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Regional ecological networks: developed geoinformation modeling approaches

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Abstract. The conceptual bases for geoinformation modeling of regional ecological networks were developed with substantiation of new algorithm by which such networks are consistently modeled from a set of (quasi)geosystems of actual natural-anthropogenic and/or (quasi)natural bio-landscape territorial structure with new artificial environmental elements addition. The modeling result has to be network ecological cores and corridors with their buffer zones, which are divided into prior and perspective for creation and must support an optimally formed frame of region’s bio-landscape diversity.

Keywords: bio-landscape territorial structure, (quasi)geosystem, regional ecological network, ecological core and corridor, geoinformation modeling

Introduction. Substantiation of ecological networks creation at regional level is now the actual problem of natural geography because such networks essentially expand national and international ecological network structures and are used as "guide" for implementation of local ecological networks supporting principles of sustainable environment development.

Review of publications. In [3–5], considering existing experience summarized in [1–2], there were proposed theoretic-applied bases for geoinformation modeling of regional ecological networks, particularly for mean by area river basins with close to ordinary degree of their economic infrastructure. So, the principal goal of this research is to improve methods of regional ecological network modeling towards increasing of their applicability in diverse economic-environmental conditions, including complicated.

Methods. The following conceptual bases for regional ecological network geoinformation modeling were formulated. Initially, ecological network modeling region (ENMR) should be considered as a combination of (quasi)natural (QNS), natural-anthropogenic (NAS) and anthropogenic (AS) structures. From here, in accordance with [3–5], dynamic of ENMR and its structures can be represented as

\[ D(ENMR) = \{QNS(\omega_{QNS}, R_{QNS}, t) \} \cap \{NAS(\omega_{NAS}, R_{NAS}, t) \cup AS(R_{AS}, t) \} \]

where \( QNS(\omega_{QNS}, R_{QNS}, t) \) and \( NAS(\omega_{NAS}, R_{NAS}, t) \) is a totality of QNS and NAS random fields; \( AS(R_{AS}, t) \) – a totality of AS determined fields (see [3]); \( \omega \) in general – a totality of elementary experimental results, i.e. \( \omega_{QNS} \) and \( \omega_{NAS} \) – number of mentioned random fields’ registering (by fields’ values and/or coordinates); \( R \) altogether – total spatial area of all fields in model (1), i.e. total boundaries of researched region under \( R \in (x,y) \) in Cartesian coordinates of chosen for modeling GIS tools, wherefrom \( R \in \{R_{QNS} \cap (R_{NAS} \cup R_{AS})\} ; t – \) continuous time interval.

ENMR (quasi)natural structure (QNS) is divided into singular substructures (SNS) (second order subsystems) – plane substructures (SNSP) and network biocentric substructure (SNNSQ), and also into integrated network bio-landscape substructure (ISNQ) in accordance with notation

\[ D(QNS) = \{QNS(\omega_{QNS}, R_{QNS}, t) \} = \{SNP(\omega_{SNP}, R_{SNP}, t) \cap SNSQ(\omega_{SNSQ}, R_{SNSQ}, t) \} = \{SNP(\omega_{SNP}, R_{SNP}, t) \cap SNSQ(\omega_{SNSQ}, R_{SNSQ}, t) \} \]

where \( \omega_{SNP} \), \( \omega_{SNSQ} \), \( \omega_{SNSQ} \) and \( \omega_{SNSQ} \) – registering number for random subfields of appropriate substructures in (2); \( R_{SNP} \), \( R_{SNSQ} \) and \( R_{SNSQ} \) – spatial subfields’ subareas of these substructures provided that \( R_{QNS} = R \), \( R_{SNSQ} = R \), \( R_{SNSQ} = R \).

In turn, firstly, (quasi)natural singular plane substructures in (2) correspond to model

\[ \{SNSP\} \in \{LS \cap PGS \cap BS \cap PDS \cap OSPS\} \]

namely they combine such substructures of ecological network modeling region (ENMR), as:

1) Landscape substructures (LS) – taxonomic units of genetic-morphological landscape territorial structure of the regional level, such as stows (ST) and sub-stows (SST), wherefrom

\[ D(LS) = \{LS(\omega_{LS}, R_{LS}, t) \} = \{ST(\omega_{ST}, R_{ST}, t) \cup SST(\omega_{SST}, R_{SST}, t) \} \]

where \( \omega_{LS} \), \( \omega_{ST} \) and \( \omega_{SST} \) – registering number for random subfields of appropriate substructures in (4); \( R_{LS} \), \( R_{ST} \) and \( R_{SST} \) – spatial subfields’ subareas of these substructures considering that total spatial area of landscape substructures is \( R_{LS} = R \in (R_{ST} \cap R_{SST}) \) and \( R_{ST} \in (R_{SST}) \);

2) Physical-geographic substructures (PGS) – certain level units of physical-geographic zoning ([1]), especially physical-geographic areas (PGA) and districts (PGD) considering that they belong to zones (PGZ), sub-zones (PGSZ) and lands (PGL) with correspondence to formalized notation

\[ D(PGS) = \{PGS(\omega_{PGS}, R_{PGS}, t) \} = \{PGS(\omega_{PGS}, R_{PGS}, t) \} \cap \{PGSZ(\omega_{PGSZ}, R_{PGSZ}, t) \} \cup \{PGL(\omega_{PGL}, R_{PGL}, t) \} \]

where \( \omega_{PGS} \), \( \omega_{PGSZ} \), \( \omega_{PGL} \) and \( \omega_{PGL} \) – registering number for random subfields of appropriate substructures in (5); \( R_{PGS} \), \( R_{PGSZ} \), \( R_{PGL} \) and \( R_{PGL} \) – spatial subfields’ subareas provided that total spatial area of PGS is \( R_{PGS} = R \in (R_{PGSZ} \cap R_{PGL} \cap R_{PGL}) \);

3) Basin substructures (BS) – on the one hand, a totality of basin territorial substructures (BTS), from the
higher rank basins (BTS$_1$) up to the lower rank basins (BTS$_n$); on the other hand, basin morphological-positional substructures (BMPs), i.e. identified within selected rank BTS watershed-plain (WPG), slope (SLG), terrace (TRG), floodplain (FPG) and riverbed (RBG) geosystems, and, very often, their combinations (CMPs). Following the logic of previous formalization, it’s possible to note that

$$D \{BTS\} = \{BTS(o_{WBTS},BTS,t) \} = \{BTS(o_{SBTS},BTS,t) \} \cap \\cap \mathbb{BMPS}(o_{SBMPs},BMPs,t) \},$$

$$D \{BTS\} = \{BTS(o_{WBTS},BTS,t) \}
= \{BTS(o_{SBTS},BTS,t) \} \cap \{BTS(o_{SBTS},BTS,t) \} \cap \{BTS(o_{SBTS},BTS,t) \}$$

(7)

$$D \{BMPs\} = \{BMPs(o_{SBMPs},BMPs,t) \}
= \{WPG(o_{SWPG},WPG,t) \} \cup \{SLG(o_{SSLG},SLG,t) \}
\cup \{FPG(o_{SFPG},FPG,t) \} \cup \{RBG(o_{SRBG},RBG,t) \} \cup \{\cap \cap \} \mathbb{CMPS}(o_{SCMPS},CMPS,t) \}$$

where $o_{WBTS} - o_{SBMPs}$ – registering number for random subfields of appropriate substructures in (6)-(8); $R_{BTS} ... R_{CMPS}$ – spatial subareas of these subfields considering that total spatial area of $BTS$ subfields is $R_{BTS} = R \in \{R_{BTS}, R \cap \cap R_{BTS} \}$ and of $BMPs$ subfields $R_{BMPs} = R \in \{R_{WPG} \cup \{ \cap \cap \} \mathbb{CMPS} \}$.  

4) Positional-dynamic substructures (PDS) – the units of positional-dynamic zoning ([1, 2]), i.e. para- 

**natural subareas and subfields of appropriate substructures in (9); $R_{PDA}, R_{PDPA}, R_{PDPA}, R_{LSA, R_{STR}}$: spatial subareas of these subfields provided that total spatial area of positional-dynamical substructures is $R_{PDA} = R \in \{R_{PDA} \cap R_{PDPA} \cup R_{LSA} \cap R_{STR} \cap \mathbb{CMPS} \}$.

5) Other (quasi)natural singular plane substructures (OSPS) – accessory under modeling substructures, which characterize geographic-biotic, zoological-geographic, geologic, hydrogeological, relief-forming, soil and other regional peculiarities, including combined by attributes.

Secondly, (quasi)natural singular network biocentric substructure (SNSN$_{QN}$) in (2) is identical to reconstructed (reproductively reproduced) elements of regional (quasi)natural biocentric-network landscape territorial structure (BNLTS$_{QN}$) (see [1, 2]), such as bio-centers (BC$_{QN}$), bio-corridors (BCR$_{QN}$) and interactive elements (IEL$_{QN}$), herefrom

$$D \{SNSN_{QN} \} = \{BNLTS_{QN}(o_{BNLTS_{CMPS}},BNLTS_{CMPS},t) \} = \{BC(o_{BCQ},BC_{QN}),t) \} \cup \{BCT(o_{BCQ},BC_{QN},t) \} \cup \{IEL(o_{IEL_{QN}},IEL_{QN},t) \}$$

where $o_{BNLTS_{CMPS}} ... o_{IEL_{QN}}$ – registering number for random subfields of appropriate substructures in (10); $R_{BNLTS_{QN}} ... R_{IEL_{QN}}$ – spatial subareas of these subfields given that $R_{BNLTS_{QN}} \neq R$.

Thirdly, (quasi)natural integrated network bio-landscape substructure (ISN$_{QN}$) in (2) can be identified with a totality of network connected elements forming (quasi)natural bio-landscape territorial structure (BLTS$_{QN}$), namely, from the one hand, reconstructed patches of LS (stow and sub-stow geosystems), BMPs (terrace-floodplain geosystems etc.) and NLTLS$_{QN}$ considering general background of (quasi)natural singular plane substructures. On the other hand, properly BLTS$_{QN}$ (quasi)geosystems are regional (quasi)natural cores (QNC) and corridors (QPCR) of bio-landscape diversity which serves as region’s quasi-natural (reconstructed) frame of bio-landscape diversity (RFBLD$_{EMBR}$). Herefrom

$$D \{ISN_{QN} \} = \{BLTS_{QN} \} \cup \{RFBLD_{EMBR} \} = \{ISN_{QN}(o_{ISN_{QN}},ISN_{QN},t) \} \cup \{RFBLD_{EMBR}(o_{RFBLD_{EMBR}},RFBLD_{EMBR},t) \}$$

(11)

$$\cap \{\cup \{NSP(o_{NSP},NISP),t) \} \cap \cup \{MR(o_{MR},MR),t) \} \cap \cup \{MN(o_{MN},MN),t) \}$$

where $o_{BLTS_{QN}} ... o_{QNC}$ – registering number for random subfields of appropriate substructures in (11); $R_{BLTS_{QN}} ... R_{NSP}$ – spatial subareas of these subfields provided that $R_{BLTS_{QN}} \neq R$.  

**NAS and AS** in (1) should be considered as **regional functional structure of nature management (RFNSM)** with the further division on natural-anthropogenic and anthropogenic regional functional and nature management substructures (RFNMS), such as agro-industrial (AIS), industrial (IS), settlement (SS), transport (TRS), nature-protective (NPS) and multi-recreational management (MRM) substructures, therefore

$$D \{NAS \cup AS \} = \{RFNSM \} \cup \{RFNSM(o_{RFNSM},S_{RFNSM},t) \} \cap \{AIS(o_{AIS},AIS,t) \} \cap \{SS(o_{SS},SS,t) \} \cup \cup \{S_{RFNSM} \cap \{NPS(o_{NPS},NSP),t) \} \cap \{MR(o_{MR},MR),t) \} \cap \{MN(o_{MN},MN),t) \}$$

(11)

where $o_{RFNSM} ... o_{MRM}$ – registering number for random subfields of appropriate substructures in (12); $R_{RFNSM} ... R_{NSP}$ – spatial subareas of subfields in (12) considering that $R_{RFNSM} \neq R$.  

In particular, NPS in (12) includes objects of nature conservation fund (NCF) and bioc-protective (BPS), other special protective (OSPS) and ecological network (ENS) substructures, that’s why

$$D \{NPS \} = \{NPS(o_{NPS},NPS),t) \} = \{NCF(o_{NCF},NCF,t) \cap \{BPS(o_{BPS},BPS),t) \} \cap \{\cap \cap \} \cup \{\cup \} \cup \{\cup \} \cap \{ENS(o_{ENS},ENS),t) \}$$

where $o_{NPS} ... o_{ENS}$ – registering number for random subfields of appropriate substructures in (13); $R_{NPS} ... R_{ENS}$ – spatial subareas of these subfields given that $R_{NPS} \neq R$ and $BPS$ substructures are both point and polygonal spatial features and groups of these features (see [4]).

In turn, ecological network substructures in (13) will agree with general notation $\{ENS \} = \{NLEN \cap \} IS-NAX \cap \{MEN \}$ and therefore they include at regional scale:

1) Substructures of national (inter-regional) and local ecological networks’ elements (NLEN), considering a level of their conservation status implementation;

2) Actual natural-anthropogenic integrated network bio-landscape substructure (ISN$_{QN}$), which is identical to actual natural-anthropogenic bio-landscape territori-
al structure \( \text{BLTS}_{\text{ANA}} \) (see for comparison (11)). Therefore the last one represents connected and/or, more often, disconnected patches of synergistically integrated certain QNS components, which are preserved (first of all "with human assistance") in close to natural state under conditions of anthropogenic pressure and impact of structure-destroying natural factors and/or are already restored. Such patches include actual elements of landscape and basin substructures \( \text{ST}_{\text{ANA}}, \text{ST}_{\text{ANA}} \) and \( \text{CMPS}_{\text{ANA}} \) and (quasi)natural biocentric-network landscape territorial structure \( \text{BNLTS}_{\text{ANA}} \) and also proper components of nature-protective substructures \( \text{NCF}, \text{BPS} \) and \( \text{OPSS} \) considering general composition of other RFSN elements (see (12)). In this case (quasi)geosystems of \( \text{BLTS}_{\text{ANA}} \) are regional actual natural-anthropogenic cores \( \text{(ANAC)} \) and corridors \( \text{(ANACR)} \) of bio-landscape diversity which form region’s actual frame of bio-landscape diversity \( \text{(AFBLD}_{\text{ENMR}}) \) preserved in close to natural state. Wherefrom

\[
\begin{align*}
D \{ \text{IS}_{\text{ANA}} \} = D \{ \text{BLTS}_{\text{ANA}} \} = D \{ \text{AFBLD}_{\text{ENMR}} \} = \\
\{ \text{BLTS}_{\text{AD}}(\omega_{\text{ANAC}}) \} = \\
\{ \text{AFBLD}_{\text{ENMR}}(\omega_{\text{ANAC}}) \} =
\end{align*}
\]

where \( \omega_{\text{ANAC}} \) – registering number for random subfields of substructures and elements in (15); \( \{ \text{R}_{\text{NS3ADD}} \} \) – spatial subfields of subfields in (14) given that \( \text{R}_{\text{NS3ADD}} \neq R \) etc.;

3) Modeling regional ecological network \( \text{(MEN)} \) regarded, firstly, as a set of \( \text{BLTS}_{\text{ANA}} \) and/or \( \text{BLTS}_{\text{OP}} \) (quasi)geosystems, initially and finally selected according to specified system of bio-landscape diversity analysis’ criteria for the purpose of current map and/or restoration and protection of such (quasi)geosystems as future ecological network’s components. Secondly, MEN structure can be extended by proper additional artificial elements of nature-protective substructures \( \text{NPS}_{\text{ADD}} \) that may provide optimal composition and formation of future ecological network. All mentioned MEN components are earmarked to support implementation and sustainable functioning of region’s optimally framed structure of bio-landscape diversity \( \text{(OFFBLD}_{\text{ENMR}}) \) which is the most close to such (quasi)natural frame (see (11)). Properly structural elements ((quasi)geosystems) of MEN are regional ecological network cores \( \text{(EC)} \) and corridors \( \text{(ECR)} \) and their buffer zones \( \text{(BZ)} \), herefrom

\[
\begin{align*}
D \{ \text{MEN} \} = \{ \{ \omega_{\text{EC}}, \text{R}_{\text{EC}} \} \} = \{ \text{EC}(\{ \omega_{\text{EC}}, \text{R}_{\text{EC}} \}) \} = \\
\text{EC}(\{ \omega_{\text{EC}}, \text{R}_{\text{EC}} \}) = \\
\{ \{ \omega_{\text{EC}}, \text{R}_{\text{EC}} \} \} \cup \text{EC}(\{ \text{R}_{\text{EC}} \}) = \\
\{ \{ \omega_{\text{EC}}, \text{R}_{\text{EC}} \} \} \cup \text{EC}(\{ \text{R}_{\text{EC}} \}) = \\
\{ \{ \omega_{\text{EC}}, \text{R}_{\text{EC}} \} \} \cup \text{EC}(\{ \text{R}_{\text{EC}} \}) = \\
\{ \{ \omega_{\text{EC}}, \text{R}_{\text{EC}} \} \} \cup \text{EC}(\{ \text{R}_{\text{EC}} \}) =
\end{align*}
\]

where \( \omega_{\text{MEN}}, \omega_{\text{NS3ADD}} \) – registering number for random subfields of substructures and elements in (15); \( \{ \text{R}_{\text{MEN}}, \text{R}_{\text{NS3ADD}} \} \) – spatial subfields of subfields in (15).

It should be remembered during modeling that ecological network cores and corridors in (15) have to be selected and analyzed as possible and then as final with their further division into prior and perspective for creation, including their relevant buffer zones.

**Results and discussion.** Considering the above preconditions, new algorithm of regional ecological network modeling contains the number of specified by criteria operations aimed at consistent creation, coordination and transformation of defined model structures with simultaneous forming and information saturation corresponding blocks of GIS database "Regional Ecological Network". Such structures are:

1) **Model structure MS-1** – the result of investigating region boundaries determination, wherefrom

\[
\{ \text{MS-1} \} = \{ R \} \cap \{ \text{R}_{\text{NS3ADD}} \} \cup \{ \text{R}_{\text{AD}} \}
\]

2) **Model structure MS-2** – ordered set of definite (quasi)natural singular substructures under model

\[
\{ \text{MS-2} \} = \{ \text{R}_{\text{NS3ADD}} \} \cap \{ \text{R}_{\text{AD}} \}
\]

3) **Model structure MS-3** – the structure of bio-landscape diversity "frame" reconstruction and initial selection of possible MEN elements in accordance with notation

\[
\{ \text{MS-3} \} = \{ \text{R}_{\text{NS3ADD}} \} \cup \{ \text{R}_{\text{AD}} \}
\]

4) **Model structure MS-4** – the structure of region’s anthropogenic transformation degree, presented as

\[
\{ \text{MS-4} \} = \{ \text{R}_{\text{NS3ADD}} \} \cup \{ \text{R}_{\text{AD}} \}
\]

5) **Model structure MS-5** – the structure of bio-landscape diversity frame (quasi)geosystems’ actualization according to equation

\[
\{ \text{MS-5} \} = \{ \text{R}_{\text{NS3ADD}} \} \cup \{ \text{R}_{\text{AD}} \}
\]

6) **Model structure MS-6** – the structure for analysis of natural-frame significance and state level concerning both sets of possible MEN cores and corridors by (19) and (20) and selection of the first set with final (principal) MEN cores and corridors \( \text{(EC}_{\text{FIN,IP}} \) and \( \text{ECR}_{\text{FIN,IP}} \) in accordance with notation

\[
\{ \text{MS-6} \} = \{ \{ \text{EC}_{\text{FIN,IP}} \} \cup \{ \text{ECR}_{\text{FIN,IP}} \} \}
\]
7) **Model structure MS-7** – the structure for OFF-BLD_{ENMR} first variant creation (see (15)) by addition and coordination with MS-6 of required NPS\textsubscript{ADD} elements and approximate BZ computation by notation 

\[ \{MS-7\} \in \{\{MS-6\} \cup NPS\textsubscript{ADD}(o_{NPS\textsubscript{ADD}}R_{NPS\textsubscript{ADD}})\} \cup \]
\[ \cup BZ(o_{BZ}R_{BZ}) = \{OFF-BLD_{ENMR}(o_{OFF-BLD_{ENMR}}R_{OFF-BLD_{ENMR}})\}_{VAR1} \]

8) **Model structure MS-8** – the structure for OFF-BLD_{ENMR} second variant creation by division of MEN cores and corridors and their buffer zones from (22) into prior (subscript "pr") and perspective (subscript "pp") according to equation 

\[ \{MS-8\} \equiv \{OFF-BLD_{ENMR}(o_{OFF-BLD_{ENMR}}R_{OFF-BLD_{ENMR}})\}_{VAR2} \in \]
\[ \in \{EC\textsubscript{pr}(o_{EC\textsubscript{pr}}R_{EC\textsubscript{pr}})\} \cup \]
\[ \cup ECR\textsubscript{pr}(o_{ECR\textsubscript{pr}}R_{ECR\textsubscript{pr}}) \cup BZ\textsubscript{pr}(o_{BZ\textsubscript{pr}}R_{BZ\textsubscript{pr}}) \} \cup \]
\[ \cup (EC\textsubscript{pp}(o_{EC\textsubscript{pp}}R_{EC\textsubscript{pp}}) \cup \]
\[ \cup ECR\textsubscript{pp}(o_{ECR\textsubscript{pp}}R_{ECR\textsubscript{pp}}) \cup BZ\textsubscript{pp}(o_{BZ\textsubscript{pp}}R_{BZ\textsubscript{pp}}) \}) \]

Prospects for further research are to improve the systematization of bio-landscape diversity analysis criteria regarding peculiarities of their application to model structures (16)-(23) adequate to proposed algorithm, to modify geoinformation-technologic approaches to implementation of mentioned algorithm and to verify developed model solutions on example of representative region’s ecological network.

**Conclusions.** The conceptual bases for geoinformation modeling of regional ecological networks were developed by formalized structuring of the region into (quasi)natural, anthropogenic-natural and anthropogenic structures, their further differentiation into substructures and modeling of these substructures’ dynamics, which allows to generate an optimally formed frame of region’s bio-landscape diversity.

New algorithm of ecological network modeling contains number of specified by criteria operations aimed at consistent creation, coordination and transformation of defined model structures with simultaneous forming and information saturation corresponding blocks of GIS database "Regional Ecological Network".

**REFERENCES (TRANSLATED AND TRANSLITERATED)**


Малиренко А., Самойленко В. Региональные экологические сети: развитые подходы к геоинформационному моделированию

**Аннотация.** Получили развитие концептуальные основы геоинформационного моделирования региональных экологических сетей с обоснованием нового алгоритма, по которому такие сети последовательно моделируются из совокупности (квази)геосистем актуальной природно-антропогенной или (квази)природной биоландшафтной территориальной структуры с добавлением новых искусственных природоохранных элементов. Результатом моделирования должны стать сетевые экологические ядра и коридоры с их буферными зонами, которые разделяются на первоочередные и перспективные для создания и должны поддерживать оптимально сформированный каркас биоландшафтного разнообразия региона.

**Ключевые слова:** биоландшафтная территориальная структура, (квази)геосистема, региональная экологическая сеть, экологическое ядро и коридор, геоинформационное моделирование