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NONLINEAR CHARACTER OF SPECIES DIVERSITY: THE CASE OF ISLAND BIRD COMMUNITIES

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Here we presented some theoretical conclusions about the nonlinear links in island bird communities. It is proved, that the relations between the specific biodiversity, structure and entropy of biogeocenosis are nonlinear. The optimal level of diversity in island bird communities does not depend on the carrying capacity. The optimal level of species diversity and the corresponding value of the total population (biomass) increases with carrying capacity and available ecological niches. The population diversity is the basis for community adaptation towards the unstable environment. Species diversity allows the community as a whole to be more efficient and to use the resources of environment more efficient by differentiating of ecological niches. The species diversity indices do not strive to stable constant, they increase along with species abundance but these dependences are rather nonlinear.

Key words: *breeding birds, island communities, nonlinear relations, specific diversity, entropy, species diversity, evenness.*

The problem of nonlinear relationships in biogeocenoses and nonlinearity of most of the biogeocenoses is remained underdeveloped for some period (Magurran, 1988; Odum, 1983; Tilman, 2001; Walker, 1992). The intensive use of mathematical tools in environmental studies were often simplistic in nature, which in turn determined the preferred linear dependencies in environmental calculations (Lawton, 1993; Zheryhyn, 2003; Isaev, 1996). This also contributed to the intensive use of correlation coefficients and linear regression calculations (Lyapunov, 1980).

The development of the computer software, the use of which requires special education and knowledge, significantly increases the possibility of nonlinear and nonparametric methods.

Most systems, including all the geographical and ecological systems – are opened (Kolmogorov, 1956). They exchange the matter, energy, and information with the environment. The opened nature of most systems suggests that the main role in the world around belongs to instability and irregularity. Prigozhin and Stingers (1986) noted that opened systems fluctuate continuously. Sometimes a separate fluctuation or a combination thereof may be (as a result of positive feedback) is so strong that the system does not stand up and destroyed. At this point in the bifurcation point, fundamentally impossible to predict in which direction will further develop, will the chaotic state of the system preserve or it will move to a new, higher level of organization.

Prigozhin emphasizes the possibility of occurrence of spontaneous order and organization from disorder and chaos as a result of self-organization process (Prigozhin, Stingers, 1986). In the linear system the emergence of unstable points (bifurcations) inevitably leads to the destruction of the system; the system of nonlinear buckling leads to more and better options. The driving forces that support the biosphere in a stable condition - are the biodiversity and population dynamics. The implementation of various organisms and community life strategies with ecological niches succession are the principles of environmental equivalence.

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The system ideas of biodiversity by V.I. Vernadskiy are the biosphere diversity of living matter and release of living matter. Living matter of the biosphere is its diversity, which is the main variety of individual living matter and the diversity of species living matter (Vernadskiy, 1978). The question of how biodiversity is associated with vitality, stability, productivity, and other important characteristics of biological systems, as well as environmental conditions in which they exist. It is extremely important from a theoretical and practical point of view. To identify the possible mechanisms of communication is necessary to explain the distribution patterns of biodiversity and study the mechanisms of its formation in different environmental conditions. In practical aspect it is essential for the predicting response of biota on anthropogenic changes in the environment and to develop the methods of compensation actions.

The role of biodiversity in maintaining ecosystem functions (first of all - their performance and stability) in the last two decades has been one of the central themes of ecology (Bigon et al., 1989). Despite some controversy, studies of biodiversity can be summarized as follows:

- Most studies show a positive relationship between diversity and stability of communities their ecological functions;
- The dependence of the efficiency and stability of ecological functions of biodiversity, usually has the asymptotic form - ecological functions hardly reduced while reducing diversity to about half of its maximum value; with a further reduction of diversity is rapid degradation functions (Alymov et al., 1997).

The increasing biodiversity in ecosystems can be associated maximum energy law, in competition with other systems and survives and remains one that best uses energy - that are preferred system with maximum efficiency and minimum entropy (Odum, 1983).

The principle of optimal diversity is the assumption that the biodiversity associated with some of the fundamental characteristics of living systems that determine their viability, i.e. the probability of survival (Bukvareva, Aleshchenko, 2005). This set a level of biosystem diversity elements that match the selected extremum of vital characteristics and maximum sustainability of biosystems. This level of diversity is supposed to be an optimal.

MATERIALS AND METHODS

The study used data on the distribution of colonial waterbirds breeding on the islands of the Sea of Azov and Sivash (Matsyura, 2003a; 2003b). Data on the bird distribution correspond to the periods of 1993-2000, 2007-2009, 2016 and represent the survey from about of 34 islands.

To calculate the correlation coefficients and diversity index we applied the Statistica 11.0 and Biodiversity Pro. To determine the pattern of the functional relationship between the studied parameters we used Curve Expert 1.4.

In some research the attempt to compare species diversity indices using the correlation coefficient we performed. It should be noted that in most cases the usage of Pearson correlation coefficient was appropriate, whereas, in our opinion, it is better to use Spearman coefficient (rank correlation coefficient) which refers to the non-parametric factors and allow for the closeness of the connection between quantitative and qualitative characteristics. In addition, Pearson index implies a linear relation between variables, whereas in reality these linkages are more complex.

RESULTS AND DISCUSSION

The ability to use the principle of optimal diversity is demonstrated by the example of model structural biosystems (under formation control system of upper level (Lyapunov 1980), which can be interpreted as a model of the optimal number of species in the community of one trophic level. The study of the model showed that the biological systems of different hierarchical levels may be the optimal level of diversity: a population formed the optimal phenotypic diversity in which the resource unit costs - or the minimum population size - the maximum, in the community set the optimal number of species where the total cost of the resource - is minimal.

There was obtained a conclusion that when the degree of stability of the environment the optimal level of diversity in populations and communities are changing in the opposite way: at destabilizing environment optimal diversity in the population increases and the optimum number of species falls: with such behavior lower trophic levels structure multi-community becomes less hierarchical).

As objective function optimization criterion used up its population size during a volume of available resources, equivalent to minimize unit costs established at the resource size (Levchenko, 1984). The population seeks to achieve maximum strength and establishes its internal diversity at the level where possible. By increasing or decreasing the diversity of individuals in the population, that is a deviation from the optimal level of diversity, there is a decline or increase in the cost resource. By reducing the stability of the environment the best value diversity in the population increases. At the same time reduced the maximum number or increasing the minimum value of the unit cost of the resource to the selected optimization criterion.

When the number of populations is less than optimal, the low efficiency of resource through the "leaky package" of certain populations can be registered. This effect can be interpreted as a denser packing of ecological niches. If we assume the overlapping niches, resource efficiency will increase with increasing numbers of populations.

As a result of their own and other studies (Zalepuhyn, 2003; Matsyura, 2003a, Tilman, 1996; Tilman et al., 1996), the increase in species diversity stabilized the ecosystem processes (the total biomass of the community), but it is not stabilized the population inner processes (annual variability of biomass of individual populations are not reduced).

Maximizing the size (biomass) with the amount of available resources and minimizing support costs populations with the full absorption of resources caused the minimizing of the costs of establishing and maintaining unity population (biomass). In populations and communities, we can observe an optimum internal diversity, in which the maximum effectiveness of these biological systems could be.

Reduction of resources to support the number of units (biomass) system will increase its stability and viability (chance of survival in the environment). The increase in population size or reduce its costs reduces the likelihood of self-extinction of the population. We believe that the species diversity in itself does not increase the stability of the community, but empirically shown that it increases the efficiency of resource and total biomass of the community, and the accumulated biomass "dampens" vibrations of the environment through feedback from the soil and abiotic components.

Automatism support stability organisms (homeostasis) and ecosystems (stability) is associated with self-regulation mechanisms cybernetic nature of these systems - using their self-feedback (Popov, Kraynyuchenko, 2003). The common mechanisms of self-sustainability of the living, technical and socio-economic stability systems can be considered as one of the most important features of the universal operation of natural and natural-economic systems, as one of the general aspects of economic evaluation.

The dependence of the stability of ecosystems to species diversity, was not linear in each case. Stability closely linked to functional than structural variety of ecosystems (Bertalanfy, 1969; Spytsnadel, 2003). "Lines are not always the best environmental evaluation unit for diversity, because different stages of the life cycle or different life forms of a type often occupy different ecological niches and whereabouts; because they contribute to the diversity of ecosystems "- noted Odum (Odum, 1983). Therefore, in assessing the stability of living systems as one of the functions of biodiversity, better focus on intraspecific, not the species or ecosystem diversity. From the standpoint of the economy is also logical, because we are not directly exploit ecosystems and specific population diversity which directly determines the stability of species and only indirectly - the stability of the ecosystem, part of which is exploited population.

We can conclude the existence of common patterns of distribution of species on recurrence systems of different nature. Graph of the number of species on the number of individuals in logarithmic coordinates is a straight line. But the model is not linear, given the identity of the sets of indicators among species and among individuals of the community to various mathematical community. This leads to regular fluctuations, requiring construction of distribution curves for each value of species and the inability construction of model parameters to some types of distribution averages.

In analyzing the relationships between the number of individuals and number of species diversity indices were obtained data shown in Table 1.

The criterion is the Pearson correlation index. As we can see, the relationship between the number of individuals and number of species in the island community were not found, or it has a pronounced nonlinear.

To test this hypothesis, we used another statistical procedure - nonparametric correlation with gamma index. The analysis presented in Table 2, which shows that between number of species and the number of individuals at least there is a linear relationship.

Table 1. **Correlation matrix of diversity indices (calculated for island bird communities)**

Indices	R	p-level
D vs C	-0,5985	0,001
D vs NS	0,5266	0,005
D vs H	0,516	0,006
C vs E	-0,6307	0,0001
C vs H	-0,7162	0,0001
E vs H	0,8331	0,0001
NS vs H	0,4379	0,013

D – Sympson diversity index, C – Sympson dominance, H – Shannon index, E – Pielou index, NS – number of species, NI – number of individuals, R – correlation coefficient, p-level – statistical significance.

Table 2. **Correlation matrix 2 of diversity indices (the case of island breeding bird communities)**

Indices	R	p-level
D vs C	-0,449275	0,001117
D vs NS	0,487500	0,000660
D vs H	0,388571	0,004522
C vs E	-0,520468	0,000171
C vs H	-0,560694	0,000046
E vs H	0,579251	0,000025
NS vs NI	0,281250	0,049445
NS vs H	0,370717	0,009483

Due to our previous results (Matsyura, 2011; Matsyura et al., 2013), in the bird island communities the lognormal distribution and random distribution are dominated.

Factors diversity with the number of species not seek to sustainable value. Changes in factors that characterize the variety of structural elements of the system reflects the faster growth of the number of individuals over the increasing number of species. Ratios of species diversity with increasing steadily growing number of species, but this dependence rather not linear.

By using Curve Expert we determined the patterns of the relationship between species diversity indices:

a) concentration of dominance and evenness: polynomial equation of third degree, y = a + bx + cx ^ 2 + dx ^ 3;

b) Simpson species diversity vs concentration: “model of water vapor pressure», y = exp (a + b / x + cln (x));

c) species diversity vs evenness: Blizdeyl equation, y = (a + bx) ^ (- 1 / c)

d) index of Shannon entropy vs evenness: polynomial equation of third degree, y = a + bx + cx ^ 2 + dx ^ 3;

e) Simpson index vs Berger-Parker: a rational function, y = (a + bx) / (1 + cx + dx ^ 2);

It was already proved (Bertalanfy, 1969; Isaev, 1996; Spytsnadel’, 2000), which in biological systems of different nature one of the criteria for structural stability is constancy or decrease the entropy of the increasing number of types of systems. Typical dependence suggests that the increase in the number of species and individuals does not increase the entropy (Fig. 1). This rather reflects the resistance patterns of species diversity. We also can assume that the preferred number of bird species in island communities could be between 8 and 11 and this is reflected the optimal quantity of ecological niches in observed conditions. We observed this in our previous research and performed preliminary mathematical models that correspond to these conclusions (Matsyura, 2011; Matsyura & Matsyura, 2011).

E. Odum (1983) came up with original conclusion that species richness and diversity of biomes occur as a result of adaptation to the power and an energy flow that comes to ecosystems. We believe that there is an optimum diversity and energy efficiency is defined ecosystem. Low species diversity is formed if achievable energy combined with intake of nutrients in quantities that exceed the needs of organisms. Such

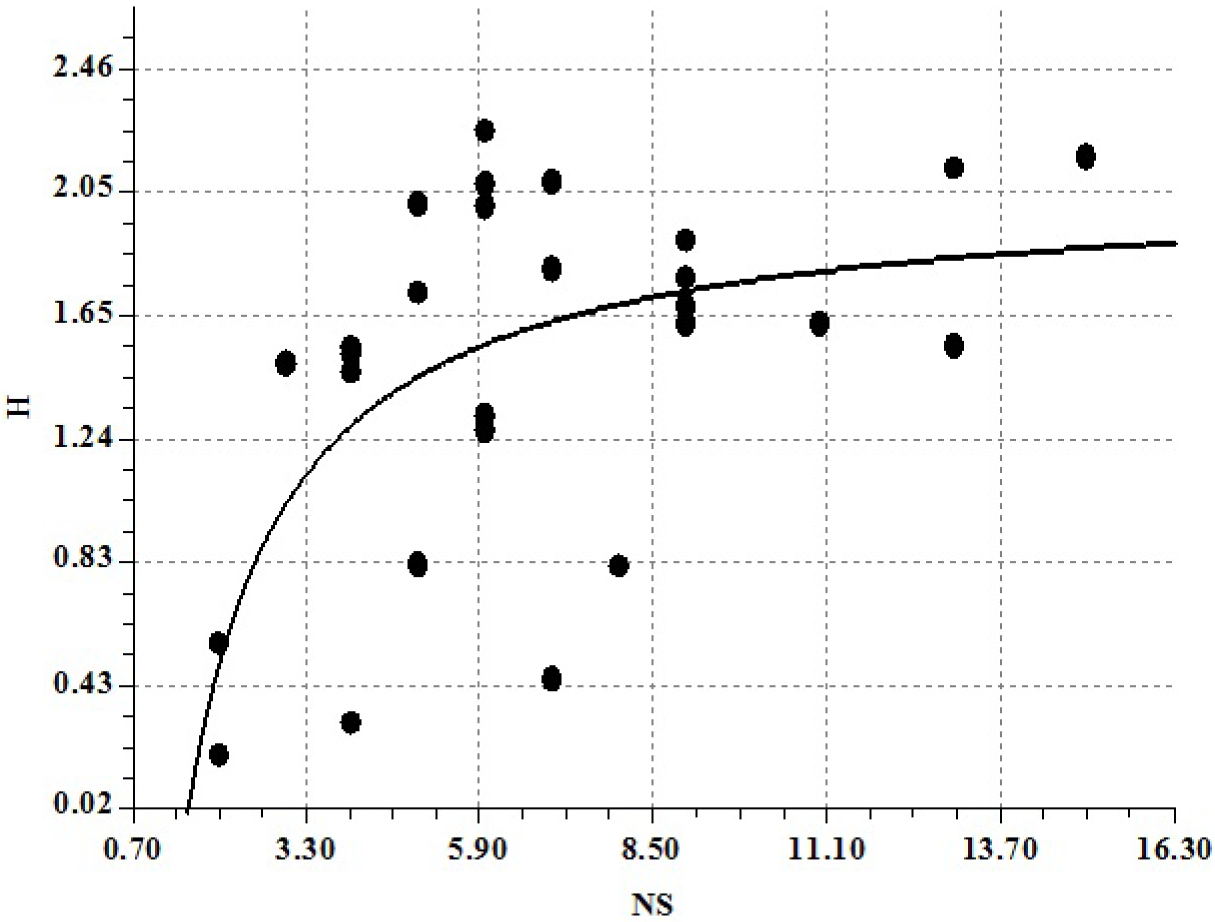

Figure 1. Shannon entropy (OY) and number of species (OX) for island breeding bird communities. Hyperbolic equation is y = a+b/x, де: a = 2,08, в = -3,14.

ecosystems may be fairly resilient and able to withstand external actions at a relatively constant flow of material over time.

How different indices of species diversity - linear. Experience of using several indices shows that they clearly assess the situation in up to 30 percent. Thus, with increasing diversity should increase evenness index and Shannon species diversity index with decrease of species concentration index, but it occurs just in 1/3 of all the cases.

CONCLUSIONS

The optimal level of diversity in island bird communities does not depend on the carrying capacity. The optimal level of species diversity and the corresponding value of the total population (biomass) increases with carrying capacity and available ecological niches. The population diversity is the basis for community adaptation towards the unstable environment. Species diversity allows the community as a whole to be more efficient and to use the resources of environment more efficient by differentiating of ecological niches. The species diversity indices do not strive to stable constant, they increase along with species abundance but these dependences are rather nonlinear.

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