The indicators of interactions between biota’s components (with the West Siberian Plain as a case study)

S N Gashev¹, A A Konovalov², M N Kazantseva² and N V Sorokina¹

¹ Department of Zoology and Evolutionary Ecology of Animals, Institute of Biology, Tyumen State University, Pirogova St. 3, 625000 Tyumen, Russian Federation
² Institute of Northern Development Problems SB RAS, Malygina St. 86, 625046 Tyumen, Russian Federation

E-mail: gsn-61@mail.ru

Abstract: This article shows that the number of biotic taxa in the region depends on the drought index. From the very beginning, in strict conformity with the drought index, the number of biotic taxa increases from tundra to the border of taiga and forest steppe, where it reaches its maximum, and then it decreases towards the steppe zone. The authors note that the interaction between the components of the biota is characterized by two basic indicators: degree of harmony $H$ and stability $Z$. The analysis of the state of biotic systems based on the use of these indicators clearly reflects the level and potential for their functioning. These results generally demonstrate the unity and interdependence of plants and animals and the dependence of both on climate.

1. Introduction

Detailed qualitative characteristics of the vegetation and fauna of the West Siberian Plain (WSP) are given in the following papers [1-9]. This article is devoted to the quantitative distribution patterns for biotic taxa and interaction between their systematic groups in the territory of WSP within the Tyumen-Omsk area.

2. Material and methods

The spatial distribution of biota mainly depends on climate. All climate elements (CE) are interlinked. The quantitative expressions of these links for the Tyumen-Omsk area [10] were specified to make it possible to determine any CE index, such as the drought index ($J$) [11]. Based on the value of $J$ the phytosphere can be divided into the northern phytosphere (cold and wet) and southern phytosphere (warm and dry). The border between them roughly coincides with isoline $J$. The heat and moisture exchange inside the northern and southern phytospheres characterised by the value of $J$ and associated parameters are inversely symmetrical. The distribution of biotic taxa and average values of $J$ across the WSP natural zones and sub-zones is shown (table 1).

3. Results

According to [12], a variety of a biota increases from poles to the equator. The numbers of the biotic taxa of both plants and animals change in the same way: from north to south they first increase and then decrease (table 1). The vector changes in the sub-taiga zone – northern forest-steppe zone, which implies
that biotic conditions are most favorable in the transitional area between the taiga and the forest-steppe zone, where drought index $J$ ranges from 0.95 to 1.2.

**Table 1.** The number of animal taxa (birds and mammals) and vascular plants taxa, and the mean values of $J$ in WSP subzone $i$.  

| $i$ | Subzone       | J   | Animals | Plants |
|-----|---------------|-----|---------|--------|
|     |               |     | orders  | families | genus   | species | units | families | genera | species |
| 1   | North tundra  | 0.35| 7+5     | 20+9    | 46+15   | 73+18   | 17     | 17       | 35     | 57      |
| 2   | South tundra  | 0.6 | 11+5    | 30+11   | 79+22   | 148+32  | 31     | 31       | 67     | 126     |
| 3   | Forest-tundra | 0.75| 15+5    | 39+12   | 107+27  | 194+42  | 28     | 28       | 58     | 99      |
| 4   | North taiga   | 0.87| 16+6    | 41+15   | 115+33  | 207+51  | 38     | 43       | 86     | 174     |
| 5   | Average taiga | 0.96| 18+6    | 48+17   | 136+38  | 257+59  | 46     | 50       | 147    | 247     |
| 6   | South taiga   | 1.0 | 16+6    | 47+17   | 130+38  | 246+60  | 57     | 73       | 203    | 380     |
| 7   | Sub-taiga     | 1.1 | 18+6    | 54+18   | 141+41  | 271+67  | 57     | 74       | 260    | 493     |
| 8   | North steppe  | 1.3 | 19+6    | 50+19   | 139+43  | 259+63  | 55     | 64       | 267    | 540     |
| 9   | South steppe  | 1.5 | 18+6    | 48+18   | 135+42  | 252+67  | 46     | 54       | 226    | 449     |
| 10  | Steppe        | 1.9 | 19+6    | 45+16   | 115+40  | 208+58  | 33     | 36       | 131    | 215     |
|     | Total         | 19+6| 55+20   | 145+47  | 369+95  | 67     | 88      | 364    | 996     |

*The maximum values of taxa are underlined, $i$ is the specifics of the geographical zones and subzones, taxa order (zoological) and units (botanical) the contents are identical.

4. Discussion
The diagrams of dependence of the number of taxa of animals $T_a$ and plants $T_p$ on $i$ (figure 1) according to the table 1 (thin lines) and their approximation (thick lines). The calculated general equation for the zonal distribution of the number of biotic taxa $T_p \approx T_a \approx T_{p,a}$ is the following:

$$T_{p,a} = A_i^3 + B_i^2 + C_i + D_i$$  \hspace{1cm} (1)

where $A$, $B$, $C$ and $D$ is empirical constants (table 2).

**Table 2.** The constant in the equation (1) and its reliability ($R^2$).

| $\bar{N}$ | Taxa       | A    | B     | C     | D     | $R^2$ |
|-----------|------------|------|-------|-------|-------|-------|
| I         | species    | -4.82| 70.5  | -225.8| 261.7 | 0.95  |
|           | genera     | -2.25| 32.6  | -100.1| 122.5 | 0.97  |
|           | families   | -0.39| 4.78  | -7.44 | 22.5  | 0.94  |
|           | units      | -0.23| 2.62  | -1.48 | 18.6  | 0.95  |
| II        | species    | 0    | -6.42 | 90    | 15.1  | 0.98  |
|           | genera     | 0    | -3.1  | 44.6  | 22.6  | 0.98  |
|           | families   | 0    | -1.01 | 14.7  | 15.2  | 0.98  |
|           | order      | 0    | -0.25 | 3.9   | 9.3   | 0.94  |

* $I$ - plants, II - animals, $A$, $B$, $C$, $D$ is empirical constants.
The reliability of the equation (1) is high, especially for animals (figure 1, table 2), where the cubic polynomial formula reduces into the simpler quadratic formula \( A = 0 \). The curves in the diagrams are roughly symmetrical \( J \approx 1.0 \).

The average zonal values of the number of plant taxa \( T_p \) and animals taxa \( T_a \) on the main three stages of the hierarchy: families \( (r = 1) \), genus \( (r = 2) \) and species \( (r = 3) \) are, respectively, equal to: \( T_p - 47, 148, 278 \) and \( T_a - 57.4, 148.4, 263 \). As we can see, in each of these categories they are close by value, with the difference between them lying within the range of the observation error.

**Figure 1.** The dependence of (a) \( T_a \) and (b) \( T_p \) on \( i \) (the curves are marked by the first letters in the names of taxa; the dashed line is the smoothed version of the fluctuation of species and genera in the tundra), \( T_a \) is number of taxa of animals, \( T_p \) is number of taxa of plants, \( s \) is species, \( g \) is genus, \( f \) is families, \( o \) is order, \( u \) is units.

The analysis shows that the dependence of average zones values \( T_p \approx T_a \approx T_{p,a} \) on \( r \) can with a high level of reliability \( (R^2=0.99) \) be expressed by the linear formula:

\[
T_{p,a} = 109.2r - 61.4
\]  

(2)

The distribution of \( T_p \) and \( T_a \) across the three mentioned stages in each subzone can also be expressed by the equation 2 with their own numerical coefficients, which can be easily calculated based on table 1. For example, in forest-tundra, the first and the second coefficients \( (A \) and \( B) \) in the equation 2 are equal to the 77.5 and 41.7; in sub-taiga – 108.5 and 61.7; in the north forest-steppe – 104.5 and 59.7; in the South forest-steppe – 81.5 and 40.3 etc.

The fourth stage in the biotic hierarchy following species \( (r = 4) \) is a population. If in equation 2 we substitute for \( r = 4 \), we obtain the approximate average zonal number of populations in biota: \( T_p \approx T_a \approx 375 \). Similarly, we can calculate the approximate number of populations in each subzone. For example, in forest-tundra: \( T_a \approx 268 \), in sub-taiga: \( T_a \approx 372 \), in north and south forest-steppe: \( T_a \approx 358 \) and \( T_p \approx 286 \) and so on.

The biotic system can be interpreted as a dichotomy – closed system of two interacting opposites, the dominant \( Y \) and subdominant \( \bar{Y} \) expressed in fractions of 1 so that \( \bar{Y} + Y = 1 \). However, the subdominant itself typically consists of several (n) fractions. If we accept it as the geometric mean of the number of these fractions \( X = \bar{Y}^{1/n} \), then the expression of the total converts into \( X^n + Y = 1 \). The value of \( Y \) decreases with the increasing of \( X \). At the points where they equate: \( Y = X = H = \text{const} \), the system is in stable equilibrium with its components, and the formula of the total takes the following form:

\[
H_n + H = 1
\]  

(3)

Obviously, this equation 3 is solved only for \( n \) in equation 4:
\[ n = \frac{\ln(1 - H)}{\ln(H)} \] (4)

The value \( H \) is derived from initial conditions (table 1). For example, when analyzing the dichotomy of the families of birds and plants in sub-taiga, we derive \( H \) by dividing plant families (dominant) into the total of the families of birds and plants:

\[
H_f = \frac{74}{54(54 + 74)} = 0.58, \text{ the same refers to genera } H_g = \frac{141}{401} = 0.65.
\]

The values \( H = H_n \), corresponding with different integer \( n \geq 1 \), form the sequence 1) 0.5; 2) 0.618; 3) 0.682;...; 31) 0.923 ..., whose terms are called Generalized Golden sections (GGS) – invariants on the basis of which systems become harmonious and stable in structure and function. The Golden Section proper is obtained through substitution in equation 3 \( n \), equal 2:

\[
\frac{H_2}{1} = 1 - \frac{H_2}{H} \approx 0.62.
\]

This proportion of equilibrium oppositions is the most typical in different systems, the optimal ratio of the structural elements of the system bringing it to the highest order [13]. In the model under study, one more curve (V) is presented, consisting, in turn, of two forming parts (segments): the X curve (with \( n = 1 ... 2 \)) and the Z curve (with \( n > 2 \)), which can serve as an adequate and a completely representative model of the flow of the so-called “life cycle” of the system, including the stages of formation (growth, progress) of the system (\( X = V \) with \( n = 1 ... 2 \)) and its degradation, decline (\( Z = V \) with \( n > 2 \)). In figure 2, this composite curve having the shape of a corner is in bold. The space between \( (1 - H_n) \) and \( H_n \) on a dome-shaped diagram representing the ‘life cycle’ of the system and including “youth” (upward movement), “maturity” and “old age” (downward movement) is a stage of maturity characterized by constant deformation rate which at that point drops to a minimum in the entire cycle. Living systems at this stage have the reproductive ability. The functioning of the system is characterized by other constants as well, which are connected with each other through the number of the fractions of \( n \) (figure 2).

![Figure 2](image)

**Figure 2.** The dependence G (H, 1 - H, Z, X and V) from \( n \). H is degree of agreement (harmony), Z is sustainability, X and Z are relative values, which are understood to mean any oppositions that coexist according to the law of unity and struggle of opposites (as a dichotomy) in such a way that the growth of one of the oppositons takes place only by decreasing the other (Conservation Law!), V is a compound curve.

The number of dividing lines – borders along which stress is concentrated – grows with the increase of \( n \). These areas (ecotones, sea shores, river banks, snow lines, inter-seasons – spring and autumn – and so on) are the most sensitive to environmental changes and the most exposed to deformation and destruction. The fewer fractions there are in the system, the fewer borders of various kinds it has and, therefore, the stabler it is. The inverse value of the number of fractions in the system \( 1/n = Z \) ranging
from 1 to 0 can serve as a relative measure of the stability of the system. It is obvious that the maximum of stability \( Z = 1 \) is achieved when \( n = 1 \) (figure 2), but in this case, the system turns into a monolith with no individual fractions, which are self-organising (self-harmonising) subjects. The result is that some “quasi-live” making the system capable of self-organising is lost. Stability or order is opposed by instability or chaos: \( X = 1 - Z \). The monotonic linear increase in \( n \) can be correlated with the flow of time in a life cycle, in the beginning of which, from \( n = 1 \) to \( n = 2 \), the living energy is growing and in \( n > 2 \) it decreases. The ability to self-organise, the living energy making any system similar to a ‘live’ one, arises at \( n > 1 \), reaches a maximum at \( n = 2 \); \( Z = X = 0.5 \) and \( H = 0.62 \), and then, as \( n \) continues to grow, decreases. The other curve, \( V \), consisting of two segments: curve \( X \) for \( n=1...2 \) and curve \( Z \) for \( n>2 \), can serve as a model of the system’s life cycle, including the stage of the formation of the system \( (X = V \text{ for } n = 1...2) \) and its degradation \( (Z = V \text{ for } n > 2) \). The most consistent and harmonious interaction of components of the system, when the potential for the development of energy (living force) is at its maximum, can be observed at \( n = 2 \), where \( Z = X = 0.5; H = 0.62 \) (figure 2).

A specific dependence of the interaction constants \( G \) (H, Z and X) on \( i \) in two biotic systems with a varying character of relationship (figure 3). The left diagrams reflect the interaction of birds and mammals constituting a single faunal biotic component and, obviously, opposing each other strongly. This is confirmed by the analysis of the degrees of constants \( H, X, \) and \( Z \). The distribution of these indicators across the hierarchical stages is close to the fractal one [14]. The zonal variations in these values are insignificant and lie within the observation accuracy. The combination of the average values of stability \( Z \approx 0.14 \) and harmony \( H \approx 0.76 \) is far from optimal. This indicates a small interdependence of birds and mammals and the chaotic character of it. A different picture can be observed when we analyse dichotomies, including the faunal and floral components of biota, opposing and balanced with each other following the ‘hunter (eater) – prey (food)’ pattern. Average zonal values \( H: 0.57; 0.59; 0.60 \) and \( Z: 0.66; 0.59; 0.56 \) in the family-genus-species chain are rather close to the optimum development: \( Z \approx 0.5 \) and \( H \approx 0.62 \), and the entire range of values \( H, Z \) and \( X \) is in the growth stage, where \( n = \frac{1}{z} < 2 \).

There are two peaks of \( H \) observed: on the border between the forest and steppe in the north forest-steppe, where \( H = 0.62 \) is optimal, and on the border between forest and tundra, where \( H \approx 0.65 \) is close to an optimum. The stability on these borders, on the contrary, is minimal, but is also close to the development optimum \( Z = 0.5\ldots0.55 \). The analysis testifies to the stability and high degree of harmony of the joint functioning of flora and fauna as a unified system [15], as well as the potential for its further positive development.

![Figure 3](image_url)

**Figure 3.** The dependence \( G (H, Z, X) \) on \( i \) in two systems: (a) mammals-birds and (b) animals-plants, \( X \) and \( Z \) is relative values, \( H \) is degree of agreement (harmony), \( G \) is interaction constant \( Z, H \) and \( X \).

5. **Conclusion**

The number of biotic taxa in the region depends on the drought index, increasing from tundra to the border of taiga and forest-steppe, where it reaches a maximum, and then decreasing towards the steppe zone.
The interaction of biotic components is characterized by two basic indicators: degrees of harmony $H$ and stability $Z$. The analysis of the state of biotic systems carried out with the use of these indicators reflects properly the level of and potential for their functioning.

All in all, the obtained results demonstrate the unity and interdependence of plants and animals and the dependence of both on climate.

Acknowledgements
The work was carried out within the framework of the basic part of state assignment No. 01201460003 by the Russian Ministry of Education and Science.

References
[1] Ananjeva N B, Orlov N L, Khalikov R G, Darevsky I S, Ryabov S A and Barabanov A V 2004 Atlas of reptiles of Northern Eurasia (taxonomic diversity, geographical distribution and environmental protection status) (St. Petersburg: Zoological Institute of RAS) p 230
[2] Arefyev S P, Gashev S N and Selyukov A G 1994 Biological diversity and geographical distribution of vertebrate animals of the Tyumen region Proc. Conf. Western Siberia - problems of development, ed V R Tsibulsky (Tyumen: IPOS SO RAN Publ.) pp 92-116
[3] Budyko M I 1971 Climate and life (Leningrad: Gidromet Publ.) p 472
[4] Dalla Torre C G and Harms H 1907 Genera Siphonogamarum ad systema Englerianum conscripta. (Lipsiae G. Engelmann) p 921
[5] Gelashvili D B, Iudin D I and Rosenberg G S 2008 Bases of the multifractal analysis of specific structure of community J. Achievements of modern biology 128(1) 21-34
[6] Gashev S N 2007 Abstracts of lectures on system ecology (Tyumen: TSU Publ.) p 212
[7] Gashev S N 2008 Mammals of the Tyumen region. Reference identifier (Tyumen: TSU Publ.) p 336
[8] Gashev S N 2012 The Workplace of the Ornithologist Available from: https://elibrary.ru/item.asp?id=21441579
[9] Ilyina I S, Lapshina E I and Lavrenko N N 1985 Vegetation cover of the West Siberian plain (Novosibirsk: Nauka Publ.) p 248
[10] Koblik E A and Arkhipov V Yu 2014 Avifauna of the States of Northern Eurasia (former USSR). Checklists (Moscow: KMK Scientific Press Ltd.) p 171
[11] Konovalov A A and Ivanov S N 2007 Climate, phytoproductivity and pollen spectra: communication, distribution and methods of paleoreconstructions (Novosibirsk: Geo Publ.) p 130
[12] Kuzmin S L 2012 Amphibians of the former USSR. (Moscow: KMK Scientific Press Ltd.) p 370
[13] Pavlinov I Ya and Lissovsky A A 2012 The Mammals of Russia: A Taxonomic and Geographic Reference (Moscow: KMK Scientific Press Ltd.) p 604
[14] Primak R 2002 Bases of preservation of a biodiversity (Moscow: Scientific and training MSU methodical center Publ.) p 256
[15] Soroko E M 1984 Structural harmony of systems (Minsk: Nauka and Techn. Publ.) p 264