U.D.C. 504.54.062.4:504.453

# METHODOLOGY OF ECOLOGICAL NETWORK FORMATION

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***Purpose.*** In this paper the spatial pattern of the regional ecological network formation (on the example of Bakhmut administrative area in Donetsk region) is considered from the viewpoint of the methodology complex evaluation of its constituent natural cores. ***Methodology.*** The comparative characteristic of natural cores in the form of their complex evaluation and topological position about the biocentric and network spatial pattern is given. The species and phytocoenotic wealth of sites (the topographic contours) of natural cores, including their rare component was evaluated by 10 point evaluation system. The topological structure of an ecological network has been estimated on its biocentric and network nature through which it is possible to highlight the central and subcentral cores by degree of connectivity them among themselves. ***Originality.*** Ranging of natural cores has been carried out according to their main characteristics– species and phytocoenotic wealth, ecological system variety, a topological connectivity and, as a result, by complex evaluation system has shown a possibility of creation of a hierarchical spatial pattern of the regional ecological network by degree of "significance" which are its natural cores. The conclusions about uneven value of natural cores of the local ecological network in priority of their making into nature reserve fund of the region are drawn. ***Practical value***. According to the 1st and 2nd rows of natural cores "significance" of the regional ecological network of the area are allocated, on the basis of which after their more detailed research the creation of new facilities EPNA (especially protected natural areas) are recommended. *References 15, figures 1, tables 6.*

**Keywords:** ecological network, natural cores, ecological corridors, biocentric and network structure of ecological network, watershed area, biodiversity, hierarchical structure of ecological network.

# МЕТОДИКА ФОРМУВАННЯ ЕКОЛОГІЧНОЇ МЕРЕЖІ

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В наведеній роботі розглянуто формування просторової структури локальної екологічної мережі (на прикладі Бахмутського адміністративного району Донецької області) з точки зору методології комплексної оцінки складових її природних ядер. Надано порівняльну характеристику останніх у вигляді їх комплексної бальної оцінки і топологічного положення щодо біоцентрично-мережевої просторової їх структури. За 10-бальною системою проведено оцінювання видового і фітоценотичного багатства ділянок (геотопічних контурів) природних ядер, включаючи їх раритетну складову. Топологічна структура екомережі оцінена за її біоцентрично-мережевим характером, завдяки чому можливо виділити центральні і субцентральні її ядра за ступенем зв'язності їх між собою. Проведене ранжування природних ядер за їх основними характеристиками - видовому і фітоценотичному багатству, екосистемному різноманіттю, топологічному зв'язку і, в підсумку, за сукупною бальною оцінкою показало можливість побудови ієрархічної просторової структури локальної екомережі за ступенем «значущості» складових її природних ядер. Робляться висновки про нерівнозначну цінність природних ядер локальної екомережі в пріоритетності їх внесення до природно-заповідного фонду регіону: виділяється, відповідно, 1-й і 2-й ряди «значущості» природних ядер локальної екомережі району, на базі яких після більш детального їх обстеження рекомендовано створення нових об'єктів ООПТ (особливо охоронюваних природних територій).

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

**PROBLEM STATEMENT.** Creating of ecological networks now is the most progressive form of nature conservation, a kind of a new zoological paradigm having replaced an old idea of separate natural objects protection (populations, types, their habitats)-the main focus of which was the conservation of rare, unique and disappearing natural objects to the idea of creating of the protected objects network and territories which the strategic objective is conservation of all biological and landscape diversity of the regions and the maintenance of balanced environment there. In other words, the precedent of system approach in environmental protection as with theoretical and so with methodological standpoints is created [1,2].

At the international level this idea has been formulated in the policy document of the European Union devoted to conservation of biological and landscape diversity of the European continent. The idea was realized in most of Europe through the establishment of the national (state) ecological networks [3,4]. Ukraine was also included into this process, having signed the relevant documents and having adopted two basic laws on creation of the national ecological network [5,6].

The process of formation of the national ecological network in Ukraine ("natsional'noyi ekomerezhi") according to the established normative instruments which should be completed by 2015. However, this process has practically stalled and on many fronts has come to a standstill for a number of reasons - economic, political and organizational measures. Though the Ukrainian scientists have also developed criteria and methods of creating of an ecological network in Ukraine [7,8], the main challenge here is the lack of opportunities in most regions of Ukraine to use these criteria and methods for real creating of ecological networks (due to the lack of sufficient financing of necessary field and remote researches, the necessary number of experts, the general methodological approach to this process and etc.).

In this paper the original method of the complex evaluation of the spatial pattern of an ecological network based on complex evaluation (in points) of its natural cores and topological location is offered. This research was carried out within the development of Donetsk regional ecological network (Donetsk REN). The main ways and methods of its creating have already been defined and its model scheme [9,10] has been developed by its developers before.

*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. The generally accepted situation is based that at the local levels of an ecological network (that is, at the structural and topographical levels from a position of a classical landscape science) any sites of natural contents appear as its main natural cores (with natural vegetation or sites with the increased biodiversity in comparison with the surrounding areas). The river systems of the explored regions or areas appear as the connecting them with the ecological (natural) corridors [11]. At bottom, the important structure of an ecological network is its biocentric and network structure [12].

The main point is that the natural cores of an ecological network are in its as the biocenters – the sites of increased biodiversity in comparison with a background which are refugiums of this biodiversity for all regions (areas) and they connect with each other by means of ecological corridors – the sites of a linear network configuration of natural contents, providing migration of organisms among themselves, and therefor for all space of an ecological network and so provide a long-term conservation of biodiversity for all regions (areas). Together the biocenters and ecological corridors linking them upon condition of their sufficient areas and the coverage of all territory of the region (area) keep as well its landscape variety and provide a steady condition of its entire natural and anthropogenic environment.

*Materials and metods of researh.* Fundamentally, the natural cores of the regional ecological network criteria have been taken from the references [7] according to which for regions "…where (natural) vegetation cover is almost reduced, any site with the vegetation close to natural have been taken, can be considered as the biocenter". Natural cores within Bakhmut area have been chosen by the schematic map visual evaluation of its land (types of land) and the Land Cadastre with linked to the river system of the area. The chosen cores were estimated on a variety of types of the lands, occupied the areas, and also by the method of an expert evaluation of their specific and phytocenotic wealth (through vascular plants). Before we have developed a methodology of making of the regional ecological network diagram and complex evaluation (in points) [13] which has also been used in the present research. The fact is that each type of lands within the borders of each natural core gets an evaluation in points (from 1 to 10) according to the following characteristics: occupied space (ha), species wealth (species of vascular plan quantity), phytocenotic variety (the number of vegetation species). To the last two characteristics additional points of rarity are added (the regional list of rare species: for 1 species - 0,25 points; for the species registered in the Red Book of Ukraine - 0,5 points; for the species registered in the European Red Book - 1 point and for species from the Red Book of IUCN - 1,5 points [14]. Quantity of phytocoenose was evaluated for ordinary phytocoenose (1 point) and for phytocoenose (2 points), registered in the Green book of Ukraine. An ecological system variety of a core was evaluated as quantity of types of lands which are available in it (but they, in turn, are determined by vegetation species that is a map sign of any natural ecological system).

As a result, the complex evaluation( in points) on each natural core (biocenter) by the method of simple summation was put down which defined the significance of each natural core in this ecological network. The Bakhmut administrative area (169.000 ha) is completely included into the Seversky and the Donetsk supra-regional watershed. About 90% of the area belongs to the watershed area of the Bakhmutka river which, along with the Kazeny Torets is the right inflow of the Seversky Donets, flows from the south to the north, approximately, in the middle of Bakhmut area and divides almost all its territory into the left and right half symmetrically. The far south-east part of Bakhmut area belongs to Lugank watershed area, falling into the Lugan river that is the territory of Luhansk region and which is also the right inflow of the Seversky Donets.

Besides the rating of an ecological network of Bakhmut area, its biocentric and network scheme was drawn up on which the degree of its biocenters connectivity among themselves has been determined by Bichem index [1,12]

**EXPERIMENTAL PART AND RESULTS OBTAINED.** The ecological network of the Bakhmut watershed area consists of 11 ecological corridors, including the main channel of the Bakhmutka river, five of its left inflows and four of its right (the last 4th right inflow is approximately divided into 2 equivalents ), 21 regional natural cores and 6 interactive elements (the natural sites of linear configuration without contacts with natural cores). The area of natural cores of the watershed area makes 20786,16 ha,the ecological corridors – 6462,6 ha, the interactive elements – 897,5 ha. Lugan`ka ecological network within Bakhmut area consists of one ecological corridor, three natural cores and five interactive elements, which, owing to their gap localities and large water storage drainage is the fragments of Lugan`ka inflows. The total area of natural cores of watershed area makes 4353,11 ha, the ecological corridor – 353,8 ha, the interactive elements – 945,5 ha. In general, the total area of all natural cores of Bakhmut area makes 25138,27 ha, or 14,9% of its area, the ecological corridors – 6816,4 ha, or 4,03% of its area, the interactive elements – 1843,01 ha, or 1,09% of its area. Thus, the total area of an ecological network within Bakhmut area makes 33797,7 ha, or 20,04% of its territory. The average area of natural cores of Bakhmut area makes 1047,4 ha. In the structure of the Bakhmut watershed the sites of natural contents in the natural cores of its ecological network is 83,2%, in the Lugan`ka watershed– 98%.

The overall structure of the natural cores of both watersheds is close, except for the areas which are under water: in the Lugan`ka watershed their proportion is nearly 38% (as a part of which the largest core there is the Uglegorsk water storage), in Bakhmut is only 2%, and also swamp lands and ravines which relative proportions in Lugan`ka watershed are many times larger, than in the Bakhmut watershed. In the last, however, a proportion of forest-covered areas is more than three times higher, than in the Lugan`ka watershed. In the Bakhmut watershed, as well, all facilities of the natural -reserved fund (NRF) of the area are in the Bakhmut watershed which proportion is 12,7% of the area of the natural cores of the watershed. As it was already mentioned above, the natural cores of Bakhmut area were evaluated in points according to a number of characteristics – areas, species (floristic) and phytocenotic wealth, ecosystem variety. In general, in Bakhmut area among the natural cores in the relative area pastures are absolutely prevail (45,4%), forest-covered areas are in second place (21,8%), plough lands are in third place (9,2%), the sites which are under water - in fourth (8,4%) and hay-fields are in fifth (5,9%). The ranging of the natural cores characteristics according to the evaluation (in points) has been carried out for the comparative analysis of their significance in Bakhmut area. (tables 1-5).

Table 1 – Ranging of natural cores according to species wealth

| IV rank (total points) (3,5 – 10,6) | III rank (total points) (10,7 – 17,8) | II rank (total points) (17,9 – 25,0) | I rank (total points) (25,1 – 32,2) |
|---|---|---|---|
| $C_2$, $C_5$, $C_6$, $C_8$, $C_{10}$, $C_{11}$, $C_{12}$, $C_{13}$, $C_{14}$, $C_{15}$, $C_{16}$, $C_{18}'$, $C_{19}$, $C_{21}$ | $C_4$, $C_7$, $C_9$, $C_{18}$, $C_{18''}$, $C_{20}$, $C_{22}$ | $C_{17}$ | $C_3$ |
| 14 | 7 | 1 | 1 |

Table 2 – Ranging of natural cores according to phytocenotic wealth

| IV rank (total points) (12,0 – 46,5) | III rank (total points) (46,6 – 81,1) | II rank (total points) (81,2 – 115,7) | I rank (total points) (115,8 – 150,3) |
|---|---|---|---|
| $C_2$, $C_6$, $C_8$, $C_{10}$, $C_{15}$, $C_{18}'$ | $C_5$, $C_{11}$, $C_{12}$, $C_{14}$, $C_{16}$, $C_{18}$, $C_{18}''$, $C_{19}$, $C_{20}$ | $C_4$, $C_9$, $C_{13}$, $C_{21}$, $C_{22}$ | $C_3$, $C_7$, $C_{17}$ |
| 6 | 9 | 5 | 3 |

Table 3 – Ranging of natural cores according to their area

| IV rank (total points) (7,0 – 12,5) | III rank (total points) (12,6 – 18,1) | II rank (total points) (18,2 – 23,7) | I rank (total points) (23,8 – 29,3) |
|---|---|---|---|
| $C_2$, $C_6$, $C_8$, $C_{10}$, $C_{11}$, $C_{12}$, $C_{15}$, $C_{18}'$, $C_{20}$ | $C_3$, $C_5$, $C_9$, $C_{18}''$, $C_{19}$ | $C_4$, $C_{13}$, $C_{14}$, $C_{16}$, $C_{17}$, $C_{18}$, $C_{22}$ | $C_1$, $C_7$, $C_{21}$ |
| 9 | 5 | 7 | 3 |

Table 4 – Ranging of natural cores according to ecosystem variety

| IV rank (total points) (3,0 – 8,0) | III rank (total points) (9,0 – 14,0) | II rank (total points) (15,0 – 20,0) | I rank (total points) (21,0 – 26,0) |
|---|---|---|---|
| $C_2$, $C_5$, $C_6$, $C_8$, $C_{10}$, $C_{12}$, $C_{15}$, $C_{18}$, $C_{18}'$, $C_{18}''$, $C_{20}$ | $C_1$, $C_3$, $C_4$, $C_9$, $C_{11}$, $C_{14}$, $C_{16}$, $C_{17}$, $C_{19}$, $C_{21}$ | $C_{13}$, $C_{22}$ | $C_7$ |
| 11 | 10 | 2 | 1 |

Table 5 – Ranging of natural cores according to complex evaluation (in points)

| IV rank (total points) (26,75 – 71,25) | III rank (total points) (71,3 – 115,8) | II rank (total points) (115,9 – 160,4) | I rank (total points) (160,5 – 205,0) |
|---|---|---|---|
| $C_2$, $C_6$, $C_8$, $C_{10}$, $C_{15}$, $C_{18}'$ | $C_5$, $C_{11}$, $C_{12}$, $C_{14}$, $C_{18}$, $C_{18}''$, $C_{19}$, $C_{20}$ | $C_4$, $C_9$, $C_{13}$, $C_{16}$, $C_{21}$, $C_{22}$ | $C_3$, $C_7$, $C_{17}$ |
| 6 | 8 | 6 | 3 |

It can be seen that according to all considered characteristics in high ranging groups (the I rank and II rank) $C_3$ cores (the 1st place according to species wealth and the 3rd place according to phytocenotic wealth and complex evaluation), $C_{17}$ (the 1st place according to phytocenotic wealth and complex evaluation, and the 2nd place according to species wealth) and $C_7$ (the 1st place according to ecosystem variety and the 2nd place on phytocenotic wealth and complex evaluation, and the 3rd place according to their area) have been included.

The cores $C_3$, $C_{17}$ and $C_7$ according to all combined characteristics of the present research should be included into the so-called first row of the significance of the regional natural cores of Bakhmut ecological network area together with the core $C_1$ (which, due to ultrahigh biological diversity and special area location has not been included into the general comparative analysis of natural cores of the area, (as discussed below). The cores $C_1$ and $C_3$ also include the large NRF facilities.

According to the results of ranging, the map chart of Bakhmut area ecological network with a rare component of its biocenters has been received (fig.1)

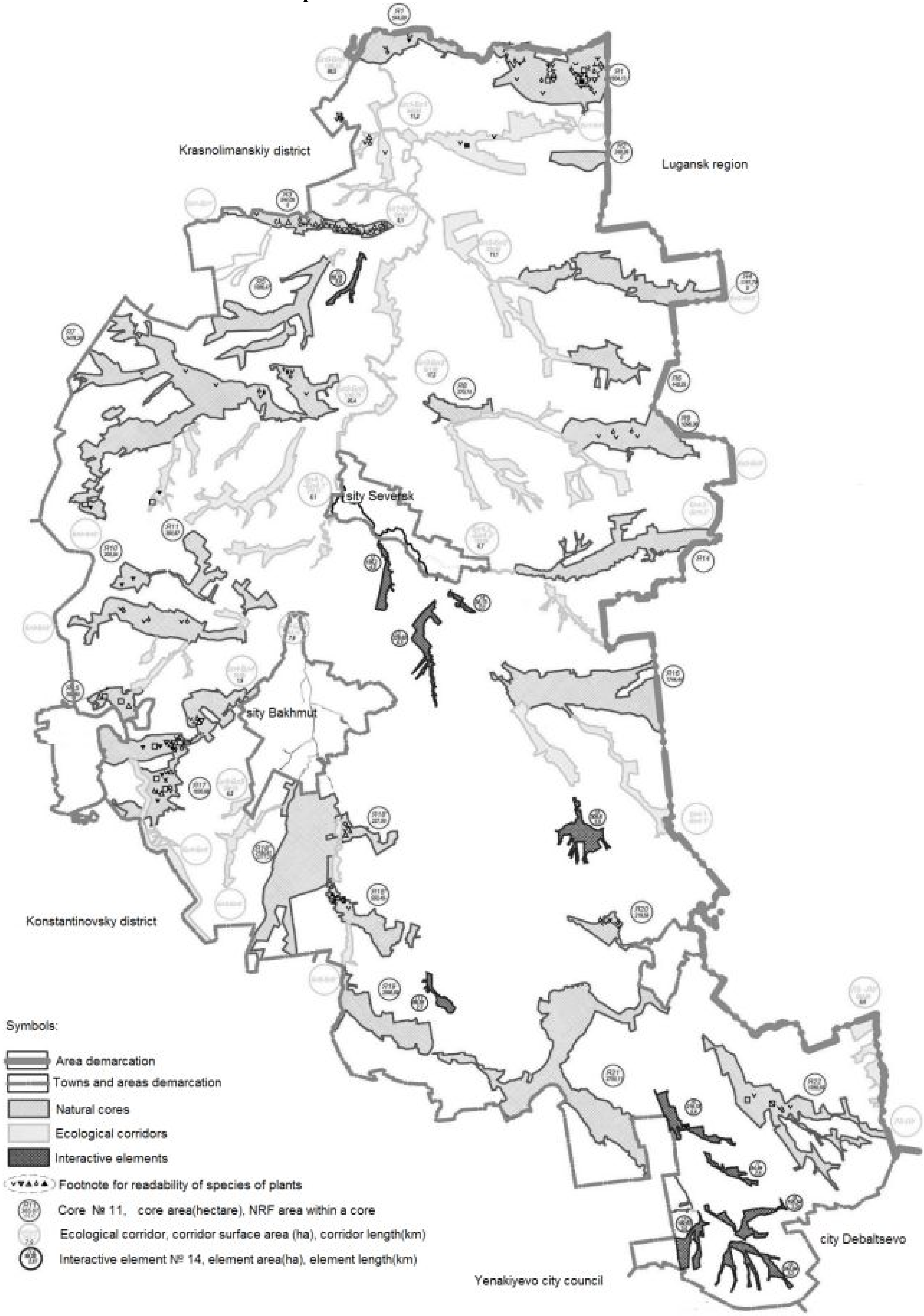


Figure 1 – The map chart of Bakhmut ecological networks area

According to their position in biocentric and network structure of Bakhmut area watersheds, where there are the areas of 2 watersheds – Bakhmut and Lugan`ka, because of their close spatial contact of the cores connecting them were considered as one whole watershed , the natural cores were evaluated by Bichem's index, showing their position in the system of centrality and peripherality (table. 6).

Table 6 – Natural cores placement by Bichem's index

| IV rank (total points) (0,26 – 0,36) | III rank (total points) (0,37 – 0,47) | II rank (total points) (0,48 – 0,58) | I rank (total points) (0,59 – 0,69) |
|---|---|---|---|
| $C_{10}$, $C_{20}$, $C_{21}$, $C_{22}$ | $C_5$, $C_9$, $C_{11}$, $C_{13}$, $C_{15}$, $C_{19}$ | $C_1$, $C_2$, $C_3$, $C_4$, $C_6$, $C_7$, $C_8$, $C_{14}$, $C_{16}$, $C_{17}$ | $C_{12}$, $C_{18}$ ($C_{18}'$, $C_{18}''$) |
| 4 | 6 | 10 | 2 |

According to the results of ranging, and the biocentric and network scheme has been charted on which the degree of connectivity of the biological centers among themselves has been determined by Bichem's index (fig. 2).

CONCLUSIONS. As it can be seen from biocentric and network scheme of Bakhmut area (fig. 2) and also the given data above, that the hydrological network of the Bakhmut watershed is arranged in this way that the majority of its natural cores have the central and subcentral position.

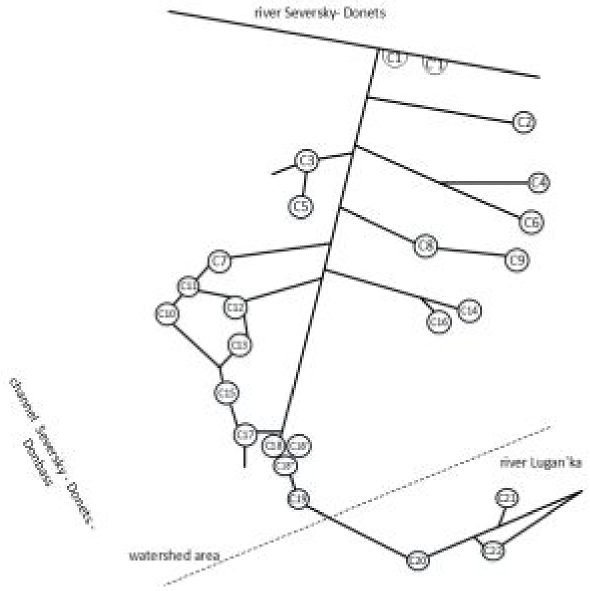


Figure 2 – Biocentric and network scheme of Bakhmut administrative area ecological network

This is due to the fact that the Bakhmut river has a type of a classical river system where all inflows and the cores linked with them are evenly distributed all over the area of the watershed. Thus, comparing two rating systems – by the characteristics given above (in points) and by Bichem's index, can be specified that it is necessary to add $C_1$, $C_3$, $C_7$, $C_{17}$ and $C_{18}$ cores in the first row of the significance of the regional natural cores of Bakhmut ecological network. The last core $C_{18}$, besides ranging the central position (max Ri) from a position of connectivity of cores in the watershed, also includes the largest facility of NRF area (the landscape preservation of the regional significance "Bakhmut garden and dendrologic plantings"), takes the 3rd place in species wealth among the cores. Within the bounds of all these cores, practically all key botanical territories (KBT) of the area include: three national significance and three regional significance. The core $C_1$ includes the key botanical territory of national importance No. 12 called "Mar`ino gora"; in the core $C_3$ – KBT No. 26 of regional importance called "Reznikovskaya"; in the core $C_7$– KBT of regional importance No. 27 called "Petrovskaya"; in a mini cluster of cores $C_{18}$ (+ $C_{18''}$ and $C_{18'}$) – KBT of national significance No. 28 called "Bakhmutskaya"; in the core $C_{17}$ – KBT of regional importance No. 29 called "Chasov-Yarska" (partially). As for the key botanical territory of national significance No. 11 "Siverskaya", it is situated at the border of Bakhmut and Krasnolimansk areas on the Bakhmutka watershed and the Seversky- Donets rivers and because of the isolated position hasn't been included in any cores of Bakhmut area [15]. In the second row of the significance of the regional natural cores can be included $C_4$, $C_{13}$, $C_{21}$ and $C_{22}$ cores which also take high positions in natural cores distribution by evaluated characteristics (mainly, they are included in the second ranks).

Thus, it is possible to conclude that special attention should be given to the natural cores of the first row of significance in forming a regional ecological network of Donetsk region. It should be considered in more detail their structure and biological diversity with a view to expanding the area of NRF facilities which already exist in them (or new facilities creation). There are two territorial clusters of the natural cores in the left-bank part of the Bakhmutka river from the topological point of view: the first one – combining of $C_3$, $C_5$ and $C_7$ natural cores where $C_7$ core lies the central position, and the second – combining of $C_{10}$, $C_{11}$, $C_{12}$, $C_{13}$, $C_{15}$ cores and $C_{17}$ where $C_{17}$ and $C_{13}$ cores are both most significant from a connectivity position, and from a position of structural and biological diversity. Definitely that these both territorial clusters need more detailed research regarding the creation of new NRF facilities -regional landscape park or nature reserves.

It is worth noting that $C_1$ core has very high biological diversity (449 points) that is a record not only for the area, but also for all researched cores all over the ecological network region. This core is a direct continuation of the largest carcass supercore in the region and which, in turn, is part of the largest forest area in East Ukraine – Seversky-Donets above flood-plain and terrace forests and most likely, it should adjoins it territorially, particulary it is directly the right-bank part of the Seversky – Donets valley. Therefore, in the comparative analysis of cores of Bakhmut area, this $C_1$ core is considered to be an artifact and hasn't been included in the general analysis of biological diversity of all the other cores.

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## МЕТОДИКА ФОРМИРОВАНИЯ ЭКОЛОГИЧЕСКОЙ СЕТИ

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Рассматривается формирование пространственной структуры локальной экологической сети (на примере Бахмутского административного района Донецкой области) с точки зрения методологии комплексной оценки составляющих ее природных ядер. Даётся сравнительная характеристика последних в виде их комплексной балльной оценки и топологического положения относительно биоцентрично-сетевой пространственной их структуры. По 10-балльной системе оценивалось видовое и фитоценотическое богатство участков (геотопических контуров) природных ядер, включая их раритетную составляющую. Топологическая структура экосети оценена по биоцентрично-сетевому ее характеру, благодаря которому возможно выделить центральные и субцентральные ее ядра по степени связности их между собой. Проведенное ранжирование природных ядер по основным их характеристикам – видовому и фитоценотическому богатству, экосистемному разнообразию, топологической связи и, в итоге, по совокупной балльной оценке показало возможность построения иерархической пространственной структуры локальной экосети по степени «значимости» составляющих ее природных ядер. Делаются выводы об неравнозначной ценности природных ядер локальной экосети в приоритетности их внесения в природно-заповедный фонд региона: выделяется, соответственно, 1-й и 2-й ряды «значимости» природных ядер локальной экосети района, на базе которых после более детального их обследования рекомендовано создание новых объектов ООПТ (особо охраняемых природных территорий).

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