Urban green infrastructure: a detailed approach to ecosystem services

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Abstract. Urban green infrastructure (GI) and protected areas (PAs) particularly are providing an extraordinary set of ecosystem services, but ecological and social components of urban livability contradict each other due to limited space and various demands of stakeholders. Definitions of regulating (R), institutional (I) and cultural (C) values were established to conduct a comparative spatial analysis of ecosystem services (ES). Three highly transformed case-study PAs (Izmaylovo park, Setun river valley reserve, Tyoply Stan reserve, with areas of 1600, 700 and 330 ha) on the outskirts of Moscow were assessed and mapped through on-site surveys of ecosystem degradation, public interviews, analytic hierarchy process, qualitative and quantitative analysis of legislative acts, modelling of 5 key ES. Fragmented and deteriorated river valleys are strongly exposed to human pressure, resulting in a relatively low ES supply (E-S = -3.9). The large green core of Izmaylovo park tends to retain less disturbed ecosystems, especially black alder forests on floodplains, and provides regulating services at a slightly larger extent than cultural ones (E-S = +1.1, possible values vary from -20 to +20). Despite the higher connectivity of habitats, Izmaylovo and Tyoply Stan PAs are still vulnerable to severe adverse transformations. Gaps in spatial planning, defined as zones of insufficient and excessive regulations on human activities, were revealed, with the first type strongly prevailing (I-R = -1.9 within Setun valley). The devised workflow may be used to assess the ES of protected areas in other cities and GI patches, as well as their value.

Keywords: urban planning, ecosystem services, protected areas.

1 Introduction

Urban green infrastructure (GI) and protected areas (PAs) are specific nature and cultural spaces in cities exposed to various adverse transformations [1]. Urban GI can be characterized as the constellation of differently scaled engineered and non-engineered elements: green roofs, road verges, private and public gardens, lawns, nurseries, squares, parks, urban forests, river valleys, i.e., natural and semi-natural ecosystems as well as those designed by human [2]. The most valuable parts of urban GI are usually under various prohibitions on human activities, i.e., referred to as PAs.

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Urban GI and PAs particularly provide a wide range of ecosystem services (ES) which are crucial and sometimes irreplaceable for nature conservation and citizens' well-being at the same time [3]. Various GI ecosystem services comprise provisioning (cultivating plants, rearing animals, gathering of wild plants, genetic material, etc.), regulating (improvement of air, water, soil quality, regulation of extreme events, reduction of noise pollution, mitigation of climate change, pest and disease control, etc.), cultural (physical, intellectual, experiential, spiritual interactions with the natural environment) ones [4,5]. Cultural services such as recreation, conservation of historic heritage, «sense of place», etc. are included in ecosystem services as well [6]. Moreover, the positive benefits of urban GI are not limited to health quality improvement but are also represented by security, the basic material for life, good social relations, and freedom of choice [7].

However, transformations of land use and land cover in the urban environment are rather complicated due to the enormous and varied human impact. Megapolises are the key drivers of world urbanization, leading to growing tensions amongst stakeholders to use and manage urban space, particularly GI [8]. At the same time, global and regional economic challenges may result in the neglect of environmental issues for basic needs, according to Maslow's pyramid of needs [9]. Another challenge for resilient urban ecosystems is the improper implementation of the urban livability concept, resulting in the transformation of semi-natural biotopes into parks with forest and shrub plantations used for leisure and entertainment predominantly [10]. Hence, urban GI is a dynamic system formed by natural and cultural transformations at the same time [11], implying that ecosystem and cultural services are currently in great contradiction in the urban environment [12].

Sustainable practices in urban and landscape planning may significantly rise the value of natural and semi-natural areas [13] and contribute to the strength of all three sustainability pillars – environment, economy, and equity in compliance with a triple bottom line framework [14]. Hence, ecosystem and cultural services of urban PAs must be retained at the same time through the flexible mechanism of trade-offs and win-wins [15].

Therefore, the main research question of our study is to devise a workflow to assess spatiotemporal ecosystem and cultural services of protected areas in the urban environment. To answer this question, three goals have been set up as follows:

- to gather spatial and textual data on land use/land cover and restrictions on them within case-study PAs.
- to carry out the comparative spatial analysis of ecosystem and cultural services within case-study PAs.
- to reveal gaps in environmental management related to the severity of regulations on human activities within case-study PAs.

2 Data and methods

2.1 Study areas

The case areas of study are three considerably large (1600, 700, 330 ha) PAs in Moscow city (Fig. 1). Two of them (Setun river valley and Tyoply Stan) are characterized by mild restrictions on human activities due to the specific protection category – «reserves» which provide wide opportunities for leisure and entertainment activities besides biodiversity conservation, according to city legislative acts [16].

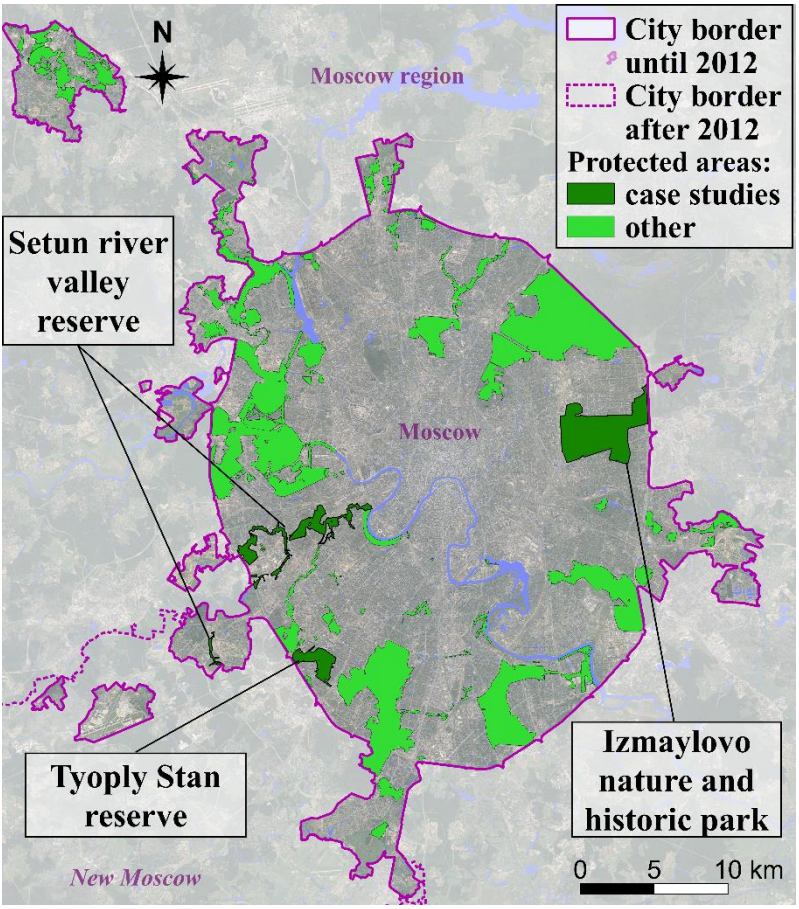

Fig. 1. Protected areas within Moscow city

All PAs within Moscow have undergone zoning procedures in 2020-2022 which have resulted in spatially differentiated regulations on land use (construction of roads, utilities, entertainment facilities, trees pruning, fertilizers feeding, flowerbeds design,

etc.) and daily human activities (usage of benches and letter bins, walking on permeable/impermeable footways, cycling, kiosk retailing, walking the dogs, etc.) [17]. Compared to reserves, Izmaylovo nature and historic park possess quite a high share of zones of strong regulations – wildlife sanctuaries (15.9%), specially protected landscapes (0.3%) and excursion (1.0%) zones in total – 17.2% (Fig. 2).

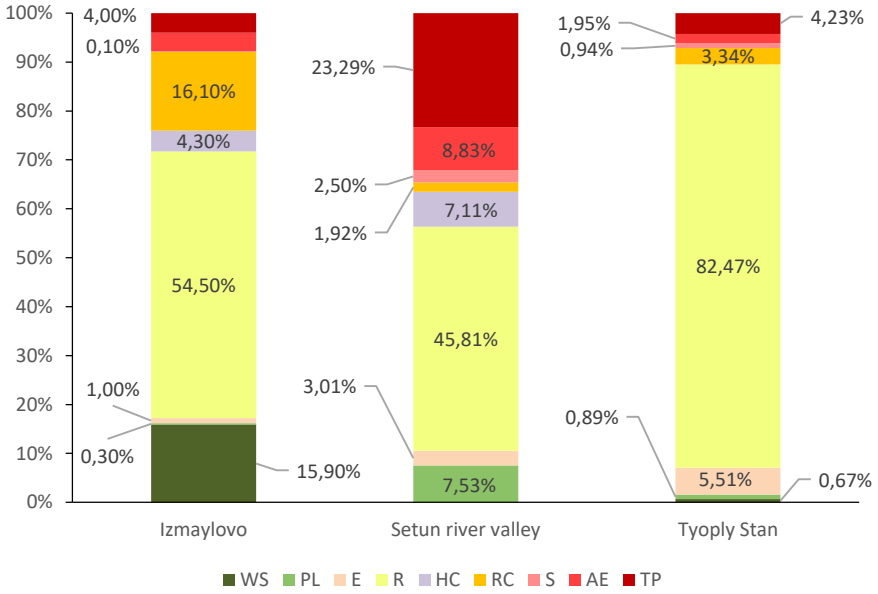

Fig. 2. Zoning of case study PAs. **Zones of relatively strong restrictions:** WS – wildlife sanctuaries, PL – specially protected landscapes, E – excursion zones; **Zones of relatively mild restrictions:** R – recreation zones, HC – historical and cultural zones, RC – recreation centres, S – sport zones, AE – administrative and economic zones, TP – third-party land-users

Despite differences in PAs' configuration (Fig. 3), each study area is surrounded by plenty of streets and highways, even dissecting ecosystems into patches. Moreover, these PAs are almost entirely squeezed between large multistorey residential blocks or industrial facilities which makes semi-natural biotopes within PAs significantly exposed to any human pressure. Therefore, these PAs are extremely varied in current land use, regulations on human activities and deterioration rate which makes these PAs to be solid candidates for the spatial comparative analysis of ecosystem services.

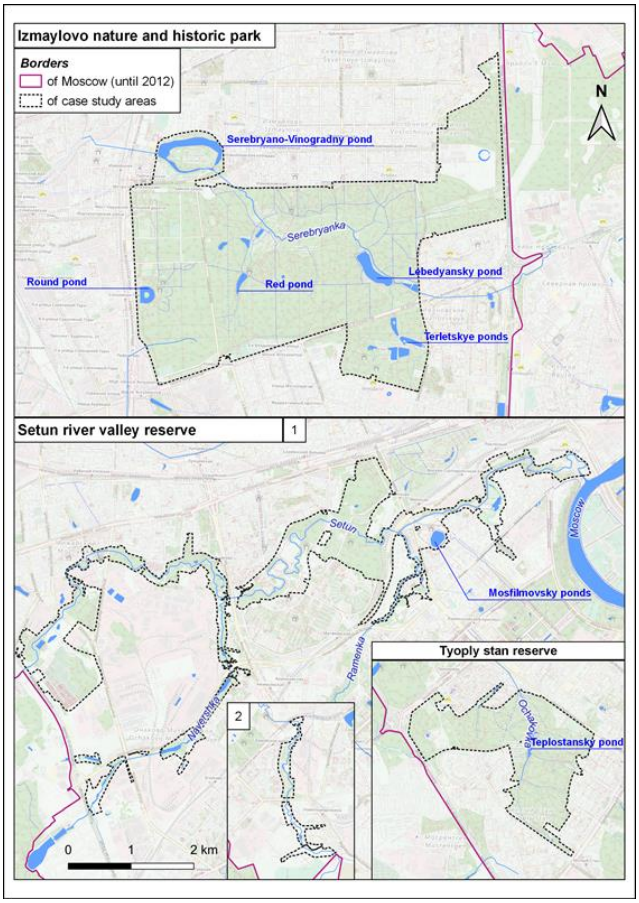

Fig. 3. Location of case study protected areas (Open Street Map)[1]

Most of Moscow's green areas protected now have been studied by biologists, geographers and social scientists for a long time [18,19]. Rare and endangered species, vegetation, soils. water bodies of Izmaylovo park and Setun river valley reserve have been thoroughly explored by academics and professionals [20,21, et al.]), but no complex review of ecosystem services/ecological condition has been conducted yet.

2.2 Workflow of comparative spatial analysis

To assess ecosystem and cultural services, a 4-stage workflow devised by authors has been implemented (Fig. 4). Three integral values (regulating, institutional and cultural) have been assessed through collecting mainly open-access spatial and text data described below from the various sources (governmental, academic, and public ones) and

[1] OpenStreetMap. https://www.openstreetmap.org/, last accessed 21 Nov., 2023

series of procedures carried out in QGIS – spatial weighted overlay, clipping, merging buffering, raster and vector algebra, etc.

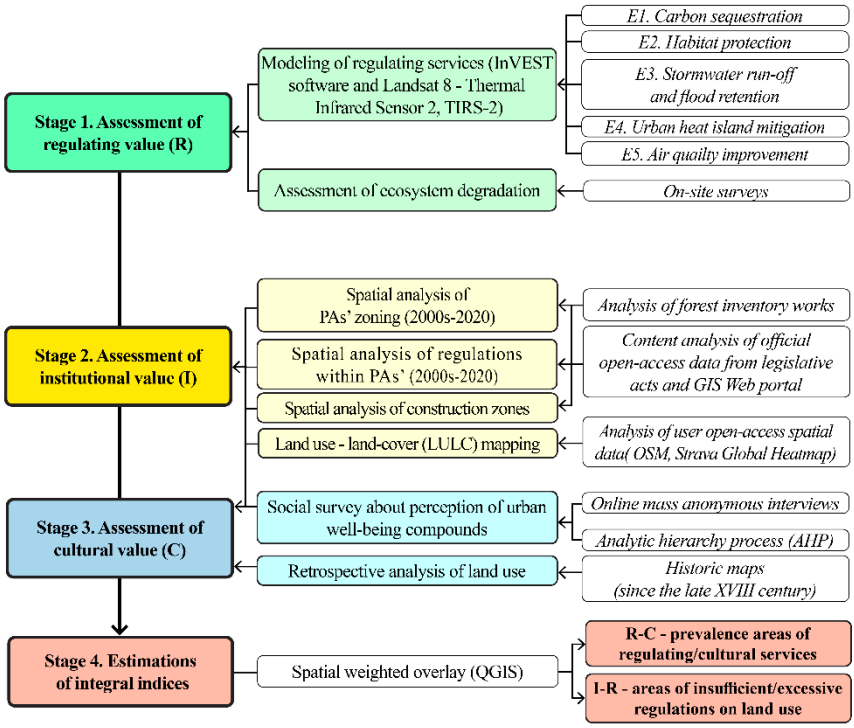

Fig. 4. Data and methods framework of ecosystem services assessment within urban GI

Regulating value

A regulating value (R) considers present landscape deterioration assessed through on-site surveys and the ability to provide five ecosystem regulating services (E1. Carbon sequestration, E2. Habitat protection, E3. Stormwater run-off and water retention, E4. Urban heat island mitigation, E5. Air quality improvement) which was evaluated through InVEST tools [22] and Landsat 8 imageries via the Semi-automatic classification plugin [23] (Fig. 4). ES choice was justified by data available: forest inventory works, Open Street Map, Global Forest Change [24], topo base map M 1:2000.

E1 is estimated through the average values of CO2 in above-ground and underground biomass [25], E2 – on approximate borders of habitats and biodiversity threats from the Red List of Moscow [26], E3 –Landsat 8 imageries of 2017-2021 (Thermal Infrared Sensor 2, TIRS-2) and parameters of surrounding buildings (Open Street Map), E4 – digital elevation models derived from topo base maps M 1:2000 and soil filtration coefficients, E5 – on the previous data of trees species ability to filter air pollutants [27]. Such input data as land-use/land-cover (LULC), forest stand age (data obtained

from local forest inventories conducted in 2012), canopy cover[2] and the results of own on-site surveys of ecosystem deterioration have been used to assess each regulating service.

The relative importance of each service, or weight *W*, is derived from the content analysis of the main environmental problems in Moscow, according to the Reports on the Environment State [28] and the project of Moscow Environmental Strategy [29]. The weight of regulating services was estimated by pair-wise comparisons through the analytic hierarchy process (AHP) [30], using the results of 26 interviews of professional and academic experts in the fields of urban planning and environmental management.

Field surveys of ecosystem degradation followed by detailed descriptions of vegetation and soil cover on 171 points were conducted in 2020-2021 within all main biotopes. These points were chosen considering not only relief, vegetation communities, water objects, and pedestrian activity, but also the borders of PAs' zones. To assess the rate of ecosystem degradation, the parameters of forest undergrowth, trampling, littering, distribution of invasive species and bonfire sites, and foliage cover were considered, using a robust 5-point scale (from «close to pristine» to «completely degraded») [31].

Institutional value

At the same time, ecosystem value can be surveyed in terms of legislative regulations, restrictions and prohibitions on land use and specific human activities. This reflection of regulating value is defined as the *institutional value (I),* i.e., the rate of regulations' 'severity imposed by the authority and administration of PAs to protect the most valuable and vulnerable biotopes. Various restrictions and prohibitions depend not only on zoning but the specific location of the zone and the presence or absence of established construction zones which include areas of allowable refurbishment or repair (present roads, utilities, administrative buildings, education, and healthcare facilities, etc.) or planned construction which is known to be not a common case within PAs. Therefore, the number of minimum areal units (MAU) in the *I* assessment framework is considerably larger than the number of zones (889 and 568 respectively within study areas in total).

[2] Global Forest Change. https://glad.earthengine.app/view/global-forest-change#bl=off;old=off;dl=1;lon=20;lat=10;zoom=3; last accessed 05 May, 2022

Cultural value

A cultural value (C) was assessed based on functional zoning, land-use regulations, construction zones, government plans of investments and GI popularity among visitors through Strava Global Heatmap data. Cultural value covers not only classic recreation and historic heritage but also specific ones:

- sport (all case-study PAs comprise workout zones, playgrounds and courts, bicycle routes with specific pavement and parcels within PAs occupied by sport facilities.).
- utilities – power supply lines, gas and water pipelines, water sewage, etc.
- transport (all case-study PAs are dissected by small auto roads, while natural areas are used by pedestrians and bicyclists as transit part of routes between city districts).
- sacral (religious facilities are located within Setun river valley reserve, despite being surrounded by artificial forest plantations and gardens).

Other, less tangible cultural services (sense of place, information, aesthetics) have not been assessed as those methods are not widely common amongst academia yet, while formal documents established by authorities cannot provide useful data.

Two adjustment procedures were implemented to increase the feasibility of the integral *C* parameter: weighting by the importance of each cultural service and considering the maximum values of any cultural service. The first adjustment operation was commenced with a social survey that included questions on the perception of 23 urban well-being economic, social and environmental compounds (income rate, transport accessibility, quality of healthcare, pollution, landscape design within green areas, water resources management, etc.). 9 groups of PAs' cultural services were aggregated afterwards and operated through AHP analysis of interviews mentioned above.

Weights obtained (table 1) strongly differ between not only PAs' zones but also within them due to various sets of restrictions. As an illustration, the construction of water-impermeable pavements and outdoor lighting is prohibited within some less disturbed recreation zones, whereas the most deteriorated spaces can be easily transformed by new utilities and even entertainment facilities.

The second adjustment procedure concerns the uniqueness of cultural objects rather than the MAU multifunctionality. As an illustration, stadiums or educational clubs with restricted access can provide only few cultural services (sport, education, science), but perform them at an extremely high level. Hence, these extremely valuable objects gained the largest (within the higher quartile) *C* values with respect to the type of cultural service (according to the relative importance of services derived from the expert interviews mentioned above).

R, *I* and *C* values were normalised using score scales from 0 to +20 to ease the integral mapping and comparison.

Services*	SC			E			R1			R2			CH			SP			T			U			RG		
Service weight in C value	0.03			0.07			0.12			0.19			0.06			0.04			0.29			0.18			0.02		
Construction zones**	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
WS	20	no	no	13	no	no	0	no	no	0	no	no	0-5	no	no	0	no	no	0	no	no	0	no	no	0	no	no
PL	16	no	no	16	no	no	5	no	no	0	no	no	0-5	no	no	0	no	no	2	no	no	0	no	no	0	no	no
E	13	no	no	20	no	no	11	no	no	0	no	no	0-5	no	no	4	no	no	4	no	no	4	no	no	0	no	no
R^1	8	no	no	14	no	no	13	no	no	0	no	no	0-7	no	no	7	no	no	5	no	no	5	no	no	0	no	no
R^2	8	5	no	14	14	no	13	9	no	0	3	no	0-7	0-4	no	7	7	no	5	5	no	5	20	no	0	0	no
R^3	6	4	4	13	14	14	13	9	9	4	7	7	0-7	0-4	0-2	7	7	7	5	5	5	5	20	20	0	0	0
R^4	4	3	3	7	9	9	20	20	20	14	16	16	0-7	0-4	0-2	10	10	10	8	8/ 20	8/ 20	8	12/ 20	12/ 20	0	0	0
HC^1	15	10	3	10	3	0	12	9	9	6	9	9	13- 20	8- 17	5	7	7	7	10	10/ 20	10/ 20	8	12/ 20	12/ 20	0	0	0
HC^2	10	17	3	15	15	0	17	17	17	14	16	16	15- 20	15- 20	10- 15	6	6	6	10	10/ 20	10/ 20	8	12/ 20	12/ 20	0	0	0
HC^3	20	20	no	20	20	no	15	15	no	5	15	no	12- 18	12- 20	no	6	6	no	10	10/ 20	no	8	12/ 20	no	0	0	no
HC^4	5	12	no	7	7	no	15	15	no	7	7	no	12- 18	15- 20	no	7	7	no	10	10/ 20	no	8	12/ 20	no	15-20		no

Table 1. A matrix of cultural value (*C*) weighted by services, zones, land-use restrictions, and construction zones within Moscow PAs (a fragment). * Services abbreviations: SC – science, E – education, R1 – soft recreation (mostly walking), R2 – active recreation (mostly entertainment), CH –cultural heritage, SP – sport, T – transport, U – utilities, RG – religious and sacral objects. ** Construction zones: 1 – not established, 2 – established (current), 3 – established (planned). The zones given in the first column are subdivided according to the regulation sets.

Integral indices

Spatial-adjusted differences between *I* and *R*, *C* and *R* were estimated through integral assessment mapping in QGIS using weighted overlay operations. The *I*-*R* index represents the areas with a regulating value that is higher or lower than it is designated by the government through legislative acts, whereas the *R*-*C* index is calculated to showcase the areas of the prevalence of regulating and cultural services. Hence, the possible range of *I*-*R* and *R*-*C* values is -20 to +20.

A similar approach has been implemented earlier in the assessment of two small (less than 200 ha in total) urban reserves in Moscow, but a smaller set of cultural services has been examined while regulating surveys have not been surveyed at all [32].

3 Results and discussion

3.1 Regulating and cultural value

Differences in the spatial distribution of *R* values (Fig. 5) are implied by a heterogenous mosaic of urban ecosystems influenced by historical peculiarities in land use, environmental planning and management. E1. Carbon sequestration is evaluated to be the most significant ES compound (W = 35.3%), E4. urban heat island mitigation and E2. habitat protection make up 25.8 and 20.4% respectively, whereas E5 and E3 constitute 10.9 and 7.5% respectively.

Izmaylovo park accounts significantly for the supply of all regulating services, especially urban heat island mitigation (mostly within wetlands of the Serebryanka river floodplain), air purification and carbon sequestration (provided mostly by birch and linden forests with high canopy cover) due to the high connectivity of large non-fragmented and predominantly forested spaces (table 2).

Tyoply Stan reserve may be characterized as a more vulnerable PA exposed to human pressure but PA status still contributes to the providing regulating services more than cultural ones. Setun river valley is represented by the strong prevalence of cultural services and weak contribution to the regulating ones, particularly habitat conservation and improvement of air quality.

Despite soft and active forms of recreation being the key service within study areas, transport and utilities also impact wildlife habitats dramatically because of dissections and triggering the «edge effect» [33].

Table. 2. Values of regulating (R), institutional (I), cultural (C) values (range from 0 to +20), R compounds I-R and R-C indices (range from -20 to +20) within study areas

Protected areas	R	R_1	R_2	R_3	R_4	R_5	I	S	I-R	R-S
1. Izmaylovo park	12.8	16.0	14.6	13.8	16.7	15.9	11.2	11.7	-1.6	1.1
2. Setun river valley reserve	8.3	10.3	4.1	12.1	3.9	10.1	6.4	12.2	-1.9	-3.9
3. Tyoply Stan reserve	10.8	15.7	10.8	14.9	12.9	12.9	9.5	9.1	-1.3	1.7

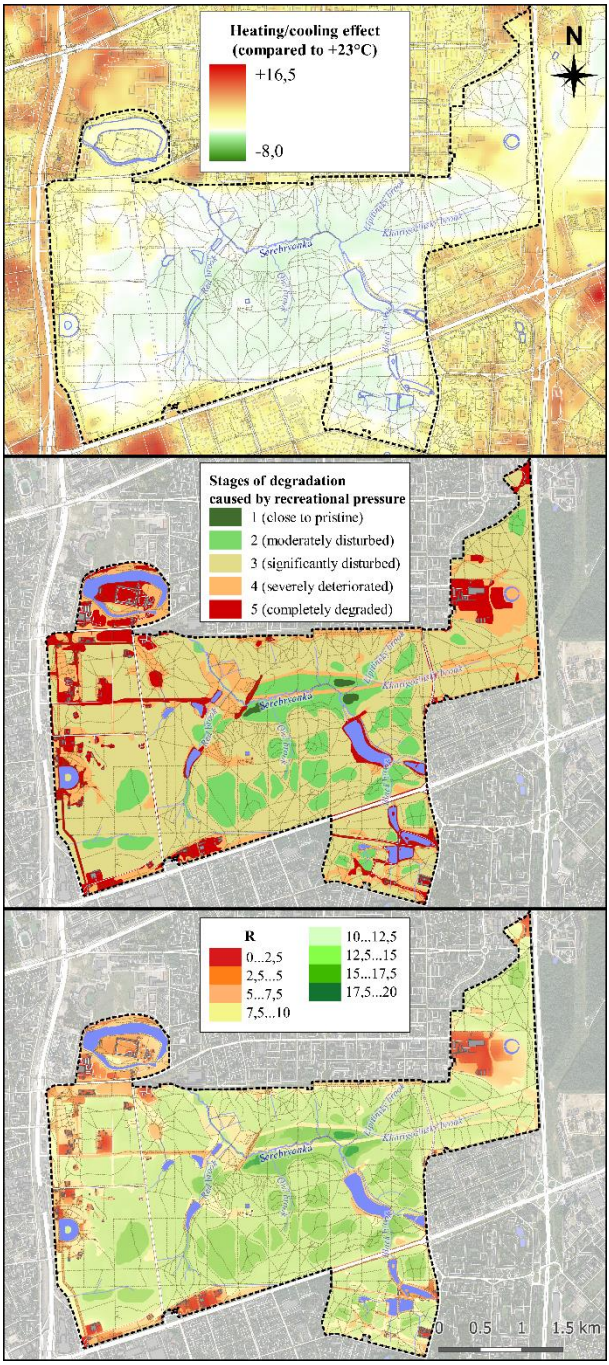

Fig. 5. Supply of regulating value (R) compounds within Izmaylovo park

The values of the *R-C* index vary strongly across PAs. The negative values are mostly related to lasting landscape transformations by residential areas, agricultural activities (including not only planting, grazing and forestry, but also horticulture, arboriculture, deploying plant nurseries, beekeeping, fishing), industrial facilities (predominantly watermills, brick and leather factories) indicated on old maps, mostly in XIX century and in the first half of XX century [34] Spaces which have been transforming for a long time possess features of cultural landscapes [35] and provide these services at a considerably higher level than regulating ones.

3.2 Regulating and institutional value

The values of *I-R* less than -5 or more than +5 can be considered as gaps in environmental planning as these areas are exposed to *insufficient* or *excessive regulations* on human activities respectively. The spatial distribution of the *R-C* index has nothing in common with historical land use. Insufficient restrictions are significantly more widespread than excessive ones (23.4% compared to 6.2%), especially within the Setun river valley (Fig. 6) – a narrow PA, extremely fragmented by built-up areas (25 officially designated patches), mostly disturbed by recreational activity (47.4% of the area is considered to be under the 4th or 5th stage of degradation – severely deteriorated or completely degraded ecosystems) and not able to provide ecosystem services at such a high level as the large green core of Izmaylovo park (table 2). Therefore, urban linear wetland PAs are supposed to be extremely exposed to overwhelming human pressure and following ecosystem degradation despite their high potential to improve well-being.

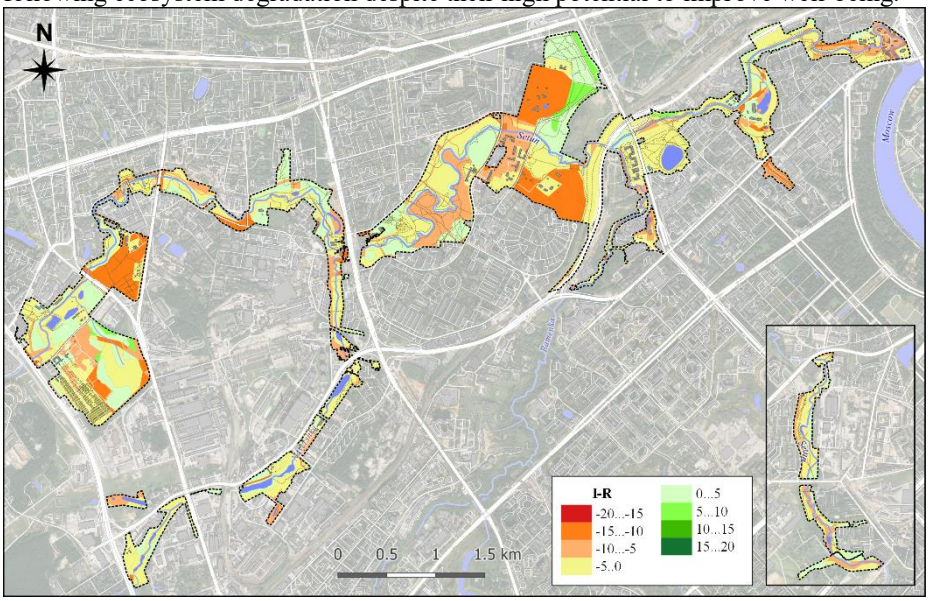

Fig. 6. Integral I-R index within Setun river valley

Results obtained differ from those of the similar assessment within Altufjevsky and Severny reserves [32] which may be attributed to the local landscape parameters and

methodology improvement. The considerable prevailing of insufficient restrictions on land use over excessive ones was revealed in contrast to the assessment of those reserves.

3.3 Opportunities to advance study

The outcomes of this study have shown quite a complicated ES supply and their institutional reflection established by law within PAs. Hence, the following issues for assessment may include, but are not limited to:

- Extension of this approach to other cities coupled with spatial analysis of other regulating services, including providing ones.
- Analysis of PAs' planning effectiveness through the spatial comparison of regulating/cultural services provided prior to legislative PA's designation and afterwards.
- Estimation of PAs' design positive effect – savings of costs which are necessary to provide similar services across PAs.
- Analysis of PAs' influence on compliance with popular rules in urban planning: 3/30/300 [36], ANGSt in regard to green infrastructure proximity [37], URGE criteria [38], GreenKeys toolbox [39], etc.

4 Conclusion

The framework devised may be implemented in resolving a dilemma between protection and exploitation and identifying the majority of gaps in GI planning and management. Thorough surveys should be conducted in areas with negative C-R values and the elements of landscape design can be adapted to less intrusive forms: elevated walkways with water-permeable pavements, construction of a strictly limited number of benches, localization of the visitors' influx in the narrow transport corridors equipped by convenient walkways, benches, litter bins, outdoor lightning. Furthermore, all mobile retail objects must be conveyed to the main park entries, occupying biotopes highly transformed already. Additionally, all downsizings of urban PAs with area compensation by remote GI patches must be prohibited due to the rapidly growing biotopes' fragmentation by various sealed surfaces, including permanent constructions.

At the same time, the social needs of citizens should not be neglected, as total prohibitions on human activities seem to be impossible in contemporary megapolises [12]. A holistic systems-thinking approach, encompassing at least all analyzed aspects of ecosystem services and involving professionals, academics, and the public, should be implemented in the planning of cities and urban fringes [13]. The mentioned issues should be considered when planning new built-up areas, contemporary parks, and public spaces in megapolises that still have remnants of semi-natural ecosystems, sometimes quite close to the pristine ones.

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