UDC 504.54.062.4:504.453

ESTIMATE OF THE MIGRATION CAPACITY FOR LOCAL ECOLOGICAL NETWORK

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Purpose. This paper is a logical continuation of the paper of the same authors in which the spatial patterns of a local ecological area network were considered from the point of view of complex evaluation of natural cores in points. However, this method giving the comparative characteristic of the structural elements of an ecological network (natural cores) doesn't allow to evaluate the principal functional characteristic of an ecological network – its migration capability. **Methodology.** In this paper the original evaluation technique of spatial hierarchical structure of a regional ecological area network of the Bakhmut watershed on the basis of determination of migration capacity between its natural cores is suggested. **Originality.** The latest method received on the ground of the gravity model of similarities of the geotops (land types) by complex evaluation of their ecological system characteristics in points. **Practical value**. As the result a spatial hierarchical structure of a regional ecological network in the form of clusters of natural cores from the 1st to the 4th rows has been received. The research concludes that discrete and continual nature of any ecological network in the process of transition of its creation from regional (the discrete level of its organization) to its area level (with the continual nature of its structural organization). *References 20, tables 1, figures 1.*

Keywords: local ecological area network, natural cores, migration capacity, biocentric and network structure of an ecological network, spatial clustering of natural cores, landscape.

ОЦІНКА МІГРАЦІЙНОГО ПОТЕНЦІАЛУ ЛОКАЛЬНОЇ ЕКОЛОГІЧНОЇ МЕРЕЖІ

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Наведена стаття є логічним продовженням статті авторів у якій було розглянуто просторову структуру локальної екологічної мережі з точки зору комплексної оцінки в балах її складових природних ядер. Але відповідний метод що дозволяє отримати порівняльну характеристику структурних елементів екологічної мережі (природних ядер), не дає змоги оцінити головну функціональну характеристику екологічної мережі – її міграційну спроможність. В наведеній статті запропоновано оригінальну методику оцінки просторової ієрархічної структури локальної екологічної Бахмутської водозбірної території на основі визначення міграційного потенціалу поміж її природними ядрами. Відповідна методика отримана на основі гравітаційної моделі подібності складаючих їх геотопів (типів земель) шляхом комплексної оцінки в балах характеристик їх екосистем. У результаті отримано просторову ієрархічну структуру локальної екомережі у вигляді кластерів природних ядер від 1-го до 4-го порядків. Зроблено висновок про дискретно-континуальний характер кожної екологічної мережі в процесі переходу її побудови від локального (дискретного рівню її організації) до регіонального її рівня (з континуальним характером її структурної організації).

Ключові слова: екологічна мережа, природні ядра, екологічні коридори, біоцентрично-мережева структура екологічної мережі, водозбірна територія, біологічне різноманіття, ієрархічна структура екологічної мережі, ландшафт.

PROBLEM STATEMENT. The majority of researches related to ecological networks are devoted to three main thematic areas: on the impact of influence of landscape complexity structure at biodiversity [1-5], the researches of migration capacity of ecological networks [6,7,8] and evaluation of landscapes complexity structure as the indicator of the condition of ecosystems [9,10]. Less significant number of publications is devoted to more vast range of researches – from influence of biodiversity on land-use [11,12] to correlation of landscape complexity structure and processes of speciation [13].

Nevertheless, there are practically no publications related to methodical and methodological aspects of construction and evaluation of local ecological networks functioning, especially at the multi-scale levels of their organization.

In our previous publication we have given a complex evaluation of natural cores in the general structure of a local ecological network (on the example of Bakhmut administrative area of Donetsk region) with a view to identifying of their priority from environmental locations [14]. However, the general analysis of a local ecological network structure on the basis of complex evaluation of its cores [14,15] doesn't consider the most important characteristic of any ecological network, which is its abilities to provide migration of forms (organisms) among its natural cores. Its biocentric and network structure only partly reflects this capability, but only at the level of having spatial(positional) link of cores among themselves, not including distance between them, affinity of their biotic structure, effect of the sizes of cores on this migration. Without all this evaluation of ecological network potential of the area is too formal and to some extent is conditional.

In this paper a new original evaluation method of spatial (positional) link of cores among themselves and efficiency of migration capability of entire ecological network in general on the basis of determination of migration capacity of its cores is offered. And as the result is the building of its hierarchical spatial scheme in the form of clusters at different level of its constituent natural cores.

At the core of the given method is the so-called "gravitational model" of mutual effect of two same structures or systems if there is a certain physical link between them. Taken from the classical laws of physics (Newton's laws of gravitation, or a mutual attraction of bodies), this model is now used rather widely and in different sciences, for example, in social and economic geography where it is applied for evaluation or a migration activity forecast or trade flows between human settlements and etc. [16] This model can be used also in case of intensity evaluation of migration capability of types of organisms between biocenters (or any other natural areas) [17,18]. In the latest case as "mass" of interacting sites of an area are considered quantity types (species wealth) of each site, and quantity of general types is regarded through the linking coefficient k. As distance between sites is taken either the shortest line space between sites if a landscape background surrounding these sites is close to them in its natural content, or length of the corridor linking them – the site of a linear configuration is similar to them on the structure of vegetation if the background area strongly differs from these sites.

However, this method is possible under the condition of detailed knowledge of biota of the research areas. In most cases according to the similar researches, the structure of biota has not properly been studied (the complete inventory of their biota has been carried out even not for all specially protected natural reservation (SPNR)) [19,4]. When there is no complete data about structure of a biota is much easier and more rapid (because it is often determined visually or, for example, by aero- and satellite photographs) to determine similarity of the research sites by type (types) of vegetation growing on them. Generally, the background area structure of their biota is approximately known and under the condition of short distance of these territories and, as a result, their location within one biogeographical or physiographic area, with high degree of probability it is possible to assume that degree of affinity of their biota is very high.

In this case to the fore there is not so much species wealth of research areas and even the space which isn't occupied by them (and, as we know, both of these characteristics are in functional link) and the types variety of organism habitat that is the types variety of vegetation and the related geotops [18,3,20]. Then migration links can be evaluated through the degree of similarity (distinction) of certain types of geotops and relative significance of the areas of these geotops within the research areas. In other words, the more the relative proportion of identical types of (geotops) habitat between two sites of an area is the more intensity of organism's migration between them.

The objective of the research: based on the complex analysis of the spatial pattern of the regional ecological network of Bakhmut area to estimate the significance of its natural cores as its backbone components.

MATERIALS AND METODS OF RESEARH. The evaluation method of migration capacity between natural cores of an ecological network is based on the following provisions:

Basis is the "gravitational model" of interaction ("attraction") of natural cores through potential migration of types of organisms (plants and animals) that inhabit them:

$$P_{i,j} = \frac{k \cdot C_i \cdot C_j}{d_{i,j}^{\ 2}}, \qquad (1)$$

where,

$P_{i,j}$ – the deegre (capacity) of mutual effect between the natural cores of C_i and C_j;

C_i and C_j – the "weight" of cores – the quantity of the types (specific structure, biological diversity) according to the cores i and j;

k – the coefficient showing the relative proportion of general views between C_i and C_j;

d_{ij} – the distance (length) of the corridor linking them.

So what, in a large majority of cases the total number of types for the next natural cores and frequently the exact amount of types in each core is unknown, so it should be allowed:

1) In general, for close natural cores within the borders of one physiographic (geobotanical, floristic, zoogeographical) area, affinity of types is almost 100%, that is, their specific structure is nearly homogeneous on the same sites of the areas (in the identical types of ecosystems);

2) Therefore it is logical to assume that degree of mutual effect between natural cores is defined, first of all, by similarity degree forming their types of sites of the areas (geotops).

In this case, as the first hypothesis, the sum of the areas forming their types of sites of areas is as the weight ("weight") of each natural core. Then k, for example, between cores C_i and C_j will be defined by degree of "area affinity" of the areas forming them in the form of their relations where lesser value is divisible by the corresponding larger one as the coefficient k should be in "0" to "1" range.

For example, shared distribution of area types ("h" – hay-fields, "p" - pastures, "w" - woods, "pl" – plowing fields, "g" -gullies, to "s" – stone heathlands).

Ci = 0.2h : 0.3p : 0.5w;

Cj = 0.1h : 0.4p : 0.2w : 0.3p;

then k_{ij} = (0.1h / 0.2h + 0.3p / 0.4p + 0.2w / 0.5w + 0p / 0.3p) / 4 = (0.5h + 0.75p + 0.4w + 0pl) / 4 = 1.65 / 4 = 0.41

Similarly, it is possible to use their absolute areas instead of the relative proportion of the area types of territories (in ha or sq.km);

3) Besides, it is desirable to use an extra factor for the corridor linking these cores in the formula 1, for example, r_{ij} that is calculated similar to k, but where larger value of n-territory type is divisible by lesser one because this coefficient should be in the denominator (or similarly it is calculated to the coefficient k_{ij}, but in this case the coefficient r_{ij} should be in the numerator of the formula):

$$P_{i,j} = \frac{k \cdot C_i \cdot C_j}{r_{i,j} \cdot d_{i,j}^{\,2}}, \qquad (2)$$

However, for more evaluation objectivity of natural cores significance as their weight ("weight") considering their biological and ecosystem diversity (and not only the areas of sites/areas types forming them), it is offered to use their complex evaluation according to all considered characteristics, that is:

C_i =the sum of all points of cores earned;

C_j = the sum of all points of cores earned.

The coefficients k and r (or k_{ij} and r_{ij}) are calculated only using (absolute or relative weights) the areas of cores.

The final result of such clustering should be the overall picture of "*the migration capacity*" of this ecological network (or its fragment), similar to "the capacity of the electromagnetic field" or link channel tension as a basis of any ecological network is its corridors (skeleton).

Thus, the overall picture of a spatial hierarchical structure of the whole river catchment area (or its parts) is built where according to the potential forming its watershed of cores by the method of the spatial clustering are determined the appropriate ranks (classes) of all ecological network (local - regional -subregional - national).

The received scheme of spatial hierarchy of ecological network can be, for example, a basis for ecological network dividing into districts throughout the country (or its large region).

EXPEREMENTAL PART AND RESULTS OBTAINED. Finding of migration capacity of ecological network of the Bakhmut watershed area. Migration capacity between natural cores of the Bakhmutka river watershed in Donetsk region has been calculated by the above technique. Their copmlex evaluation was used as "weight" of cores received before (table. 1 in [14]). The linking coefficients k_{ij} and r_{ij} have been defined by the percentage (%) of the types of geotops (in our case land grounds types) where lesser values have been divided by the larger ones. As a result, the formula of migration linking is:

$$P_{i,j} = \frac{k_{i,j} \cdot r_{i,j} \cdot C_i \cdot C_j}{d_{i,j}^{\,2}}, \qquad (3)$$

where,

P_{ij}- the migration capacity between cores i and j;

C_i and C_j –the complex evaluation (where there is evaluation (in points) on species and phytocoenotic wealth, including also their rare component, according to the occupied areas of each type of geological systems);

k_{ij} – the coefficient of common similarity for both cores of geosystems types as measured by the proportion of lesser value for larger one for each type of geosystems;

r_{ij} – the coefficient of types similarity of geosystems between cores and the corridor linking them is calculated similar to k_{ij}, but the area of the common types of geosystems of cores is taken as average arithmetic average between them and correlates to the ecocorridor;

d_{ij} - distance (km) between cores i and j linking them by the ecocorridor fragment (river net).

For example: evaluation of migration capacity between cores C1 and C3: complex evaluation of cores in points C1 = 488.0 points, C3 = 177.0 points.; length of the river network fragment linking them - 15.36 km;

$k_{1/3}$ = (14.7 / 50.6 (w) + 28.3 / 36.6 (p) + 0.2 / 8.2 (g) + 2.6 / 29.0 (s) + 2.0 / 7.7 (pl)) / 5 = 0.28;

$r_{1/3}$ = ((17.5 / 0.5 (14.7 + 50.6) (w) + 0.5 (28.3 + 36.6) (p) + 0.3 / 0.5 (0.2 + 8.2) (g) + 5.3 / 0.5 (2.6 + 29.0 (s) + 4.7 / 0.5 (2.0 + 7.7) (pl)) / 5 = 0.49;

$P_{1/3}$= 0.28 · 0.49 · 488.0 · 177.0 / 15.362^2 = 50.23.

The matrix of migration capacities between the cores of the Bakhmut watershed are provided in the table 1.

Only the core C2 from 21 natural cores of the Bakhmut watershed isn't linked directly with the others through the river system of a watershed (it is separated from near water passageway by a quarry and a human settlement area).

All other cores of a watershed are very closely related to its river system owing to what can be considered directly linked among themselves. Passing of river valleys through settlement areas in this case wasn't considered as an obstacle of migration links between cores, as in the most cases river valleys are covered with vegetation close to natural in settlement areas. To simplify the calculation, the relative areas of ecocorridors (river valleys) between all cores have been taken average for all watershed, but not for its separate fragment which is directly linking this couple of cores.

As can be seen from the table 1 that migration capacity of links between cores has wide dispersion of the absolute values and at first sight there is no any patterns here except that the cores which are close to each other have on average higher values of migration capacity between themselves, than with more distant. Nevertheless, even among the situated cores there is the essential difference in their migration capacities which can be explained by various degree of the types similarity of geosystems constituting both of them between themselves, and the ecocorridor linking them (Bpi - Bpi′).

Besides, from the matrix of migration capacities can be seen that their higher values form particular compact groups in it, being grouped in matrix boxes, directly linked between themselves in horizontal, vertical direction or diagonally.

Table1 – Matrix of migration capacity of Bakhmut region ecosystem

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	$C_{18'}$	$C_{18''}$	C_{19}	$\sum_{ij}$
C_1		-	**50.3**	**46.33**	**55.44**	8.25	**31.25**	4.60	16.38	0.91	4.58	4.29	10.26	8.41	0.98	3.45	10.41	2.92	4.32	3.49	3.49	**269.99**
C_2	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
C_3	50.23	-		**64.44**	**698.13**	**21.15**	**25.51**	3.47	7.72	0.28	2.31	3.35	4.35	4.89	0.24	2.30	5.08	1.23	1.57	1.48	1.15	**898.88**
C_4	46.33	-	64.44		**20.35**	**10.41**	**11.20**	1.79	5.62	0.20	1.79	2.08	5.24	3.93	0.23	1.29	1.75	1.30	1.07	0.91	1.37	**181.3**
C_5	55.44	-	698.13	20.35		1.52	**15116.16**	1.1	3.21	0.14	1.01	1.61	2.55	2.47	0.24	0.87	4.95	0.56	0.68	0.62	0.68	**15912.29**
C_6	8.25	-	21.15	10.41	1.52		3.05	0.54	1.45	0.007	0.47	0.32	0.56	0.56	0.016	0.47	0.75	0.30	0.15	0.19	0.28	**50.44**
C_7	31.25	-	25..51	11.20	15116.16	3.05		**26.61**	**37.52**	0.44	**12.0**	**14.65**	**15.46**	**25.70**	0.52	**10.73**	**10.15**	8.19	3.72	2.92	4.04	**15359.82**
C_8	4.60	-	3.47	1.79	1.10	0.54	26.61		**66.30**	0.18	1.25	0.86	1.96	1.28	0.14	1.02	0.94	0.22	0.61	0.68	0.34	**113.89**
C_9	16.38	-	7.72	5.62	3.21	1.45	37.52	66.30		0.19	4.44	3.04	7.20	7.30	0.14	2.85	2.15	1.80	0.64	1.39	1.68	**171.02**
C_{10}	0.91	-	0.28	0.20	0.14	0.007	0.44	0.18	0.19		**171.39**	8.05	**309.46**	0.34	2.64	0.084	7.12	0.16	0.00	0.32	0.22	**502.13**
C_{11}	4.58	-	2.31	1.79	1.01	0.47	12.00	1.25	4.44	171.39		**198.81**	**302.89**	4.53	3.07	3.02	**23.24**	1.23	2.08	2.12	1.21	**741.44**
C_{12}	4.29	-	3.35	2.08	1.61	0.32	14.65	0.86	3.04	8.05	198.81		**2222.05**	4.88	3.64	3.40	**24.37**	5.00	1.97	7.07	2.66	**2512.10**
C_{13}	10.26	-	4.35	5.24	2.55	0.56	15.46	1.96	7.20	309.46	302.89	2222.05		9.48	**33.08**	3.56	**81.09**	**11.86**	7.45	6.78	5.26	**3040.54**
C_{14}	8.41	-	4.89	3.93	2.47	0.56	25.70	1.28	7.30	0.34	4.53	4.88	9.48		0.35	**12.85**	4.07	4.37	3.06	1.77	2.36	**102.6**
C_{15}	0.98	-	0.24	0.23	0.24	0.016	0.52	0.14	0.14	2.64	3.07	3.64	33.08	0.35		0.08	**634.54**	0.15	0.20	0.13	0.15	**680.54**
C_{16}	3.45	-	2.30	1.29	0.87	0.47	10.73	1.02	2.85	0.084	3.02	3.40	3.56	12.85	0.08		4.85	0.86	1.27	1.48	1.09	**55.52**
C_{17}	10.41	-	5.08	1.75	4.95	0.75	10.15	0.94	2.15	7.12	23.24	24.37	81.09	4.07	634.54	4.85		**31.29**	**10.24**	5.81	**15.66**	**878.46**
C_{18}	2.92	-	1.23	1.30	0.56	0.30	8.19	0.22	1.80	0.16	1.23	5.00	11.86	4.37	0.15	0.86	31.29		**1846.85**	**1255.75**	**106.40**	**3280.44**
$C_{18'}$	4.32	-	1.57	1.07	0.68	0.15	3.72	0.61	0.64	0.00	2.08	1.97	7.45	3.06	0.20	1.27	10.24	1846.85		**94.48**	**39.17**	**2019.53**
$C_{18''}$	3.49	-	1.48	0.91	0.62	0.19	2.92	0.68	1.39	0.32	2.12	7.07	6.78	1.77	0.13	1.48	5.81	1255.75	94.48		**99.87**	**1487.26**

Standing out the general numerical background such groups of cores also form primary spatial clusters (clusters of the 1st rank) in ecological network by migration capacity between them (in the table 1 they are highlighted in bold type) that exceeded the rest of the values of migration capacity several times higher.

Except the general fact of close link existence between cores, these clusters show also the most significant cores according to their migration capacity in this cluster if these cores exceed (or a core) the rest ones by the number of links between all cores in a cluster. In other words, in such cluster can be identified central (or central and sub central) core.

Besides, from the matrix can be seen (tab. 1) that some cores having essential values of migration capacity can be in different clusters simultaneously. Such cores are linking these clusters between themselves forming the clusters of the 2nd rank in this way. Grouping the clusters of the 1st rank through linking their cores in the clusters of the 2nd rank, it can be seen that there are cores which link between themselves and the clusters of the 2nd rank, that is form the clusters of the 3rd rank (or the whole clusters of the lower rank at the same time can enter two different clusters of a higher rank). In other words, there is a patched hierarchical configuration type of a landscape structure when two or several topographic contours configurations, being in whole or in part covering between themselves form topographic contours structure of a higher rank, as a rule, more difficult organized [18].

In our case a hierarchical directivity is created not just by growth of number of cores included a cluster of the subsequent rank but also by increasing of clusters area covering, the growth structural (ecosystem and biological) varieties of all area that actually can be reflected in complex evaluation of their forming cores.

Thus, the diagram of spatial clustering of cores of ecological network of the Bakhmut watershed is the following type:

Clusters of the 1st rank: include cores which migration capacity significantly exceeds the background between them. As a lower limit value is the capacity value = 10.00.

1.1. Cl1: cores (C1 + C3 + C4 + C5 + C6 + C7); Ni = 6

Values of their migration capacity (in descending rank)

C5 ÷ C7 = 15116.16   C3 ÷ C5 = 698.13
C3 ÷ C4 = 64.44   C1 ÷ C5 = 55.44
C1 ÷ Я3 = 50.23   C1 ÷ Я4 = 46.33
C1 ÷ C7 = 31.25   C3 ÷ C7 = 25.51
C3 ÷ C6 = 21.25   C4 ÷ C5 = 20.35
C4 ÷ C7 = 11.20   C4 ÷ C6 = 10.41

The number of links between cores n_i = 12.

The average value of migration capacity in a cluster: 16150.6/12 = 1345.90

There is no central core, but the number of links in the cores C3 and C4 is equal to C5 and in the cores C1, C5 and C7 is equal to C4 and in a core C6 is equal to 3.

1.2. Cl2: the cores (C7 + C8 + C9); Ni = 3

C8 ÷ C9 = 66.30
C7 ÷ C9 = 37.52
C7 ÷ C8 = 26.61

The number of links of n_i = 3; Average value of migration capacity in a cluster: 43.48.

There is no central core, all cores are equivalent by the number of links.

1.3. Cl3: the cores (C7 + C11 + C12 + C13 + C14); Ni = 5

C7 ÷ C14 = 25.70   C7 ÷ C13 = 15.46
C7 ÷ C12 = 14.65   C7 ÷ C11 = 12.00

The number of links n_i = 4; the average value of migration capacity in a cluster: 16.95.

The core C7, having four links is central in a cluster whereas the rest cores have only one link.

1.4. Cl4: cores (C7 + C16 + C17); Ni = 3

C7 ÷ C16 = 10.73   C7 ÷ C17 = 10.15

The number of links n_i = 2; average value of migration capacity potential in a cluster i: 10:44.

The core the C7 is the central in a cluster.

1.5. Cl5: cores (C10 + C11 + C12 + C13); Ni = 4

C12 ÷ C13 = 2222.054
C10 ÷ C13 = 309.46
C11 ÷ C13 = 302.89
C11 ÷ C12 = 1998.81
C10 ÷ C11 = 171.39

The number of links n_i = 5; average value of migration capacity in a cluster: 640.92.

There is no central core, the cores C11 and C13 have three links, the rest cores two ones.

1.6. Cl6: cores (C11 + C12 + C13 + C14 + C15 + C16 + C17 + C18); Ni = 8

C15 ÷ C17 = 634.54   C13 ÷ C17 = 81.09
C13 ÷ C15 = 33.08   C12 ÷ C17 = 24.37
C11 ÷ C17 = 23.24   C14 ÷ C16 = 12.85
C13 ÷ C18 = 11.86

The number of links n_i = 7; the average value of migration capacity in a cluster: 117.29.

The core C17 having four links in a cluster is the central, C13 has three links and it is the sub central to C15 has two links in a cluster, the rest cores have only one link.

1.7. Cl7: cores (C17 + C18 + C18′ + C18″ + C19); Ni = 5

C18 ÷ C18′ = 1846.85 C18 ÷ C18″ = 1255.75
C18 ÷ C19 = 106.40   C18′ ÷ C19 = 99.87
C18′ ÷ C18″ = 94.48   C18′ ÷ Я19 = 39.7
C17 ÷ C18 = 31.29   C17 ÷ C19 = 15.66
C17 ÷ C18′ = 10.24

The number of links n_i = 9; the average value of migration capacity in a cluster: 388.86.

There is no central core.

The 2nd rank clusters: are formed by the group of the 1st rank clusters through the general cores between them.

2.1. [[Cl1 + Cl 2 + Cl 3 + Cl 4]] = [(C1 + C3 + C4 + C5 + C6 + C7) + (C7 + C8 + C9) + (C7 + C11 + C12 + C13 + C14) + (C7 + C16 + C17)]

The average value of migration capacity of the 2nd rank cluster we obtain by the simple arithmetical sum of similar values of the 1st rank clusters forming its clusters divided into their number: (1345.9 + 43.48 + 16.95 + 10:44) / 4 = 354.19.

Core C7 is linking here (the 1st rank in one general cluster) and the central (according to the number of links).

2.2. [Cl3 + Cl5] = [(C7 + C11 + C12 + C13 + C14) + (C10 + C11 + C12 + C13)]

The average value of migration capacity of a cluster: (16.95 + 640.92) / 2 = 328.94.

The cores C11, C12, C13 are the linking ones.

2.3. [Cl5 + Cl6] = [(C10 + C11 + C12 + C13) + (C11 + C12 + C13 + C14 + C15 + C16 + C17 + C18)]

The average value of migration capacity of a cluster: (640.92 + 117.29) / 2 = 379.11.

The cores C11, C12, C13 are the linking.

2.4. [Cl6 + Cl7] = [(C11 + C12 + C13 + C14 + C15 + C16 + C17 + C18) + (C17 + C18 + C18′ + C18″ + C19)]

The average value of migration capacity of a cluster: (117,29 + 388,86) / 2 = 253.08.

The cores C17 and C18 are the linking, and the core C17 is also the central by the number of links.

The 3rd rank clusters: are formed similar to the 2nd rank clusters

through combining them through the general (the linking) cores or the 1st rank clusters.

3.1. = ([Cl1 + Cl2 + Cl3 + Cl4] + [Cl3 + Cl5])

The entire cluster of the 1st rank Cl3, that is the cores C7, C11, C12, are the linking, and the core C7 is also the central.

The average value of migration capacity of a cluster: (354.19 + 328.94) / 2 = 341.57.

3.2. (2.2 + 2.3) = ([Cl3 + Cl5] + [Cl5 +Cl6])

The linking cluster is Cl5, that is the cores C11, C12, C13.

Average value of migration capacity of a cluster: (328.94 + 379.11) / 2 = 354.03.

3.3. (2.3 + 2.4) = ([Cl5 + Cl6] + [Cl6 + Cl7])

The linking cluster is Cl6 , and that is the cores Я11, Я12, Я13 и Я17, Я18 are in it.

Average value of migration capacity of a cluster: (379.11 + 253.08) / 2 = 316.1.

The 4th rank clusters: are formed through the link of all 3rd rank clusters in the entire watershed:

4.1. (3.1 + 3.2 + 3.3) = {(2.1+ 2.2) + (2.2+2.3) + (2.3+2.4)} = {[(C1 + C3 + C4 + C5 + C6 + C7) + (C7 + C8 + C9) + (C7 + C11 + C12 + C13 + C14) + (C7 + C16 + C17)] + [(C7 + C11 + C12 + C13 + C14) + (C10 + C11 + C12 + C13)] + [(C7 + C11 + C12 + C13 + C14) + (C10 + C11 + C12 + C13)] + [(C10 + C11 + C12 + C13) + (C11 + C12 + C13 + C14 + C15 + C16 + C17 + C18)] + [(C10 + C11 + C12 + C13) + (C11 + C12 + C13 + C14 + C15 + C16 + C17 + C18)] + [(C11 + C12 + C13 + C14 + C15 + C16 + C17 + C18) + (Я17 + C18 + C18′ + Я18″ + C19)]}

In this combined cluster the core C7 is found for six times, the core C17– for five times, the combination of cores (C11 + C12 + C13) is found for 10 times and the combination of cores (C17 + C18) – for four times.

The average value of migration capacity of a cluster, that is of the whole watershed is equal to: (341.57 + 354.03 + 316.1) / 3 = 337.23.

Thus, in the general spatial structure of the Bakhmut watershed ecological network all natural cores ranging them are grouped in four-level hierarchical structure of clusters in which it is possible to highlight the central and sub central cores according to their linking function. First of all, the cores C7, C17 and C13, having the greatest number of links with high migration capacity throughout ecological network among which the core C7 is the central (the number of significant migratory links is equal to 12), and the sub central cores C17 and C13 (the number of significant migratory links is accordingly equal to respectively 8 and 7).

In the theme of a spatial clustering of natural cores these cores also play the central role, been seeing most often in the areas of «overlapping» of clusters. Referring to the schematic map of spatial structure of an ecological network of the Bakhmut watershed, we can say about two "fields of concentration" of its migration capacity: this so-called small central field of the increased concentration of migration links – in the triangle of cores (C11 + C12 + C13), where the core C10 can be included because of geographical proximity, and the large central field of the increased concentration of migration links in the triangle which angles are the cores C7, C17 и C18 and + (C18′, Я18″). And the first small field is in the space of larger one (fig.1).

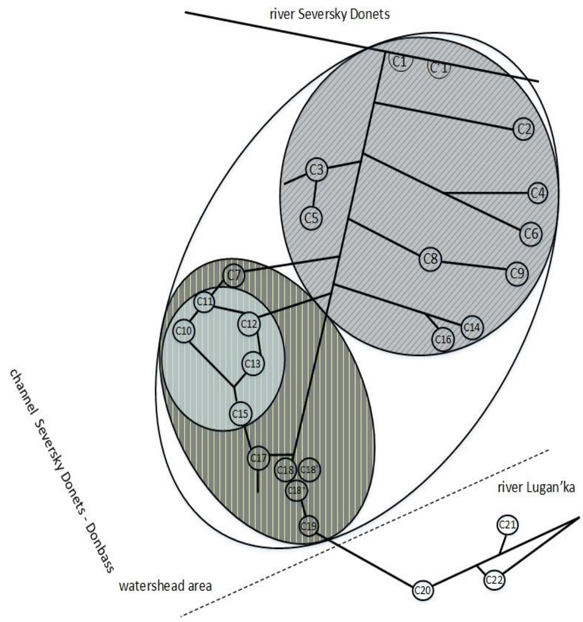

Figure 1 – Biocentric and network scheme of Bakhmut administrative area ecological network

Comparing the data on the migration capacity of natural cores of an ecological network of the Bakhmut watershed of these cores by their evaluations in points according to the above listed characteristics [14], it can be definitely speaking about special importance in an ecological network of a watershed of the cores C7 and C17. Having received the highest points practically according to all features, and, as a result, by combined evaluation, they also hold the leading position in potential migration links of a watershed. This draws special attention to them in design of an ecological network in this region.

It would be very desirable to add the more valuable areas of their territory in the nature reserve fund (NRF) of the region after their more detail study. Possibly, added in NRF of the whole cluster between "triangle" of cores (C11 + C12 + C13) and core C17 as the regional landscape park (RLP) with the functional zoning of its territory.

CONCLUSIONS. Thus, the method of a spatial clustering of natural cores on the basis of their migration capacity shows inevitability of migration from the discrete principle of the creation of an ecological network at the local (topical) level of its research when it is possible to highlight and estimate its elementary structural units – natural cores (biocenters), to continual approach at the structural and regional levels at which its certain functional characteristic is in the first place (in this case its migration capacity). And the method of a spatial clustering helps to identify discrete and contiguous nature of any ecological network in the process of changing of its creation scale.

In general, analyzing biocentric and network structure of the Bakhmut watershed ecological network, it can be stated rather high degree of connectivity, practically of all its natural cores, and, therefore, and the migration capacity of an entire ecological network. This is due to the fact that the river Bakhmutka has a form of classical river system where all inflows and cores connected by them are evenly distributed through the territory of a watershed. Nevertheless, finding on the basis of the analysis of the degree of the topographic contours similarity of natural cores and ecological corridors of special "fields of a concentration" of the migration capacity of entire regional ecological network linking them, provides clearly to find concrete areas in a watershed which need to be emphasized from the point of view of a new SPNR creation on them.

REFERENCES

1. Duro D.C., Coops N.C., Wulder M.A., Han T. Development of a large area biodiversity monitoring system driven by remote sensing. *Progress in Physical Geography*, 2007, no. 31, pp. 235-260.

2. Fahrig L., Baudry J., Brotons L., Burel F.G., Crist T.O., Fuller R.J., Sirami C., Siriwardena G.M., Martin J. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecology Letters*, 2011, no. 14, pp. 101-112.

3. González-Megías A., Gómez J.M., Sánchez-Piñero F. Spatio-temporal change in the relationship between habitat heterogeneity and species diversity. *Acta Oecologica*, 2011, no. 37, pp.179-186.

4. Chape S., Harrison J., Spalding M., Lysenko I. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. *Philosophical Transactions of the Royal Society B: Biological*, 2005, no. 360, pp. 443-455. DOI: 10.1098/rstb.2004.1592.

5. Wagner H.H., Fortin M.J. Spatial analysis of landscapes: concepts and statistics. *Ecology*, 2005, no. 86, pp.1975-1987. DOI: 10.1890/04-0914.

6. George J. Chirima, Norman Owen-Smith, Barend F.N. Erasmus. Changing distributions of larger ungulates in the Kruger National Park from ecological aerial survey data. *Koedoe*, 2012, Vol.54, no.1, P.24-35.

7. Ziółkowska E., Ostapowicz K., Radeloff V. Assessing differences in connectivity based on habitat versus movement models for brown bears in the Carpathians. *Landscape Ecology*, 2016, no. 31, pp. 1863-1882. DOI: 10.1007/s10980-016-0368-8.

8. Coulon A., Morellet N., Goulard M., Cargnelutti B., Angibault J-M., Hewison A.J.M. Inferring the effects of landscape structure on roe deer (*Capreolus capreolus*) movements using a step selection function. *Landscape Ecology*, 2008, no. 23, pp. 603-614.

9. Sandra MacFadyen, Cang Hui, Peter H. Verburg, Astrid J. A. Van Teeffelen Quantifying spatiotemporal drivers of environmental heterogeneity in Kruger National Park, South Africa. *Landscape Ecology*, 2016, no.31, pp. 2013-2029. DOI: 10.1007/s10980-016-0378-6.

10. Samuel A. Cushman, Falk Huettmann Spatial complexity, informatics, and wildlife conservation. *Springer Tokyo Berlin Heidelberg New York*, 2010, 452 p. DOI: 10.1007/978-4-431-87771-4 – ISBN 978-4-431-87770-7.

11. Maile C. Neel, Kevin McGarigal, Samuel A. Cushman Behavior of class-level landscape metrics across gradients of class aggregation and area. *Landscape Ecology*, 2004, no.19, pp. 435-455. DOI: 10.1023/B: LAND.0000030521.19856.cb.

12. Joern Fischer, David B. Lindenmayer Landscape modification and habitat fragmentation: a synthesis. *Gobal Ecology and Biogeography*, 2007, vol. 16, Issue 3, pp. 265-280. DOI: 10.1111/j.1466-8238.2007.00287. x.

13. Doebeli M., Dieckmann U. Speciation along environmental gradients. *Nature*, no. 421, pp. 259-264. DOI: 10.1038/nature01274.

14. A. Blakbern, O. Kalinihin Metohodology of ecological network formation. *Ecological safety*, 2016, Issue 1 (21), pp. 18-23.

15. Blackburn A.A., Derbentseva A.V., Mulenkova E.G., Ostapko V.M., Endeberya A.Y. Formirovanie rajonnykh ekologicheskikh setej na primere Slavyanskogo i Krasnoli-manskogo rayonov Donetskoj oblasti [Formation of regional ecological networks as an example of the Slavic and Krasnolimanskiy Donetsk region]. *Zapovidna sprava v Ukrainy*, 2010, vol. 16, no. 2, pp. 1–8.

16. Brunsdon C., Fotheringham A., Charlton M. Geographically weighted summary statistics a framework for localised exploratory data analysis. // *Computers, Environment and Urban Systems*, 2002, Vol. 26, Issue 6, pp. 501-524. DOI: 10.1016/S0198-9715(01)00009-6.

17. Grodzinsky M.D. Osnovy landshaftnoyi ekologii [Basics of landscape ecology]. Kyiv: Lybid, 1993. 224 p.

18. Grodzinsky M.D. Piznannya landshaftu: mistse i prostir [Knowledge of the land-scape: the place and space]. Kyiv: Print. center«Kyiv University», 2005, vol. 1, 431 p.

19. Spencer R. Meyer, Kate Beard, Christopher S. Cronan, Robert J. Lilieholm. An analysis of spatio-temporal landscape patterns for protected areas in northern New England: 1900–2010. *Landscape Ecology*, 2015, Issue 30, pp. 1291-1305. DOI: 10.1007/s10980-015-0184-6.

20. Gould W. Remote sensing of vegetation, plant species richness, and regional biodiversity hotspots. *Ecological Applications*, 2000, Vol. 10, No. 6, pp. 1861-1870. DOI: 10.2307/2641244.

ОЦЕНКА МИГРАЦИОННОГО ПОТЕНЦИАЛА ЛОКАЛЬНОЙ ЭКОЛОГИЧЕСКОЙ СЕТИ

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Данная статья является логическим продолжением статьи этих же авторов, в которой рассматривалась пространственная структура локальной экологической сети с точки зрения комплексной оценки в баллах составляющих ее природных ядер. Однако данный метод, дающий сравнительную характеристику структурных элементов экосети (природных ядер), не позволяет оценить главную функциональную характеристику экосети – ее миграционную способность. В этой статье предлагается оригинальная методика оценки пространственной иерархической структуры локальной экологической сети Бахмутской водосборной территории на основе определения миграционного потенциала между ее природными ядрами. Последний получен на основе гравитационной модели сходства составляющих их геотопов (типов земель) путем комплексной оценки в баллах их экосистемных характеристик. В результате получена пространственная иерархическая структура локальной экосети в виде кластеров природных ядер от 1-го до 4-го порядков. Делается вывод о дискретно-континуальном характере любой экологической сети в процессе перехода ее построения от локального (дискретного уровня ее организации) к региональному ее уровню (с континуальным характером ее структурной организации).

Ключевые слова: локальная экологическая сеть, природные ядра, миграционный потенциал, биоцентрично-сетевая структура экосети, пространственная кластеризация природных ядер.

Ключевые слова: экологическая сеть, природные ядра, экокоридоры, биоцентрично-сетевая структура экосети, водосборная территория, биоразнообразие, иерархическая структура экосети, ландшафт.