

Context-Based Spatial Decisions in Landscape-Ecological Planning

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Abstract

Context

The vital challenge for the context-based landscape planning is integrating assessments of for both intrinsic properties of a unit and its value in a broad spatial context.

Objectives

The purpose is to develop the procedure which provides context-based criteria at relevant scales, considers matter flows and dynamic events.

Methods

The methodology involves identification of landscape patterns, revealing mechanisms of radial and lateral relationships, considering changes of landscape patterns, and revealing functioning mechanisms causing directed changes. The proposals proceed from multiplicity of patterns and integrate knowledge of processes in biophysical units, catenas, basins, and matrix elements. The plan was elaborated for the taiga landscape in northern European Russia.

Results

Development of ecological network is aimed at increase of forest cover in basins up to 35% to enhance runoff regulation, prevent soil erosion, and stabilize the riparian biocorridor. The highest significance was assigned to the units that have intrinsic ecological values and contribute to lateral transportation of matter over vast areas. Width of buffer strips intercepting input of pollutants to rivers was adapted to proportions of elements and neighborhoods in catenas. Outside the ecological network, we identified priorities for the multifunctional use of units based on the assessment of drainage conditions, soil quality, and risk of erosion.

Conclusions

The procedure takes into consideration landscape hierarchy and multiplicity of spatial patterns. Integrating multiple models is in compliance with the systemic essence of a landscape ensuring understanding of geodiversity, lateral connections, and the emergent effects that ensure the landscape services for society.

Introduction

The roots of landscape-ecological planning are traced back in fruitful studies aimed at projecting sustainable urban landscapes, nature protection and agriculture as early as in the nineteenth century. At this early stage the important ideas of landscape multifunctionality, requisite diversity, proportions, and lateral interactions between spatial elements demonstrated its relevancy for planning at heterogeneous territories in the works by F.L. Olmsted, V.V. Dokuchaev, P. Geddes. The synthesis of ecological, socio-economic and cultural approaches to spatial planning dates back to the second half of the twentieth century (McHarg 1969; Fabos et al. 1978; Dorney 1976, Austin and Cocks 1978; Ružička and Miklos, 1982).

The term “landscape” in the title of the approach implies that planning decisions consider: (i) interactions between geocomponents (i.e. parent rocks, water, air, soil, vegetation, animals) and possible chain reactions between them under exterior impact, (ii) remote effects “impact here – effect there”, and (iii) specific emergent effects resulting from combined influences of landscape units and their interactions. This follows from understanding landscape as a system. The geosystem approach to landscape-ecological planning deals with the properties and the internal matter turnovers in landscape systems and uses biophysical units as a base for distributing land use types in space (Solnetsev 1948, Dyakonov et al. 2007; Bastian et al. 2015; Mikloš and Špinerova 2019; Antrop and van Eetvelde 2017, Khoroshev 2020b). Within the matrix concept (Dramstad et al. 1996; Botequilha Leitão and Ahern 2002; Turner and Gardner 2015) landscape structure is treated as a framework for projecting neighborhoods and desired emergent effects. Though the twentieth century evidenced heated debates devoted to search for the most relevant way of delineating landscape units, now most researchers agree that recognition of multiplicity of landscape

patterns is inevitable and allows considering higher diversity of integrating mechanisms in a landscape as a complex system (Khoroshev 2020b). Present-day understanding of landscape heterogeneity involves at least five types of landscape patterns: genetic-morphological (focus on the contribution of abiotic template and genesis), paragenetical (mosaic pattern induced by matter flows along the lines of concentration), positional-dynamical (catena-based organization), basins, and biocentric-network (i.e., matrix concept) (Grodzinsky 2014). We argue that all of them are crucially important for decision-making in landscape-ecological planning.

Differentiated classification of land-use types largely takes specific site characteristics of the individual land-use types into account (Tasser et al. 2020). Both physical geography and landscape ecology have at their disposal the powerful tool of spatial analysis which allows coordinating site-specific and context-dependent solutions in allocation of land use types. Spatial analysis provides the opportunity to identify flows of living and non-living matter that can induce remote effects of land use decisions or affect the success of such decisions. Landscape-ecological tools enable a researcher to reveal the emergent effects of interactions among spatial units being critical for the viability of animals' populations, seeds dispersal, disturbance spreading (Turner and Gardner 2015). Landscape research (in East-European scientific tradition, in particular) has concentrated much on how runoff, microclimate, geomorphic processes, chemical elements migration in a landscape depend on the neighborhoods and toposequences of landscape units (Perelman 1972; Fortescue 1992; Sommer, Schlichting, 1997; Khoroshev and Koshcheeva 2009; Haslauer et al. 2016). For example, buffer zones are projected as strips of permanent vegetation grown alongside river channels or along the fields margins to protect the water course from the impacts of activities on the adjacent land (Balazy 2002; Bentrup et al. 2003; Diebel et al. 2009). The concept of geochemical barriers was applied as an effective tool for protecting vulnerable natural or anthropogenic objects from undesirable flows (Perelman 1972; Ryszkowski et al. 1999; Avessalomova et al. 2016).

Viewing ecosystems as complex adaptive systems emphasizes how ecosystems are organized, how interactions and relationships among individual parts or processes can give rise to collective behaviors that cannot be readily predicted by looking only at its individual parts (i.e., emergent properties) (Messier and Puetmann 2011). One of the most difficult purposes of landscape-ecological planning is to ensure the optimum proportions of land use units within the constraints imposed by more or less static heterogeneous abiotic template (i.e., geodiversity).

Since any spatial unit is involved into lateral interactions by means of matter and energy flows, consideration for spatial context during the planning procedure is critically needed. The argument that the location's priority is based not only on its own characteristics but on those of other locations as well (Trombulak 2010) is significant for both planning nature conservation and intensive land use. Spatial context provides rationales for evaluation of rareness vs. typicality of landscapes, their socio-economic and ecological values (Turner 2019). Evidently, perception of values and subsequent land use decisions concerning, say, forest stand or arable lands will greatly be dictated by whether a unit is widely spread in a region or occurs outside its main areal. More widely, higher-order system imposes constraints for the functional role of the lower-order one. The relation of a unit's properties to the regional or local normal range of landscape conditions may be used as a criterion for its ecological or socio-economic evaluation. For example, the concept of Habitat development potential implies that extreme sites have a higher habitat development potential (von Haaren et al. 2019).

In this context, the relations between ecosystem services, their synergies vs. competition have recently become an important focus in ecosystem services studies (Kandziora et al. 2013; Angelstam et al. 2013, Bukvareva et al. 2017; Stammel et al. 2020, Tasser et al. 2020). The recent trend is the particular interest for the notion of landscape services (Termorshuizen and Opdam 2009; de Groot et al. 2010; Bastian et al. 2014) that emphasizes economic value of the emergent properties generated at landscape scale due to combined influence of spatial elements.

The purpose of this paper is to develop the procedure of context-based landscape-ecological planning aimed at answering the questions as follows:

- What spatial context-based criteria and at which scale should be applied for ecologically safe allocation of land use types in a landscape?
- How to consider involvement of a landscape unit to matter and energy flows while choosing the appropriate land use type?

- Which corrections for landscape plan may be needed with due regards to landscape dynamics and evolution?

Methodology

We rely on the idea that landscape context is a matter of crucial importance that should be treated as a binding factor for land use decisions. The proposed methodology treats landscape as a holistic entity. It means that: (i) a landscape consists of properly delineated spatial elements with potentially moving boundaries; (ii) within each spatial element geocomponents interact by means of radial matter cycles, (iii) both radial and lateral flows may generate irreversible changes in emergent properties. In this connection, we used the classification of domains in landscape modeling by Topchiev (1988). Topchiev distinguished four domains as follows.

1. Structural-static domain is aimed at identification and classification of stable landscape patterns.
2. Functional-static domain reveals mechanisms of landscape functioning (radial and lateral relationships between components) at a certain moment of development.
3. Structural-dynamic domain involves modeling changes of landscape patterns, comparison of landscape patterns at the different stages of development.
4. Functional-dynamic domain studies a range of possible dynamic reversible states of a landscape and mechanisms causing directed changes.

The Topchiev's four domains form the main pillars for landscape planning procedure together with socio-economic view on landscape as an environment for a man (Table 1). At each step a researcher consequently: a) identifies appropriate spatial units, b) reveals actual or potential chain reactions under an impact, c) assesses stability/mobility of boundaries and accessible area, and d) predicts possible irreversible changes in functions. The procedure applies a kind of consecutive exclusion (McHarg 1969) or negative selection (Ružička 2000). The purpose is, first, to delimit the ecological network, and, second, to distribute land use type among natural landscape units outside the ecological network (Khoroshev 2020a).

Table 1
 Framework for context-based landscape planning

<i>Questions and outcomes</i>	<i>Pillars of landscape science</i>				
	<i>Structural-static</i>	<i>Functional-static</i>	<i>Structural-dynamic</i>	<i>Functional-dynamic</i>	<i>Socio-economic</i>
	<i>Purpose</i>				
What units in the landscape are currently in demand by local community?	1. Identifying natural biophysical landscape units.	-	-	-	2. Identifying land-use units and their accessibility.
Are changes in land use patterns needed and, if yes, where?	-	3. Identifying exterior natural or anthropogenic threats to land-use units. 4. Mapping areas of undesirable man-induced changes in between-components relationships.	-	-	5. Assessing correspondence with legal regulations. 6. Revealing current land-use conflicts.
<i>Outcome I: necessity of changes in land use</i>					
What units are of particular importance for nature, human, and economy?	7. Evaluating uniqueness/rareness of landscape units and habitats in broad geographical context and in local landscape/basin.	8. Assessing functional role of landscape units in local matter flows in a landscape/basin/catena. 9. Revealing existing buffers between undesirable flows and vulnerable natural or anthropogenic objects.	10. Mapping unstable boundaries of dangerous flow-induced units, vulnerable objects, and possible buffer strips.	11. Mapping highly significant corridors and shelters for zonal species in anthropogenic landscape.	12. Proposal for appropriate management of aggressive and valuable flow-induced units. 13. Proposal for land units' neighborhoods 14. Proposal for legal protection of ecologically valuable landscape units.
Which changes are expected in the landscape	15. Identifying rare/unique units requiring special protection under current natural and anthropogenic changes.	-	16. Mapping unstable units with directed irreversible changes in area and/or shape.	17. Mapping units with irreversible changes in resource supply.	18. Evaluating possible gains and losses resulting from changes in landscape structure.
What units will be included into ecological network?	19. Ranging landscape units by ecological significance and admissibility of resources exploitation.	-	-	-	20. Establishing protection measures and allowable land use regimes for ecological network.
<i>Outcome II: ecological network</i>					

<i>Questions and outcomes</i>	<i>Pillars of landscape science</i>				
	<i>Structural-static</i>	<i>Functional-static</i>	<i>Structural-dynamic</i>	<i>Functional-dynamic</i>	<i>Socio-economic</i>
	<i>Purpose</i>				
Which spatial proportions of land use units will ensure sustainable functioning of the landscape and economic activity?	21. Checking whether economically-acceptable spatial proportions of land use units can be provided by adapting them to biophysical units.	-	-	22. Determination of spatial proportions that ensure desirable emergent effects in landscape/basin functioning.	23. Distribution of land use functional zones in landscape/basin space.
What biophysical units beyond the limits of ecological network are suitable for resources exploitation	24. Ranging landscape units by suitability for various kinds of economic activity	25. Assessing possible chain reactions in between-components relationships under anthropogenic loads	26. Evaluating available area for economic activity	27. Evaluating significance of current natural trends for future economic activity (reliability).	28. Revealing similar claims of land users for landscape units and checking for their compatibility and possible conflicts.
Are there alternative locations for economic activity	29. Revealing analogous landscape units and comparing their accessibility	-	-	-	30. Distributing types of land use with similar claims among alternative analogous locations.
Which locations are optimal for the kinds of economic activity	31. Choosing optimum placement and neighborhoods of economic activities adapted to properties of biophysical units.	32. Checking whether any land use is possible at non-optimum locations with insufficient resource supply and/or potentially negative chain reactions between geocomponents.	33. Checking whether any land use is possible at non-optimum locations with directed undesirable natural trends.	-	-
<i>Outcome III: optimum land use pattern</i>					
Which anthropogenic loads and configuration are admissible?	-	34. Identifying critical thresholds for sustainable between-components relationships.	35. Establishing spatial limits and configuration for land use aimed at prevention of undesirable movement of landscape units boundaries.	-	36. Establishing limits for resource exploitation, size, and shape of land use units.
Which technologies are the most ecologically and economically effective within the limits of land use units	-	-	-	37. Setting limits for technologies to prevent irreversible loss of values and undesirable remote ecological effects.	38. Distributing appropriate technologies among units with the same land use type.

Questions and outcomes	Pillars of landscape science				
	Structural-static	Functional-static	Structural-dynamic	Functional-dynamic	Socio-economic
	Purpose				
Outcome IV: ecologically safe distribution of land use technologies					

Results

Below we show the step-by-step implementation of the proposed planning procedure (Table 1) on the example of the small river basin with combination of priorities for agriculture, forestry and traditional gathering of non-timber resources.

Inventory of landscape and land use spatial pattern and accessibility (steps 1–2)

Natural biophysical landscape units. The research was performed in the middle taiga of East-European plain (the southern Arkhangelsk region of Russia) (Fig. 1). The study area is the Zayachya river basin (154 km²) which is located within the plateau composed of Permian sedimentary rocks at elevations ranging from 100 to 175 m a.s.l. (Khoroshev 2019, 2020a). The lower part of the basin is the rugged terrain which was deforested as early as seven centuries ago due to relatively fertile well-drained soils (Umbrisols or Rhendzic Leptosols). Humus accumulation is the highest in soils with close to surface marls at the slopes and marginal sections of the interfluves. Podzolization develops on poorer substrates where loams are covered by 10–70 cm thick sandy layer inherited from Pleistocene glacial lakes and on sandy river terraces. Forests are concentrated in the upper part of the basin where the morainic mantle is thick and relief is flat or rolling. Peat accumulation occurs mainly in the oligotrophic mires at the central sections of flat interfluves.

Land-use units. Agriculture is concentrated in the lower part of the basin with good drainage and fertile soils on the narrow interfluves, backslopes and footslopes. Nutrient-poor soils on terraces are plowed as well due to good drainage and perfect accessibility. Few sections of terraces are still covered by pine forests and used for recreation and gathering berries and mushrooms both for own consumption and selling. All the settlements are located in the well-drained edge sections of the interfluves close to slope shoulders. Floodplains are used for haymaking. In the less-drained upper part of the basin with infertile wet soils the landscape is used for timber harvesting, hunting, and gathering berries and mushrooms.

Accessibility. In general, good accessibility of the study area in relation to railroad, highways, and food production industry has encouraged economic advantages in comparison to many other agricultural and sylvicultural districts of the Arkhangelsk region. The settlements are concentrated along the ring paved road and few branches with paved or unpaved roads. Distant fields have poorer connections with the main road network due to the higher soil humidity resulting in a bad state of unpaved roads during wet rainy period and snowmelt. Locally, formerly cultivated terraces and slopes were abandoned due to absence of bridges.

Threats and conflicts (steps 3–6)

Threats and man-induced changes. Extensive forest cutting in the upper basin in 1970-1980s resulted in increased surface runoff in spring with superposition of water input from the fields and from the cut areas. By this moment, cutover areas are covered by small-leaved forests 30–40 years old which is the age of the highest transpiration rate (Fig. 1). Therefore, runoff volume in the lower reaches decreased critically resulting in lower level in summer. The most critical changes in between-geocomponent relationships were induced by plowing on slopes with gradient over 5–8°. Humus horizon was totally removed from the convex slopes by sheet erosion with subsequent exposure of marls.

Legal regulations. All the forests in the basin have protected status which means permission for only selective cutting. Legal regulation concerning water protection zones require prohibition for allocation of any sources of pollution within the belt 50 m wide along each bank of a river.

Land-use conflicts. The socially-significant effect of selective cuttings is the decrease in areas used for gathering berries and mushrooms which is the important traditional source of income for the local community. Settlements located in the upper small catchments cause chemical impact (Fig. 2) that produces remote effects on water hydrochemistry (chlorides, organic phosphorus) and resulting decrease of suitability for bathing and fishing. Significant geochemical changes in soils (increase of Ca, Cr, V, Co, Ni, Cu, Zn contents) and water chemical properties (Mg^{2+} , HCO_3^- , NO_3^- , etc.) are induced by soil erosion (Avessalomova et al. 2016). However, corresponding accumulation at the footslopes ensure higher yields (Fig. 2).

It follows that the landscape-ecological plan is expected to deal with the following priority objectives: to change land use proportions at the basin scale to improve runoff properties, to correct neighborhoods at the catena scale aimed at protecting water from pollution, to coordinate location of cutover areas and arable lands with the everyday needs of the local communities.

Natural landscape values and their protection (steps 7–14)

Uniqueness and rareness. The regional-level constraints for the local-level land use decisions are imposed by the peculiarity of the landscape for the landscape structure of the Dvina-Onega interfluvium. Unlike the regional background conditions (dominance of low-fertile Haplic Podzols), co-occurrence of patches with fertile soils and well-drained river valleys acquire critical importance for the regional economy. The demand for preserving the unique soil resource potential is in contradiction with the decrease in quality of ecologically important floodplain biocorridor that connects huge forest expanses in the upper and lower reaches within the limits of the cultivated agrolandscape.

Functions of units in matter flows. Oligotrophic and mesotrophic mires within the flat interfluviums are important controls over runoff regime which is of particular importance in the basin which is subject to extensive cutting. Decrease of water-regulating function of the harvested coniferous forests is partially compensated by bogs. The proportion of forests in the Zayachya basin accounts for 47% which is less than required in the taiga zone for the proper regulation of runoff volume and regime. Critical decrease of forest area since 1970s forces both to restrict cutting in the upper reaches and to support the afforestation tendency of the abandoned fields. The remnants of forests on steep ($10-30^\circ$) slopes between cultivated fields at the distant sections of footslopes in most cases serve as buffer strips 100–200 m wide across the pathway of chemicals and silt from the cultivated fields towards the streams (Fig. 2).

Unstable boundaries. Unstable boundaries are characteristic of a few sections of river terraces adjoining to the deeply incised floodplains (Fig. 2). In most cases forests sustain bank erosion. Locally, meadow buffer strips are preserved above the shoulder of the eroded terraces slope. Expansion of mires is an important prerequisite for the decrease in forest productivity in adjacent units on the interfluviums (Fig. 2). Hence, cutting in close neighborhood of mires should be avoided.

Corridors and shelters. In the agricultural area forest corridors and isolated remnant forest patches on the flat interfluviums provide habitats for the birds and carnivores that use cultivated areas as fodder fields and regulate abundance of insects and rodents. One of the patches intrudes deeply to the agrolandscapes and ensures migration of forest species from the flat interfluvium to the riparian corridors. The Zayachya floodplain has a function of a critically important biocorridor surrounded by arable lands (Fig. 3). The most significant migration nodes are located in the widest sections of the Zayachya floodplain where the neighboring mouths of the converging tributaries and gullies ensure the opportunity for animals (*Castor fiber*, *Mustela lutreola*, *Lutra lutra*, *Lepus timidus*, *Sus scrofa*, *Grus grus*) to have appropriate shelters, feeding habitats, and to choose direction for migration (Emelyanova et al. 1999).

Management of flow-induced geosystems. Currently, in the conditions of heavy sheet erosion on cultivated slopes, the main adaptive technology is the choice of the crop rotation with alternation of cereals (three years) with perennial fodder grasses (four years). Downslope direction of plowing, which encourages sheet erosion, is economically preferable though ecologically harmful.

Necessary neighborhoods. Since sheet erosion and cutting generate the strongest anthropogenic effects most propositions involve regulations for adjustment of land units with transformed and natural vegetation and soil cover within a basin or catena. The width of existing buffer meadow strips (5–10 m) at the distant sections of the footslopes is insufficient neither to prevent neither loss of arable area resulting from bank erosion nor to intercept chemicals and silt washed out from cultivated

backslopes and footslopes. Therefore, there is a need either to increase meadow strip or to create pine or spruce forest strip (on sandy and loamy soils, respectively) (Fig. 3). Their desirable width may vary from 50 to 100 m depending on the structure of a catena. The smaller is the distance from the footslope to the floodplain, the wider buffer strip is needed. To avoid unnecessary reduction of arable areas, no specially created buffer strips are needed within the catenas that include wide flat terraces that separate the footslopes and the floodplains (Fig. 2).

Legal protection of ecologically valuable landscape units. The legislation allows establishment of local-scale natural protected areas. The Land Code implies the opportunity to establish the sub-category “particularly valuable lands” within the category “lands of specially protected territories”. The agrolandscape correspond to the criteria of both valuable cultural landscape and rare landscape. The recommended regime involves restrictions for the use of highly fertile soils for industrial purposes and construction building as well as anti-erosion measures at slopes aimed at protection of soils and rivers.

Ecological network: 1) runoff-regulating mires, 2) headwaters, 3) water-protecting forests, 4) riparian forests, 5) riparian biocorridor, 6) riparian buffer 7) erosion-control forests, 8) forest corridor, 9) rare isolated forest habitat with nemoral herb species, 10) social value

Required changes of neighborhoods: 11) enhance riparian buffer to intercept agricultural pollution, 12) enhance riparian buffer to intercept communal pollution, 13) enhance green space in settlement

Preserving current land use: 14) crop rotation, 15) timber industry, 16) selective cutting, hunting, gathering, 17) preserve forest habitats, 18) preserve mosaic pattern for haying, hunting, 19) prevent afforestation, power lines

Support current trend: 20) afforestation

Recommended land use changes: 21) replacement of plowing by forest strips or meadows, 22) limit selective cuttings to preserve social values, 23) afforestation on disturbed lands, 24) restore pasturing or haymaking, 25) restore plowing

Recommended changes in configuration: 26) change field configuration for parallel to contour lines

Recommended changes in technologies: 27) change plowing technology to prevent erosion, 28) intercept communal wastes, 29) intercept dairy farm wastes

Unstable units (steps 15–18)

Since rareness of natural units in the landscape is related to marls, the main matter of care is the state of forest communities with high abundance of nemoral species at the northernmost border of their geographic range (Fig. 3). The current trend for afforestation of lands adjacent to such patches is a positive phenomenon providing the effective buffer zone. Thus, the planning measures should involve supporting the natural expanding of such buffer zones and avoiding expansion of arable lands towards them (Fig. 3). The loss of attractiveness of soil resources at remote fields with soil gleization resulted in emergence of the highly mosaic pattern consisting of birch and pine coppice, wet meadows, and shrubs. This phenomenon caused significant increase of game resources (*Ursus arctos*, *Sus scrofa*, *Lepus timidus*, *Lyrurus tetricus*). Their exploitation, if in compliance with hunting rules, may be treated as the environmentally-friendly land use.

Establishment of ecological network (steps 19–20)

To summarize the assessment of the ecological values, we distinguish four categories of elements in the ecological network with restrictions for economic activity (Fig. 3).

The highest significance was assigned to the units that have intrinsic ecological values (critical habitats, high biodiversity, uniqueness etc.) and serve as the important controls over processes on vast areas by means of critical contribution to lateral transportation of living and non-living matter. We assigned this highest value to the bog expanses that regulate multi-directional dispersion of runoff and provide important nesting habitats (*Grus grus*), the forested nodes of biotic migration, the riparian forests at the upper reaches of the rivers, and the socially important forests with central position among villages. Traditional

exploitation of non-timber (*Vaccinium myrtillus*, *Rubus chamaemorus*, *Oxycoccus palustris*) and game resources are allowed in concordance with legislation, but any kinds of cuttings, peat mining, construction building and land reclamations should be forbidden. The critically important migration routes and nodes in the Zayachya floodplain were assigned to this category with the admissibility of haymaking on meadows (normally, in late June or July after the nesting period).

The second-highest value was assigned to the units containing intrinsic values such as valuable habitats of animals, habitats of nemoral plant species. Steep slopes and hills on marls with nutrient-rich Rhendzic Leptosols or Umbric Albeluvisols fall into the group of regionally rare landscape units. Since these units are often used by burrow mammals (*Vulpes vulpes*, *Meles meles*) hunting should be strictly regulated. Forest patches on steep slopes fulfil important water-regulating functions, therefore cuttings should be forbidden. Gathering berries of *Ribes rubrum* and *R. nigrum* is allowed. Due to frequent emergence of groundwater at the contact of the morainic loams and marls some units are suitable for the construction of small infrastructure (0.01–0.02 ha) made from timber for the short-term recreation. Filling bottles with high-quality drinking water is quite popular among local community and is a good stimulus for preserving forest patches.

The third-highest value was assigned to the units that are typical for the landscape and region but are critically significant as buffer spatial elements between sources of undesirable matter flows (e.g., arable lands on slopes, settlements) and ecologically vulnerable objects, such as small rivers, floodplains. The principal management measure is increasing their width, if possible, by promoting regeneration of meadows and coppice. In the upper catchment of the polluted rivers, enhancement of buffer zones should be supplemented by measures aimed at interception of the polluted water and sediments from the settlements.

The fourth-highest value was assigned to the typical forest units (patches or corridors) surrounded by the recently cut areas. Temporal restrictions for cutting are needed until forest stands in the neighboring areas reach the age of 25–30 years and comprise sufficient area (over 50–60% of the basin) to restore runoff-regulating functions, that is transfer of surface flow to subsurface one.

Thus, we have performed a “negative selection” of units (Ruzicka 2000) and now turn to the spatial arrangement of the main economical activities. The next steps of the planning procedure deal with the land units that were not included into the ecological network and, hence, have much less ecological restrictions and are available for the choice of suitable land use type (Fig. 3).

Projecting land use proportions (steps 21–22)

At a basin scale the matter of concern is the runoff regime and hydrochemistry in the Zayachya. Forest percentage less than 20–25% and dominance of plowing encourage changes in biogenic elements ratio in surface water with decrease of organic P and increase of mineral P and NO_3^- contents. Improvement of ecological network should be aimed at increase of forest cover in small basins up to at least 35%. This would ensure hydrochemistry close to regional background in taiga. Afforestation is relevant on steep slopes, where actually the yield is quite low, in gullies, and distal sectors of footslopes. The recommended decrease of the endangered arable lands accounts for 288 ha from 3130 ha currently cultivated. Additionally, 39 ha are recommended for increasing buffer zones at the footslopes. Since the structure of catenas varies over the territory, the replacement of fields by buffer zones is needed not everywhere but in locations where the plowed footslopes or slopes directly neighbor the floodplains (Fig. 2). The loss may be compensated by cultivation of present-day fallows at the total area 331 ha on the terraces and footslopes close to the villages and the former pastures on the flat interfluvies enriched with nutrients (Fig. 3). By so doing, the cultivated area can be preserved and even slightly increased up to 3134 ha, while the forests/fields proportion will improve the state of soils and waters.

Distribution of land use (steps 23–27)

Suitability for various kinds of economic activity. The detailed planning decisions in the agricultural zone should be aimed at the distribution of crop rotations and technologies in accordance with advantages and limitations of individual units. We distinguished five degrees of priority based on the assessment of drainage conditions, soil quality, and risk of erosion (Table 2).

Table 2
Recommended adaptation of agricultural land use to landscape pattern

Priority for plowing	Landscape units	Soil quality and drainage	Optimum land units
1	Marginal well-drained sections of the flat or slightly convex interfluves with loamy Anthri-Rhendsic Leptosols, Anthric Umbrisols or Anthri-Umbric Albeluvisols	Highly fertile for the taiga zone. High content of humus and exchangeable base cations. Perfect drainage.	Priority for grain crops
2	Slightly inclined footslopes with loamy Anthri-Umbrisols	High fertility due to accumulation of humus washed out from the adjacent slopes	Priority for grain crops
3	Terraces with sandy Anthri-Albeluvisols and Anthri-Umbric Podzols	Low humus and base cations content	Vegetables (potatoes)
4	Flat interfluves with loamy-sandy Umbri-Gleyic Albeluvisols	Poor drainage. Elevated acidity. Low content of base cations and humus. Land reclamation required	Priority for annual fodder grasses. Bear hunt on specially cultivated small oats fields. Pastures. Hayfields. Suitable for the construction building zone.
5	Steep valley slopes with eroded Anthri-Rhendsic Leptosols Anthri-Umbrisols alternating with exposures of marls.	Low humus content. High spatial variability of soil properties. Good drainage and heat supply on south-facing slopes.	Hayfields. Limited plowing parallel to contour lines with priority for perennial fodder grasses.
5	Remote sections of interfluves with loamy-sandy Umbri-Gleyic Albeluvisols	Poor drainage. High acidity. Low content of humus, nutrients, and base cations. Low accessibility	Natural afforestation or pastures.

Reliability. We predict several most evident chain reactions between geocomponents and/or between units. The recent transition to keeping cattle in stables has reduced the demand for pastures but increased that for growing forage on lands falling into 3^d or 4th priority for plowing. We face high probability that fields on the wet interfluves may experience rise of groundwater level due to decrease of evapotranspiration in comparison with meadows and coppice. The permanently plowed fields are subject to progressive impoverishment of soils and, hence, require mandatory input of fertilizers and manure. On slopes, this kind of management results in washing out chemicals from fields to ephemeral streams and rivers with risk of pollution.

The productive capacity of an ecosystem is not static and changes over time, through both natural processes and the influences of humans upon it (Bug 2019). Therefore, the next step of the algorithm is devoted to the assessment of long-term reliability of spatial units for a certain type of land use. One of the principal threats to food security worldwide comes from climate change, with the potential impacts of climate change upon agriculture featuring in important work by geographers for at least the last three decades (Robinson 2018). Current climatic trend in the Arkhangelsk region involves rise of annual, winter and summer temperatures, growth of winter precipitation and decrease of summer precipitation. On flat areas, this trend is highly likely to favor increase of crops productivity due to higher evaporation from soils subject to gleization. In this respect, reliability of these fields for agriculture will increase. Second, higher longevity of snowmelt can reduce the duration of vegetation period which, surely, could be compensated to some extent by higher heat supply and evaporation in summer. Third, thicker snowpack will generate greater surface runoff in spring which will be detrimental for soils that could suffer from stronger erosion, at north- and east-facing slopes in particular. It follows that the proposal to convert fields to meadows on the steepest slope is in compliance with both the purposes to enhance ecological network and to avoid economic losses from plowing unreliable fields. More stable growing conditions are characteristic of the flat interfluves and terraces, much less stable – of slopes and footslopes. However, the reliability of agricultural use of gentle slopes can be increased by correct choice of appropriate crop rotation and technologies.

Minimization of land use conflicts (steps 28–33)

Possible conflicts. Growing population of Nagorskaya village resulting from depopulation of the small remote villages, forces to increase the settlement zone. The ecologically and economically preferable direction is the northward expansion to the over-humidified flat interfluves. This could save space to the south of the village with well-drained nutrient-rich soils for plowing and exclude dispersion of pollutants in the rugged terrain. However, the northward expansion could cause a conflict situation since the dairy farm has recently expanded in the same direction and replaced former arable lands and pastures. The legislation requires at least 1000 m wide sanitary protection zone around the farm with prohibition for building new houses. Thus, the opportunities to increase the area of the settlement zone are limited both in southward and northward directions while the other directions are characterized by domination of protective forests.

Nevertheless, the existing official Master plan of the settlement implies southward expansion of Nagorskaya involving both flat area (200 m wide) and steep slopes (300 m wide, gradient up to 5–10°). During the construction works multi-directional dispersal of fine earth and chemicals to several catchments will be induced with the subsequent accumulation on footslopes or in the rivers. This is a wrong decision since it will produce detrimental remote effects for the riparian ecosystem. The alternative option, which existed 10 years ago, implied allocating the new dairy farm south of the village, would have been much more detrimental. The compromise solution could be found in increasing the width of the buffer forested strip along the gullies and constructing sediment traps at the toe-slope.

Adjusting loads and technologies (steps 34–38)

If there are several comparable opportunities for allocation of an object within the suitable or semi-suitable landscape unit, the decision should be aimed at minimum possible detrimental effects to land use or ecological values in the neighboring units. Furthermore, a spatial decision should not cause irreversible changes of geocomponents or boundaries of a landscape unit. In Table 3 we explain the principles for allocating objects in non-optimum units targeted at minimizing negative effects. The recommended technologies (Table 3) will ensure anthropogenic loads below the critical thresholds for sustainable functioning of geocomponents and between-components relationships preventing irreversible loss of ecological functions and economic value as well as undesirable remote ecological effects.

Table 3

Principles of allocating objects and recommended land use technologies in non-optimum or ecologically sensitive landscape units

Land use type	Landscape unit	Requirements for allocation and configuration	Recommended technologies
Road construction	Valley slope	Choose the least suitable section for plowing. Cross at diagonal direction to reduce risk of road erosion and shrinkage of neighboring land use units.	Build silt fences and sediment traps along the ditches to prevent siltation of rivers. Re-establish vegetative cover at the ditch slopes to ensure soil stabilization.
	Floodplain	Select the narrowest section and cross by perpendicular to minimize detriment to ecological corridor and habitats.	Ensure the least possible earthwork at the wettest sites. Exclude unnecessary dams to enable water and animals' migration.
Construction building	Sandy terrace	Avoid close adjacency to the stream, prefer sections with wide floodplain between terrace and stream.	Collect polluted water and avoid their infiltration to soil and groundwater.
	Interfluve	Avoid shallow depressions collecting drainage runoff to exclude dispersion of pollutants downstream. Choose the areas with the disturbed soils that are no longer suitable for plowing.	Avoid chemical pollution of close to surface groundwater.
Arable land	Gentle slope	Orient the longest side of a field along the contour lines to reduce soil erosion.	Establish crop rotation with prolonged cover by perennials. Orient the tillage direction along the contour lines.
			In case a footslope fully overlies a terrace, preserve the widest possible meadow or forest strip between the edge of a field and a floodplain.
	Terrace with sandy soils	Orient a field along the edge of a terrace.	Allow row crops with low nutrients demand.
Cutting	Valley slope	Orient a cutover parallel to contour lines to reduce the rate of surface runoff.	Prefer hand felling to minimize a mechanical load on a soil.
	Gullies	Avoid felling in gullies to preserve diversity of habitats and normal runoff or, if impossible, orient a cutover perpendicular to a stream.	Exclude timber transportation along gullies to prevent stream pollution and disturbance of habitats.

Discussion

We define *landscape-ecological planning* as a hierarchical system of spatial decisions aimed at ecologically safe, economically efficient and socially conflict-free adaptation of multifunctional land use to landscape structure. The context-based approach to spatial planning described in this paper proceeds from the idea that the significance of landscape units or geocomponent is determined by the potential detriment from its loss for a territory of a certain rank order. In other words, the smaller the number of the alternative sites for a land use type of interest, the higher is the significance and the higher is the necessity to preserve current ecological or socio-economic value. Thus, the main principle of the context-based landscape planning is the due consideration for both intrinsic properties of a unit and its value in a broad (regional, national, or international) spatial context. The analysis of spatial proportions of land use units is needed to assess the closeness to the critical ones under which the normal zonal-type functioning could be disturbed. We showed how to regulate lateral abiotic and biotic flows aiming at adaptation of land use to

natural migration pathways. Changing configurations, neighborhoods, and connectivity of land parcels is the planning tool that can diminish socio-ecological conflicts.

The described planning procedure allows reaching the purposes as follows.

1. Preservation of ecological and socio-cultural values that constitute the region's identity and uniqueness. On the one hand, the plan sustains the agricultural values which ensure the importance of the landscape for the regional economy which suffers from the lack of fertile and well-drained soils. On the other hand, high biotic and hydrological values may be maintained despite the obvious economic benefits from agriculture and forestry.
2. Providing sustainable functioning of ecological network as a condition of landscape and economy stability in a mosaic landscape as well as a space for environmentally-friendly land use. The proposals ensure the preservation of rare and typical landscape units as well as the connection of the most critical habitats and biocorridors.
3. Neutralization of harmful matter flows and other impacts on vulnerable natural and anthropogenic objects as well as preservation, stimulation or management of desirable flows. The set of proposals imply enhancement or creation of buffer zones to isolate agricultural areas and settlements from the streams.
4. Creation of spatial pattern and proportion of land use types that ensure minimization of man-landscape and stakeholder-stakeholder conflicts. Maintaining natural trends for the development of mosaic forest-and-meadow patterns allow gaining benefits from resources exploitation, and multifunctional use or positive interactions of land units.
5. Building comfortable environment for society (including aesthetics, microclimate, safety, accessibility of economically significant objects, and combination of private and public spaces). For this purpose, we proposed creating optimum combinations and neighborhoods of land units with due regard to the traditional parcels for leisure activities and gathering non-timber resources.

The proposed procedure deliberately concentrated on nature-based criteria and provided less details concerning communication with stakeholders and authorities since these issues is a constant focus in literature (Brandt et al. 2000, Selman 2006, Sayer et al. 2013, Carlsson et al. 2017, Trovato and Ali 2019). Unlike most planning methodologies (Dramstad et al. 1996, Izakovičova 2006, Özyavuz 2012, Turner and Gardner 2015, Serrano Gine 2018, Hersperger et al. 2020) to make planning proposal we applied several theoretical models of landscape pattern depending on the objective. The genetic-morphological model was helpful to identify natural units with internal uniformity of properties and resources providing the opportunity for uniform land use and technology, The paragenetical model allowed identifying the pathways of pollutants from the anthropogenic sources along water streams, the accumulation sites in the lower topographic positions, and the degree of danger for the natural soils and communities. The positional-dynamic model enabled us to assess the necessity for buffer strips and correction of technologies according to structure of catenas. The basin model was used to reveal relations between the proportions of land use types in a basin and the hydrological and hydrochemical regimes. Hence, this enabled us to make proposals for correcting land use proportions and to choose appropriate genetic-morphological units for this. Finally, the biocentric-network (matrix) model was applied to evaluate the contributions of spatial units to maintenance of viable populations of animals that depend on areas, connectivity, fragmentation, neighborhoods, and land use proportions.

Conclusions

The procedure of the context-based landscape planning implies the sequence of steps that starts with the inventory of landscape structure and land use pattern with the purpose to reveal the necessity for land use changes. It continues with assessments and corresponding mapping aimed at establishment of ecological network. The identification of ecologically significant landscape units is based on information on what is the function of a unit in a broader geographical context starting from a regional level and finishing at the catena level. The position of a unit in a matter pathway (mobilization, transit or accumulation of abiotic or biotic matter) is critical in determining its significance for regulation of natural processes or its threat to natural or anthropogenic objects. After that the procedure focuses on adjusting neighborhoods of land use units to important matter flows as well as on projecting the necessary buffer strips. Before creating the final project of the ecological network with limitation for land use, it is critical to consider natural or anthropogenic trends that could cause short-term changes in a landscape. The regime of use and protection of the units within the ecological network is adapted to their resilience and dynamic character. Then, the units beyond

the limits of the ecological network are treated as candidates for the intensive land use. The procedure focuses on the emergent effects at a landscape and/or basin scale level to ensure appropriate proportions of land use units. The next steps are aimed at distributing land use types among the natural landscape units with due consideration for supporting necessary proportions, configurations, and neighborhoods. At the final step relevant technologies are proposed for the chosen land use types in certain spatial units.

The proposed procedure takes into consideration the hierarchical organization of nature and multiplicity of landscape spatial patterns. Neither physiography-based nor flow-based nor matrix model separately cannot ensure the correct choice of land use decisions. We support the idea that multiplicity of landscape models is helpful in getting important insights into landscape analysis for land management (Franch-Pardo et al. 2017, Antrop and van Eetvelde 2017). Combination of multiple landscape models comprises the systemic essence of a landscape via proper understanding of diversity of elements, connections between them, and the resulting emergent effects that ensure the required landscape services for society.

Declarations

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Consent to participate Not applicable

Consent for publication Not applicable

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Code availability Not applicable

Authors' contributions Not applicable

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Figures

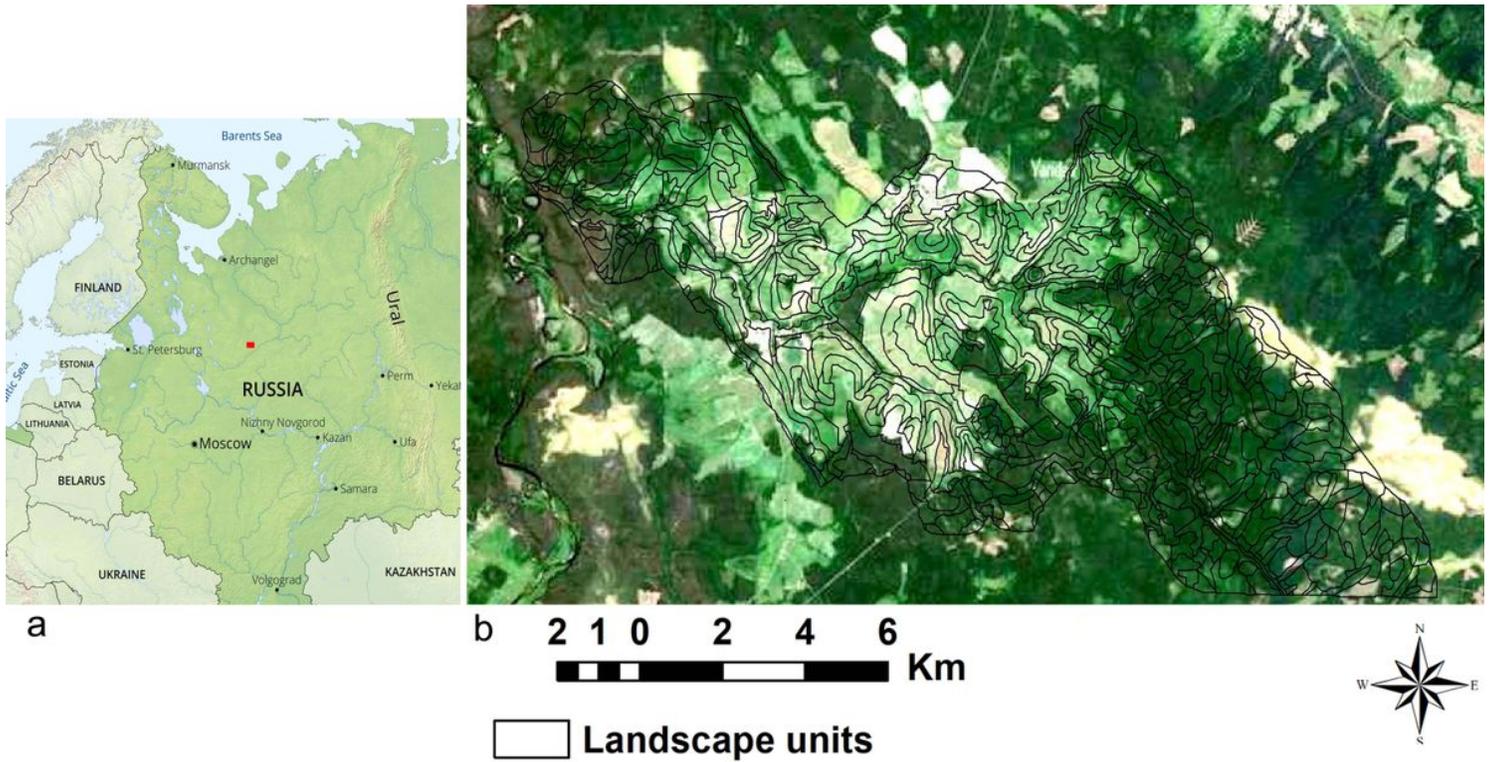


Figure 1

Study area: a Location of the study area in the East-European Plan, Arkhangelsk region (red rectangle). Source of map: www.freeworldmaps.net/russia/european-russia; b Physiographic landscape units in the Zayachya river basin (Khoroshev 2020a). Source of satellite image: Google Earth, 2020 CNES/Airbus. Bogs are seen as white patches, coniferous forests—dark green, small-leaved forests—medium green, agricultural lands and cutovers—light green

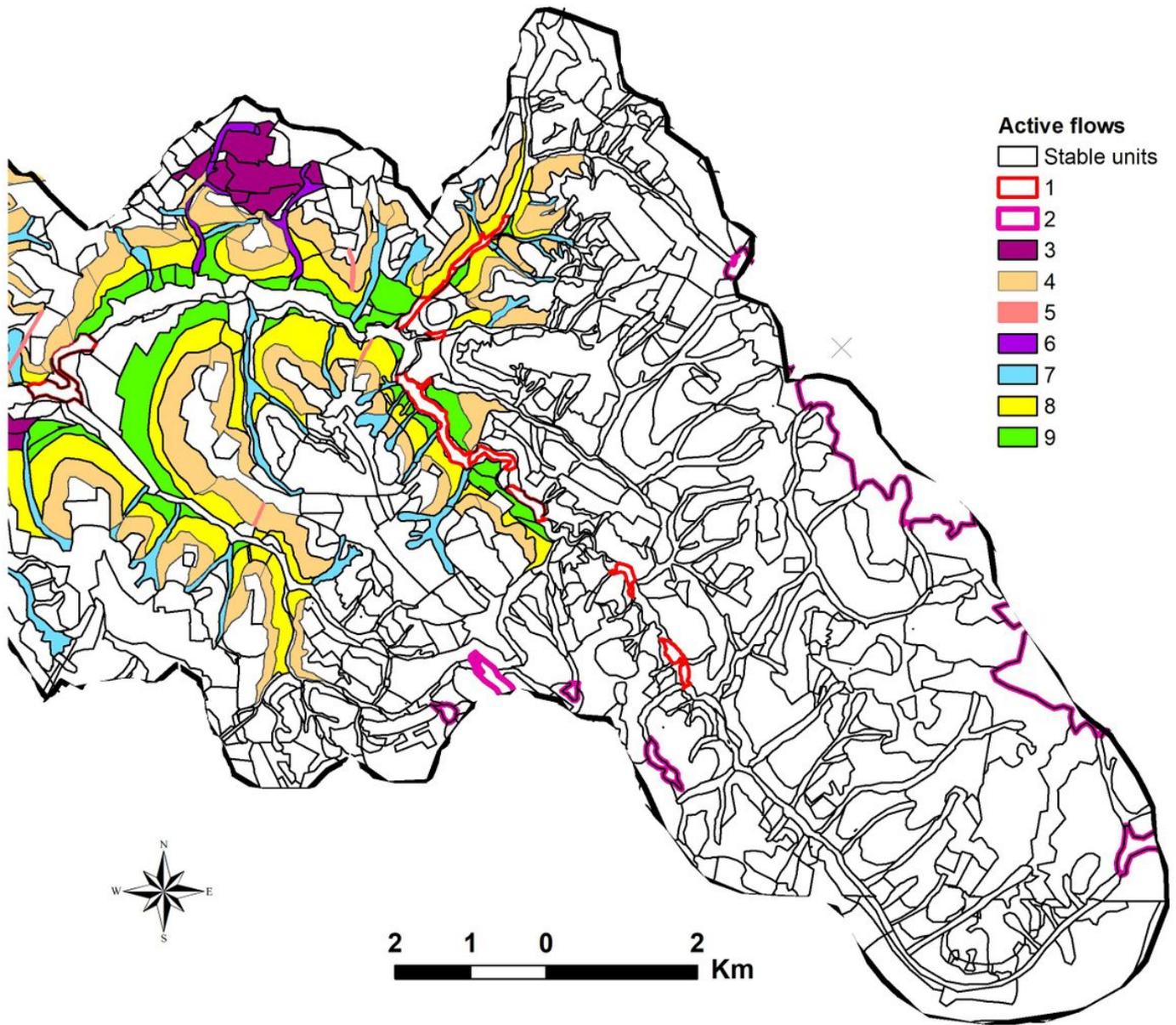


Figure 2

Dynamic events and matter flows inducing changes in spatial pattern and geocomponent structure in the Zayachya river basin: 1 – active bank erosion causing reduction of terrace or slope units; 2 – expansion of mires causing decrease of timber production; 3 – sources of pollutant flows (communal wastes, dairy farms); 4 – sources of solid matter flows caused by road erosion; 5 – sources of matter flows caused by sheet erosion on plowed backslopes and shoulders; 6 – linear pathways of pollutants from settlements and dairy farms; 7 – linear pathways of pollutants washed out from arable lands on backslopes; 8 – accumulation of agricultural pollutants on footslopes; 9 – terraces serving as a natural buffer zone between eroded slopes and floodplains

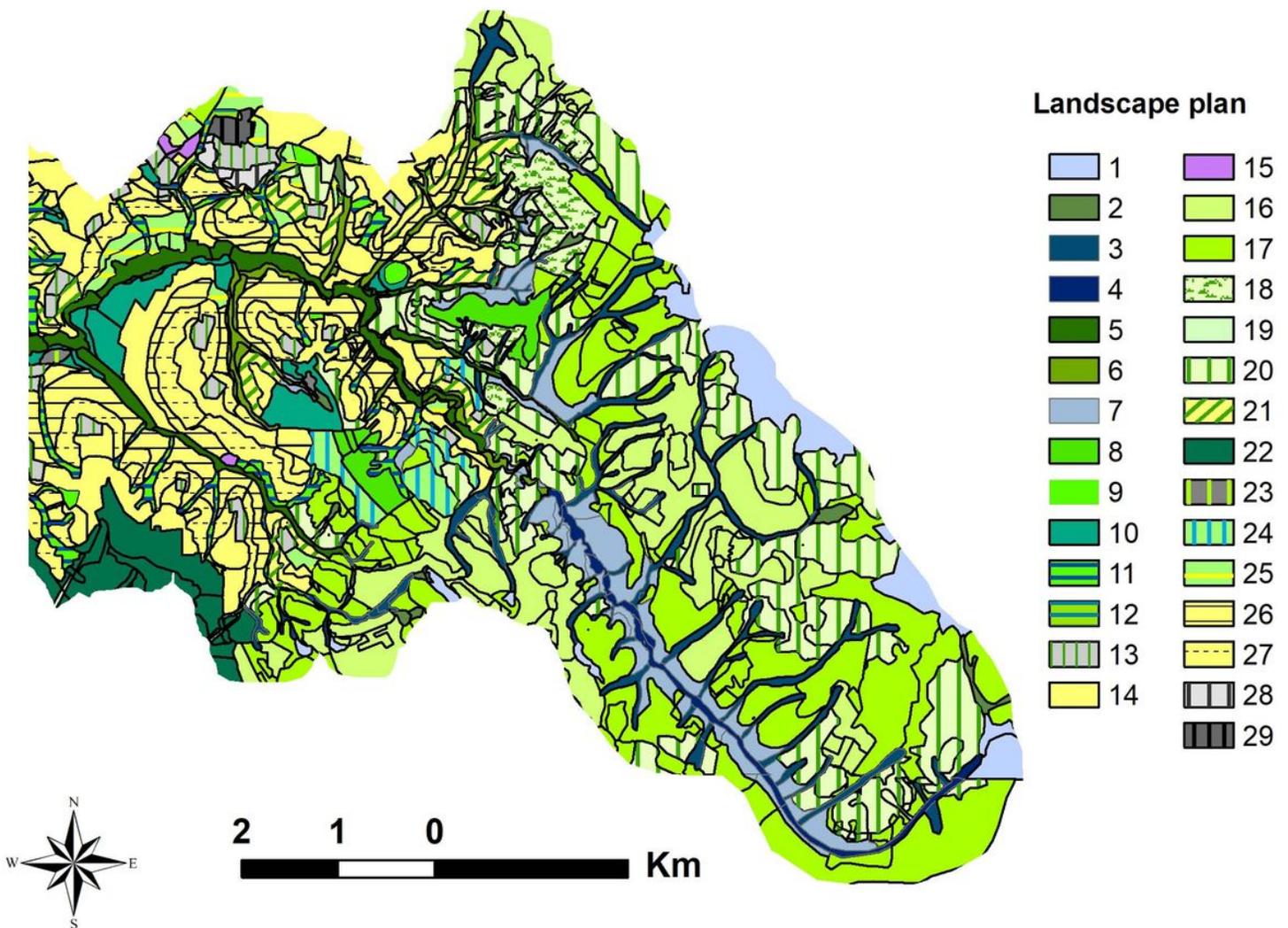


Figure 3

Landscape plan for the Zayachya river basin Ecological network: 1) runoff-regulating mires, 2) headwaters, 3) water-protecting forests, 4) riparian forests, 5) riparian biocorridor, 6) riparian buffer 7) erosion-control forests, 8) forest corridor, 9) rare isolated forest habitat with nemoral herb species, 10) social value Required changes of neighborhoods: 11) enhance riparian buffer to intercept agricultural pollution, 12) enhance riparian buffer to intercept communal pollution, 13) enhance green space in settlement Preserving current land use: 14) crop rotation, 15) timber industry, 16) selective cutting, hunting, gathering, 17) preserve forest habitats, 18) preserve mosaic pattern for haying, hunting, 19) prevent afforestation, power lines Support current trend: 20) afforestation Recommended land use changes: 21) replacement of plowing by forest strips or meadows, 22) limit selective cuttings to preserve social values, 23) afforestation on disturbed lands, 24) restore pasturing or haymaking, 25) restore plowing Recommended changes in configuration: 26) change field configuration for parallel to contour lines Recommended changes in technologies: 27) change plowing technology to prevent erosion, 28) intercept communal wastes, 29) intercept dairy farm wastes