7	0,89		2	5,1	0,89
	3	3,7	0,7		3	4,2	0,73
	4	2,7	0,51		4	3,1	0,55

2.3. Fractality of taxa distribution according to hierarchal ranks. As known, many systems under certain mathematical representation are fractal or self-similar on all districts of its habitat and lifetime. B. Mandelbrot who introduced the notion of fractality for scientific use gave it quite a general definition (according to [4]): "... fractal is a structure which consists of parts similar to the whole". An example of such structures is tree crown, river basins and its affluent, hemal system, etc. System hierarchies can also be considered fractal including biotic ones: species – genus – family – order. Such hierarchies usually represent geometric progressions with approximately fixed factor, i.e. multiplier reflecting conformity of its components.

Let us consider the hierarchy of values of mn coefficient, which equals ratio of the previous component Wj=ln Nj to the following Wj+1 =ln Nj+1 in sequence: 1) species; 2) genus; 3) family; 4) order (i.e. j = 1, 2, 3, 4):

$$W_1 / W_2 \rightarrow W_2 / W_3 \rightarrow W_3 / W_4 \quad (5)$$

In Table 5 there are values of m_n coefficient for taxa of main groups of biota (according to Table 4). Analysis of Table 6 demonstrates that the ratio of hierarchy components (5) is described by the formula:

$$m_n = (m_{1,2})^n , \quad (6)$$

where n is the sequential number of the ratio in the hierarchy (5). Correlations in (6) are denoted by one letter m with indices pointing out taxa numbers in the row: 1) species... 4) order. The first correlation is (W1/ W2) = (m1,2)1, the second one is (W2 / W3) = (m1,2)2, and the third one is (W3 / W4) = (m1,2)3.

Table 5. Factual and calculated values of m1,2 , m2,3 and m3,4

Groups	Values	Factual value of $m_{1,2}$ - $m_{3,4}$	Calculated value of $m_{1,2}$ - $m_{3,4}$
I	$m_{1,2}$	1,13	1,13
	$m_{2,3}$	1,26	1,27
II	$m_{1,2}$	1,13	1,13
	$m_{2,3}$	1,27	1,27
	$m_{3,4}$	1,37	1,44
III	$m_{1,2}$	1,11	1,11
	$m_{2,3}$	1,29	1,24
	$m_{3,4}$	1,53	1,37
IV	$m_{1,2}$	1,11	1,11
	$m_{2,3}$	1,23	1,23

It can be concluded out of formula (6) that hierarchy components (5) are fractal, notably, the coefficient of a similitude (fractal dimension) for all taxa of groups under study (I...IV), both animals and plants, equals $W_1 / W_2 = m_{1,2} \approx 1,12$.

Now we can approximately estimate the third hierarchy component which is missing (5), i.e. correlation between orders and families of plants m 3,4, and the quantity of orders as such: W3/ W4 = m 3,4= (m 1,2)3= 1,4; further on, according to Table 4 we find: W3 = ln N3 =3,8; from where we get: W4= 3,8/1,4=2,7, while the quantity of orders – N4=exp(2,7) ≈15. There can also be calculated even theoretically the correlations between the following biotic hierarchy components (classes, phyla, etc.). Then when n equals 4, there is W4/ W5 = (m 1,2)4= 1,57, from which we get W5 = 2,7/1,57=1,71, and N5=exp(W5) ≈6, etc. Value of mn in the formula (6) approximates 1, when n increases, and that corresponds to the top of biotic taxonomy, i.e. biosphere.

3. Conclusion

The quantity of biotic taxa depends on their hierarchal rank and geographic location. The maximal values of taxa which corresponded to ideal existence conditions are observed in sub-boreal forest or in northern forest-steppe. The taxa quantity decreases in the north and in the south of the region due to lack of heat in the north and its abundance in the south. There were derived formulas of dependence of taxa quantity of both plants and animals of any rank on dryness index that is a complex climatic variable showing the correlation of heat and moisture in a certain area.

There has been determined self-similarity (fractality) of biotic taxa in hierarchal system *species … order*, when on a logarithmic scale.

In whole, the obtained results demonstrate integrity and interdependence of plants and animals existence and their shared climate dependence.

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