RESEARCH PAPER

HOW PROTECTED AREAS ARE TRANSFORMING WITHIN MEGAPOLIS: AN ADVANCED SPATIOTEMPORAL LEGISLATIVE MODEL

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ABSTRACT. Compared to pristine ecosystems, urban protected areas (PAs) are exposed to intensified pressure and deterioration due to rapid population growth and entangled stakeholders' interests. At the same time, these valuable ecosystems provide cities with ecosystem services, including cultural ones, and enhance the quality of life. Spatial analysis of PAs' transformations in the context of the multidisciplinary approach contributes to the detection and safeguarding of vulnerable ecosystems. The study object is the protected areas of Moscow megapolis (within boundaries until 2012), whereas the study subject is the spatial and temporal PA's transformations established by legislative acts. The research question is to devise a model of transformations designated by law within urban PAs and affecting their borders, land use, and rate of ecosystem deterioration. To achieve the research question, three goals were set: to gather spatial data on PAs' transformations within Moscow designated by legislative acts; to design a comprehensive and exhaustive classification of PAs' transformations established by legislative acts; to model spatial and temporal trends in transformations of Moscow PAs (1985-2022), according to the classification devised. The 3-compound framework for the analysis of legislative transformations (downgrading, downsizing, degazettment of protected areas) was coupled by content analysis of transformation events, GIS mapping, and spatial analysis of urban vegetation through NDVI (normalized difference vegetation index) estimations and raster computations in QGIS and GDAL software. The originality of our study derives from: the analysis of the 4th transformations' compound (design failures of new PAs); spatial comparison with positive transformations, strengthening nature conservation; uncovering detailed subtypes and levels of transformations; applying this approach to the local scale of megapolis. Our study is based on: 1985-2022 legislative acts with text and map representations of PAs' borders, zones and land-use designated by regional government and national ministries; national and Moscow open-access spatial data hubs; Moscow online news; 2001-2021 Landsat imageries and Global Forest Change data on Moscow region. Adverse transformations affected a larger area than positive ones (53.8% of a total PA area compared to 22.6%). Positive transformations contributed by PAs' design (49.5%) mostly, while adverse ones – by easing of restrictions on land use (60.3%) and failures in the design of new PAs (22.8%). Adverse transformations are mainly reflected in the downsizing of zones with the strictest prohibitions on land use (-68% on average) and a low share of designed PAs (54%) through the period 1985-2022. Woodland plantations dramatically expanded (+86.5%), replacing semi-natural urban forests (2005-2021). Hence, PA's ability to supply ecosystem services has been considerably diminished. In regard to Moscow, considerable adverse trends in nature protection were revealed, generally hidden from the public. The analyzed typology of Moscow PAs' transformations is quite conventional and may be improved through comparisons with other megapolises abundant in natural heritage to advance the model devised and elicit threats to nature conservation.

KEYWORDS: adverse and positive transformations of protected areas; PADDD (protected area downgrading, downsizing, degazettement); Moscow protected areas; nature conservation; urban planning; environmental legislation

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INTRODUCTION

Urban protected areas (PAs) are transformed specific natural and cultural spaces, heavily affected by population growth, increasing recreational pressure, habitat fragmentation and entangled interests of the state, regional, city institutions, dwellers, third-party land-users, academic community (Leroux and Kerr 2013, Trzyna et al. 2014). Moreover, urban dwellers contribute about 55% of the total world population now, and about 68% is expected

by 2050 (United Nations 2019). Despite all efforts to retain urban ecosystems, the amount of green infrastructure per capita of the largest European cities has significantly (e.g., more than 12% in Rome and Paris) declined in recent years (Aurambout and Vallecillo 2016). Hence, our study's relevance is substantiated by the contribution of spatial analysis of PAs' transformations to the safeguarding of vulnerable ecosystems.

Many PAs transformed by human impact may be considered highly valued cultural landscapes (Berkes and Folke 1998; Ban et al. 2013; Sarmiento-Mateos et al. 2019). Although urban PAs have a rather low ecosystem value due to the high deterioration, they should be considered the most valuable parts of urban green infrastructure. These spaces provide not only supporting, provisioning, and regulating ecosystem services, but also cultural ones (MEA 2005; Haines-Young, Potschin 2018), e.g., enhancing the comfort of life, recreation, landscape aesthetics, spiritual values, sense of place, cultural identity, etc. (MEA 2005; Daniel et al. 2012; Baro et al. 2014).

To date, plenty of multidisciplinary case studies related to urban planning and protected areas concurrently are known (Elmqvist et al., 2013; Trzyna et al. 2014; Tenk 2016; Girault 2017; Ioja et al. 2018; Mahmoud and Morello 2021; Gan 2021 et al.), while classic environmental surveys do not comprehensively cover the management issues of nature conservation in cities. For the time being, the task of linking social sciences with nature conservation still exists due to contradictions within academia, between policies and locals, urban planners and biologists (Vaccaro et al. 2013).
PAs' adverse transformations enacted by law may be divided into downgrading, downsizing, and degazettment (PADDD), widespread in areas of intensive land use (Mascia and Pailler 2011; Golden Kroner et al. 2019), including urban areas. PADDD ramifications have yet to be explored. Now, the PADDD number is increasing worldwide: 64% of them have been enacted between 2008 and 2018. Moreover, PADDD have been dramatically striking marine PAs (Albrecht et al. 2021) and UNESCO World Heritage iconic PAs (Siyu et al. 2019). However, not every PADDD should be considered an adverse one – e.g., Buffalo National Park in Alberta, Canada, and some others were abolished due to strong bison growth and accomplishing park aims (Lothian 2010).

Most urban PAs' studies are dedicated to one of the PADDD compounds – mostly downgradings and less often downsizings. However, any delays in PAs' design and failures in establishing new PAs can drastically reduce ecosystem value due to the rapid deterioration of urban ecosystems, e.g., deforestation within Kuskovo park for highway construction (TEEB-Russia 2021). Moreover, slow PAs' designation hits non-urban PAs as well and arouses adverse transformations of ecosystems combined with habitat deterioration (Stepanitsky and Kreyndlin 2004). Therefore, the incorporation of the fourth PA4D component is justified by human pressure on landscapes, outpacing complicated procedures of establishing new PAs and appropriate regulations on land use.

The study object – is the PAs of Moscow megapolis within boundaries until 2012, whereas the study subject – is the spatial and temporal PA's transformations established by legislative acts. According to the city borderline until 2012, Moscow had one of the largest urban PAs' networks in the world – 17.8% of the total area (139 PAs)[1].

To address issues in urban PAs' transformations, the following research question has been set up: to devise a model of transformations designated by law within urban PAs and affecting their borders, land use, and rate of ecosystem deterioration. To achieve this question, three goals were set:

- to gather spatial data on PAs' transformations within Moscow designated by legislative acts;
- to design a comprehensive and exhaustive classification of PAs' transformations established by legislative acts;
- to model spatial and temporal trends in transformations of Moscow PAs (1985-2022), according to the classification devised.

MATERIALS AND METHODS

The main sources of data on transformations are law acts followed by functional zoning, mostly of 2020, known as "Polozhenija" (Regulations) of PAs, designated by Moscow authority and the Ministry of Natural Resources and Environment (fig. 1). These data have been retrieved mainly from two open-access online hubs aggregating spatial data, text descriptions and illustrations: IAIS OGD (Information System Ensuring Spatial Planning) focused on Moscow and national Russia Protected Areas database[2]. Moreover, advanced descriptions of some legislative acts with appendices have been obtained from the Bulletin of Moscow[3].

Most of the PAs' borders have been changed by these Regulations. Moreover, a system of nature conservation restrictions on land use (prohibited and allowed human activities) has been established. The Regulations are supplied by maps and text representations, including coordinates of borders and zones, but sometimes coordinates are not disclosed.

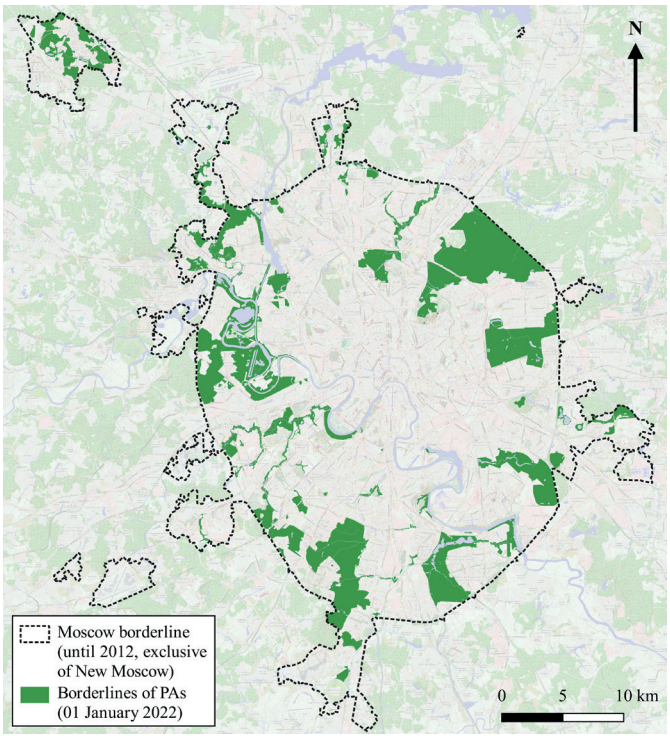

Fig. 1. Protected areas of Moscow (*IAIS OGD database and OpenStreetMap*[4])

[1]IAIS OGD (Information System Ensuring Spatial Planning on a GIS Server). Available at: https://isogd.mos.ru/isogd-portal [Accessed 10 Jan., 2022]
[2]Russia Protected Areas. Available at: http://oopt.aari.ru/ [Accessed 10 Feb., 2022]
[3]The Bulletin of Moscow (law acts of Moscow city). Available at: https://vestnikmoscow.mos.ru/ [Accessed 5 Jun., 2022]
[4]OpenStreetMap. [online] Available at: https://www.openstreetmap.org/ [Accessed 10 Feb., 2022]

Speaking about categories of Moscow PAs, nature monuments (NMs) are the most popular category due to mild prohibitions, small sizes, and management ease. These PAs may be located в within other larger PAs (inland nature monuments) or outside them (separated ones). However, more than 60% of the total PAs' area is occupied by 11 nature and historic parks – large (1075.5 ha on average) green areas combining semi-natural ecosystems and highly transformed cultural landscapes. Besides these, 28 so-called nature reserves under mild prohibitions, two eco-parks and 5 botanical gardens are included in the PAs' network. Thus, the categories of Moscow PAs have no direct relation to the IUCN categories (Lausche, 2011), except the national park and nature monuments.

Moscow gained its unified comprehensive system of PAs' zoning in 2020. Before that, some large PAs had had own zoning complicated by multiple variations of the zone's names. These variations were established by planning projects of the Moscow government and transformed later during forest inventory works carried out in 2010-2013. One notable exception is Elk Island National Park (NP) zoned 5 times: 1979, 1988, 2002, 2010, 2012. At the same time, land use restrictions within historical and cultural zones are designated by heritage law acts, special development blueprints and management plans in each PA specifically.

Previous environmental impact assessments or ecosystem services' assessments of the largest Moscow PAs were carried out in the Bitcevsky forest (Semenyuk and Bodrov 2019), Moskvoretsky park (Kolbowsky et al. 2015), Elk Island NP (Lelkova, Pakina, 2020), Sparrow Hills reserve (Samsonova et al. 2013), etc. A significant number of surveys are dedicated to vegetation and its ecosystem services, including cultural ones (Rysin 2012; Kiseleva et al. 2019; Reitz et al. 2021; Semenyuk et al. 2021 et al.). Few issues of Moscow's environmental policy resulting from spatial planning peculiarities have been examined over the last years (Kolbowsky et al. 2015; Mukhin et al. 2015; Frolova and Batarin 2015; Kryukov 2021 et al.), but there is no complex review.

Implementation of the 3-compound PADDD framework into the study focused on urban ecosystems requires a multidisciplinary approach. This approach has been applied for the analysis of legislative transformations through the following steps of mixed qualitative and quantitative procedures:

1. retrieval of actual spatial data on PAs established by law;
2. content analysis of transformation events within PAs;
3. devising a typology of PAs' transformations;
4. dynamic GIS mapping of transformation events;
5. retrieval of spatial data on urban vegetation;
6. raster computations of urban vegetation distribution;
7. spatial analysis of historical transformations within PAs.

Downsizing and upsizing information has been obtained from IAIS OGD – to gain the latest versions of borders, The Protected Areas of Russia and Bulletin of Moscow – to collect older borders in the vector format.

Data on degazettment events and ad hoc design of PAs have been collected through the Russia Protected Areas database, online news, and comparing the current PAs' network with the planned one. The plan of the PAs' network of 2005 from the Bulletin of Moscow and the last versions of borders from IAIS OGD have been extracted to obtain information about the design of protected areas.

Upgrading and downgrading transformations have been assessed based on 12 large Moscow PAs represented about 59% of the total Pas' actual area with at least one zoning earlier, before the 2020 version.

Secondly, all data retrieved have undergone content analysis which is common in qualitative and quantitative legal and policy studies (Paloniemi et al., 2012; Slapin and Proksch 2014; Hall and Steiner 2020) to reveal the exact areas affected by all types of adverse and positive transformations.

As the next, 3[d] step, all PAs' transformations have been divided into two broad categories: adverse (PA4D) and positive (PA4P) on biodiversity protection. PA4D in Moscow are expressed in different forms which require more meticulous examination than the classic 3-type PADDD structure (Fig. 2). The fourth extra type has been identified in the typology of transformations – design of PAs planned earlier. Some components of the PA4P model are similar to PA4D, but the numerous distinctions between them have been revealed (see Appendix A).

The results of transformed areas extraction and QGIS spatial vector overlays (Longley et al., 2005; Ahlqvist 2008) have been combined with our advanced PA4D-PA4P typology through QGIS mapping (4th step).

Afterwards, the actual vegetation distribution and dynamics within PAs have been revealed through NDVI (normalized difference vegetation index) computations of Landsat 7 (2001) and Landsat 8 (2021) and images which are considered to be a reliable source for analysis of green infrastructure (Vogelmann et al. 2001; Claverie et al. 2015). Deforestation of reserved PAs, but not designed yet, has been assessed on the basis of Global Forest Change[5] data with a spatial resolution of 30 meters. QGIS and GDAL software have been used to carry out these procedures (raster calibration, clipping, elimination of null and invalid values, cleaning of raster grids corrupted by cloudiness, calculation, zonal statistics extraction, overlay with PAs' borders in vector format).

Finally, a statistical comparison of borders, zones, restrictions on land use, and vegetation has been carried out through QGIS tools of spatial analysis. Speaking about the analysis of upgrading and downgrading, two versions of 2020 and 2002-2010 have been compared through QGIS overlay spatial analysis to assess the extent of positive and adverse transformations. Since there are no open-access vector data on zones' borders of 2002-2010, digitized raster grayscale images based on the Bulletin of Moscow have been used. The cadastral borders[6] and the latest borders of zones, partly overlapping with the former ones, have been added to increase the accuracy of raster images.

Therefore, the originality of our study derives from: the implementation of the 4th transformations compound (design failures of new PAs); spatial comparison with positive transformations, strengthening nature conservation; uncovering detailed subtypes and levels of transformations; and applying this framework to the local study scale of megapolis.

RESULTS

As it was mentioned, adverse and positive transformations have been divided into 4 main types (Fig. 2). Transformation mapping has revealed a wide range of changes in sizes and regulations on land use, features of planned PAs and degazettment cases (Fig. 3).

Adverse transformations (PA4D)

1. Downgrading

1.1. Full downgrading is a transformation of PA's status at the general level to another with milder restrictions. No PAs in Moscow exposed to these transformations are known yet. Such transformations may be related to the governing level (national/

[5]Global Forest Change. Available at: https://glad.earthengine.app/view/global-forest-change [Accessed 12 Feb., 2022]
[6]Public Cadastral map. Available at: https://pkk.rosreestr.ru/#/search [Accessed 10 Feb., 2022]

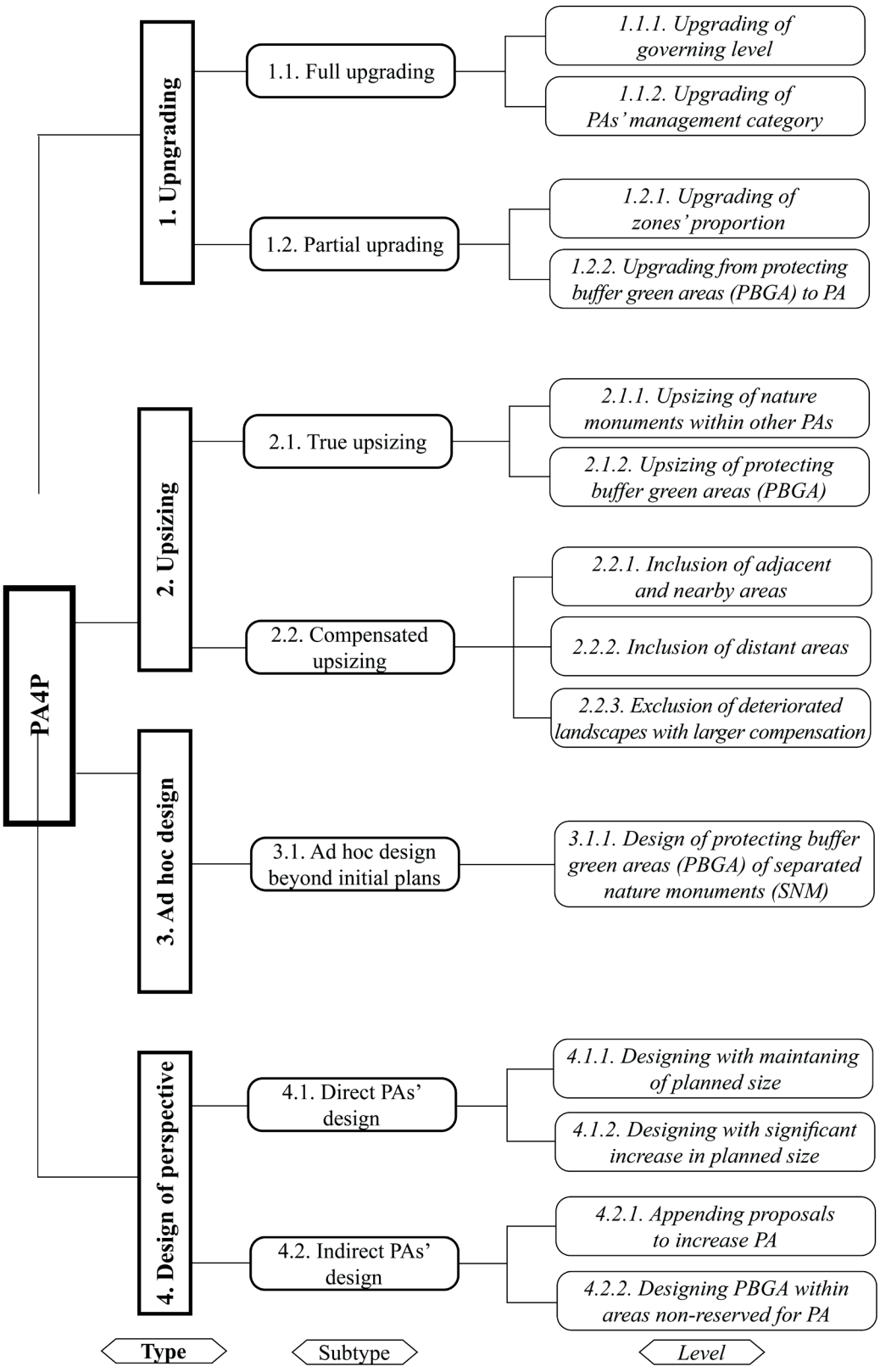

Fig. 2. Advanced PA4D model. Devised by the authors

regional/municipal) (1.1.1) or PA's category, e.g., downgrading from nature reserve to eco-park (1.1.2).

1.2. Partial downgrading has been divided into 3 levels.

1.2.1. Downgrading of zones' proportion comprises a decline in zones with strong restrictions on human activities ("cores") and an increase in zones with less strong restrictions.

To date, 9 types of zones have been established, attending to different restriction levels on land use activities (Tables 1-2).

Besides those, some activities are banned within all zones by default, e.g., tree cutting in the birds' nesting season, planting of introduced species, extraction of birch sap and resin etc. Land use restrictions within historical and cultural zones are defined by other documents protecting heritage objects – legal acts and special development plans.

Zones' names given are deciphered as follows: WS – wildlife sanctuaries, PL – protected landscapes, E – excursion and education zones, R – recreation zones, HC – historical and cultural zones, RC – recreation centres, S - sport zones, AE – administrative and economic zones, TP – third-party land-users. Subtypes of recreation zones (R1-R4) have been revealed through content analysis, as zones with the same name can differ in regulations on land use.

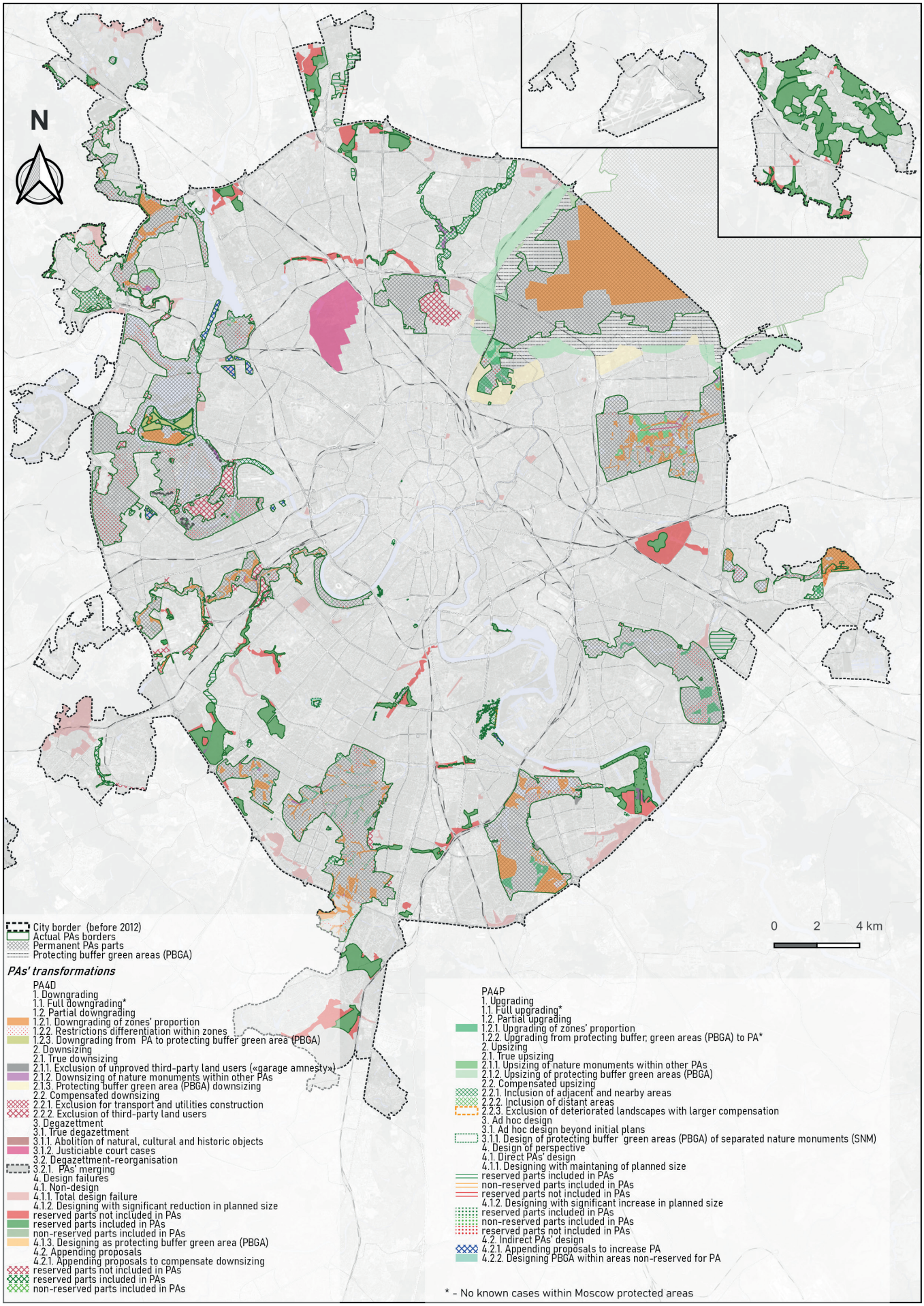

Fig. 3. Protected areas' transformations within Moscow (based on the Bulletin of Moscow, data hubs Russia Protected Areas, IAIS OGD)[7]

[7] This map at a scale of M 1: 75 000 is available here: Supplementary 1.

Table 4. Zones and restrictions on land use within Moscow PAs (The Bulletin of Moscow; data hub Russia Protected Areas, IAIS OGD). Prohibited land use activities are coloured red, and permitted ones are coloured green. The activities' numbers are transcribed in Table 2

Types of land use activities	Number of land use activities	Zones										
		WS	PL	E	R				RC	S	AE	TP
					R1	R2	R3	R4				
Relief and water bodies	1											
	2											
	3											
	4											
	5											
	6											
	7											
	8											
Vegetation and animals	1											
	2											
	3											
	4											
	5											
	6											
	7											
	8											
	9											
	10											
	11											
Social infrastructure	1											
	2											
	3											
	4											
	5											
	6											
	7											
	8											
	9											
	10											
	11											
	12											
	13											
	14											
	15											
	16											
	17											
	18											
	19											

Table 2. Land use activities within Moscow protected areas (The Bulletin of Moscow; data hub Russia Protected Areas). ***Activities' numbers are given in Table 1***

Relief and water bodies	Vegetation and animals	Social infrastructure
1. Any activities transforming natural relief followed by changes in absolute height 2. Any activities transforming natural relief followed by changes of absolute height more than 0,5 m 3. Draining of waterlogged spaces 4. Slope reinforcements based on artificial material 5. Any activities could lead to significant hydrogeological, soil transformations, erosion and landslides without using technical arrangements to decrease environmental impact 6. Springs captured using natural substances 7. Springs captured using natural-like substances 8. Springs captured using artificial substances	1. Designing of flowerbeds 2. Designing of flowerbeds with no linkages with culture and historical landscape 3. Elimination of fallen leaves 4. Elimination of organic debris, except fallen leaves 5. Raking fallen leaves and other organic debris and putting it around trees and shrubs 6. Irrigation of trees, shrubs groups and meadows 7. Trees and shrubs whitewashing 8. Cutting lower tree branches, except dangerous for people and transport vehicles; crowns pruning 9. Planting in non-forested areas after trees/shrubs elimination due to abnormal weather conditions or deadwood cuttings 10. Use of organic fertilizers 11. Use of mineral fertilizers	1. Building of mobile non-permanent constructions 2. Maintenance and reconstruction of current walkways 3. Maintenance and reconstruction of current roads and utilities, except outdoor lighting 4. Maintenance and reconstruction of current permanent buildings and constructions 5. Designing of permanent buildings and constructions 6. Designing of motor roads and utilities, except outdoor lighting 7. Construction of pedestrian walkways covered with waterproof artificial surfaces 8. Construction of pedestrian walkways covered with permeable surfaces made of natural substances 9. Maintenance, reconstruction and deploying of children's and sport playgrounds 10. Maintenance, reconstruction and deployment of street furniture (benches, fountains, sculptures, garbage bins, etc.) 11. Artificial lighting 12. Artificial lighting at nighttime in wildlife habitats 13. Deploying of mobile retail objects 14. Designing of cycling routes 15. Designing of inline skating routes 16. Designing of information areas 17. Designing of beachfront recreation spaces 18. Organization of picnic spaces 19. Dog walking

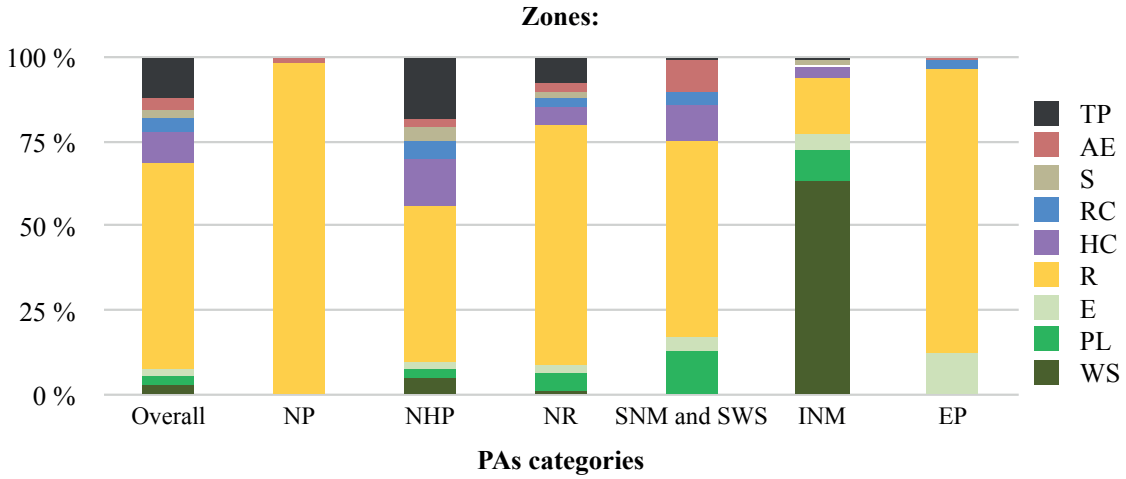

Fig. 4. Zones within Moscow PAs of different categories (for abbreviations of zones see Table 1). ***Estimated by the authors through the Bulletin of Moscow and Russia Protected Areas. *Botanical gardens are not included (zoning is almost absent)***

Wildlife sanctuaries, protected landscapes, excursion and education zones being under the strictest prohibitions are not widespread (7.8% of the total area), while recreation zones are the most common (60.5%) (Fig. 4).

The analysis of zones' dynamics within 12 large PAs has been focused on the PA "cores" – the sum of WS+PL+E zones of the strongest restrictions. There is no clear relation between PAs' categories and their cores' dynamics (Fig. 5).

The most excessive reductions took place in Elk Island National Park (Kryukov and Golubeva 2022) and Silver Pinewood nature monument.

1.2.2. Restriction's differentiation derives from the differences in prohibitions on land use within recreation zones. As an illustration, about 29% of the total recreation zones area in Moscow have no restrictions on maintenance and construction of utilities and motor roads, crowns pruning, use of mineral fertilizers, retail objects deploying etc., i.e., are under mild restrictions.

It is the most complicated way of downgrading that is difficult for laymen to reveal.

1.2.3. A sole case of downgrading from PA to protecting buffer green areas (PBGA) has been found within Silver Pinewood nature monument.

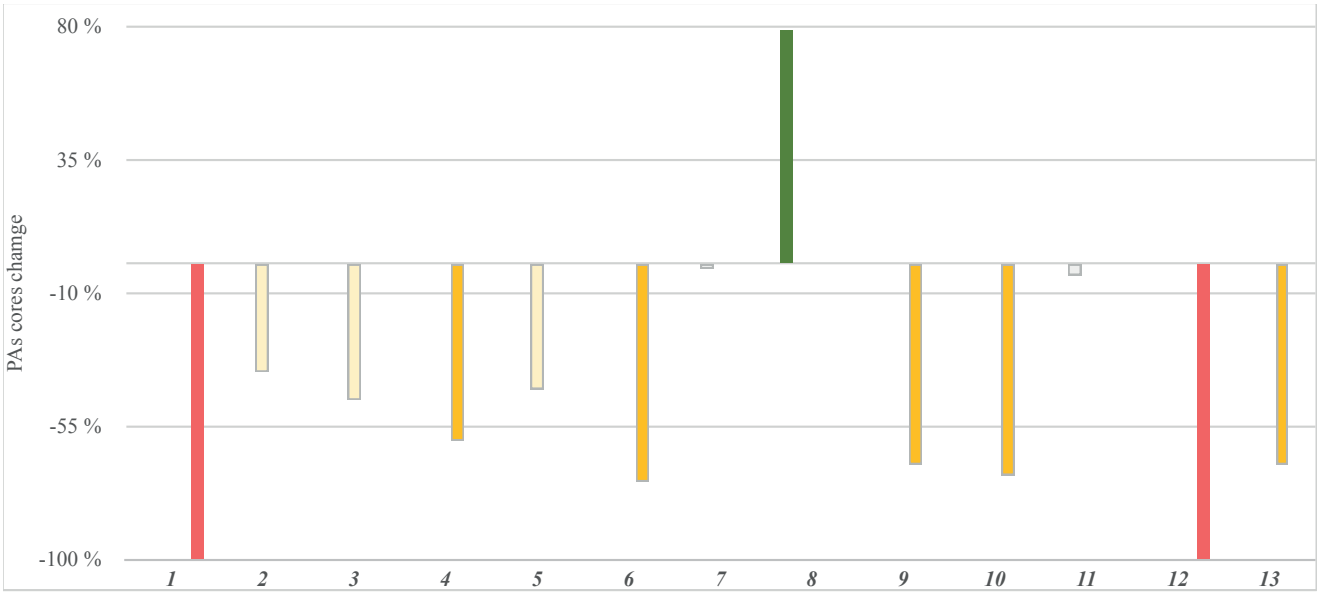

Fig. 5. PAs' cores change, % of the total sum (*1 – Elk Island national park; 2-8 – nature and historic parks: 2 – Bitcevsky forest, 3 – Izmaylovo, 4 – Tsaritsyno, 5 – Tushinsky, 6 – Kosinsky, 7 – Pokrovskoe-Streshnevo, 8 – Sokolniky; 9-11 – nature reserves: 9 – Setun valley, 10 – Tyoply Stan, 11 – Skhodnya valley in Kurkino; 12 – Silver Pinewood nature monument; 13 – overall value). Estimated by the authors using the Bulletin of Moscow and IAIS OGD data hub*

2. Downsizing

2.1. True downsizing is rare because of the legislative ban without offsetting. However, 11 PAs lost their parts occupied by garages in 2016 (about 0.5% of the total PA area at that moment) – "garage amnesty" (2.1.1). Such transformations allowed additional construction there, which may lead to an increase in human pressure on ecosystems. Borders of some inland nature monuments within large PAs have been transformed in 2020 *(2.1.2)*.

Only one downsizing case of protecting buffer zone *(2.1.3)* is known – around Elk Island National Park in 2022, despite the conservation ability of these zones.

2.2. Compensated downsizing occurs through all PAs' categories and is caused by transport and utility development *(2.2.1)* or the elimination of third-party land users *(2.2.2)*. There are no formal indications of adverse transformation, but compensation areas may have less strict restrictions than excluded areas.

3. Degazettment

3.1. True degazettment is the abolition of PA, established by the main entity of executive authority or by a court decision:

3.1.1. The elm in the square of Povarskaya street was cut down in 2013 because of an alarm condition, Dutch elm disease infestation, and the threat of fall on city dwellers[8];

3.1.2. Petrovsko-Razumovsky reserve lost its status in 2010 due to violations in design by regional authorities in the federally administered area[9].

3.2. Degazettment-reorganisation is related to the merging of two or more PAs *(3.2.1)*. Only nature monuments, mostly located within larger PAs and often overlapped, are exposed to this subtype (less than 0.4 % of the total transformations' area).

4. Design failures

Only 38 out of 112 PAs proposed in 2005, besides inland nature monuments and wildlife sanctuaries within other PAs, have been designed by 01.05.2022 – about 46% of the total proposed area. All cases fall into two subtypes.

4.1. Non-design. A lot of proposed PAs (65) have not yet been designed, occupying about 46% of the total reserved area. There is no information about their legal state and therefore these PAs are referred to as *totally failed (4.1.1)*.

The share of barren areas is quite large (5.9%) in these proposed PAs. Moreover, the significant increase in barren areas (+40.4% of 2001 value) and cultural landscapes occupied by woodland plantations (+86.5%) is revealed. Fragile grasslands have also dramatically declined within included PAs' parts (-38.3%) due to replacement by contemporary parks and secondary succession.

Deforestation of proposed, but not designed areas (2000-2020) affects little space, i.e., about 1.1% of the total area. However, 9 large PAs have a deforestation rate of more than 2%, especially one swamp with high biodiversity (7.1%) and the slope of the Moscow River valley (23%).

The most remarkable illustration of the *4.1.2 level (designing with significant reduction in proposed area)* is Kuskovo park, covering only about 12% of the initially proposed area.

4.2. Appending proposals. 9 of the proposed PAs were not established as separate but were appended to other, larger PAs. As a result, about 54% of the overall reserved area gained PA status. These transformations have taken place to compensate for exclusions from larger PAs.

Positive transformations (PA4P)

Some components of the PA4P model are similar to PA4D, but the numerous distinctions between them have been revealed (see Appendix A).

1. Upgrading and 2. Upsizing

Like full downgrading, ***full upgrading actions (1.1)*** are unknown in Moscow. ***Partial upgradings (1.2)*** are less spread than partial downgradings as opposed to partial upsizing-downsizing pair.

Cases of upgrading from the protecting buffer zone to a protected area (1.2.2) are unknown.

Two subtypes of upsizing are defined: ***true (2.1)*** and ***compensated (2.2),*** which makes up almost all upsizings (99.6%), while 2.1 is represented by upsizing two inland and one separated nature monuments (*2.1.1*) only. Upsizings of protecting buffer green areas are unknown (*2.1.2*).

Compensated upsizings are divided into inclusions of adjacent and nearby areas (*2.2.1*) or inclusions of distant areas (*2.2.2*). Such differentiation seems to be

[8]Available at: https://ria.ru/20130221/924143646.html [Accessed 5 Jun., 2022].
[9]Available at: http://sudbiblioteka.ru/vs/text_big3/verhsud_big_44789.htm [Accessed 5 Jun., 2022].

the most evident in assessing ecosystem value because the remoteness of green patches is strongly related to biodiversity loss (Benedict and McMahon 2006). Distant (more than 100 meters from PAs' borders or separated by large highways or railroads) upsizings are more common (75% of total area), which pinpoints issues in the effectiveness of nature protection.

The exclusion of highly deteriorated and transformed landscapes (*2.2.3*) within nature monuments has been carried out with a following increase in protected areas. Formal borderlines established earlier (e.g., the Moscow River floodplain has been designated as a rectangle with rounded edges) have been fixed by these changes in legislative acts.

3. Ad hoc design

The establishment of protecting buffer green areas around separated nature monuments in 2020 is considered to be the only case of such transformation (*3.1.1*), but not significant (about 0.2% of the total PAs' area). Other PAs' design cases not established by official plans are unknown.

4. Design of perspective

Multiple cases of ***direct PAs' design (4.1)*** are known in Moscow. However, many proposed parts may be finally placed beyond PA. It could be justified by an elaboration of development plans or detailing of biodiversity studies. Only 5.6 % of reserved PAs have maintained (5%) or increased (0.6%), while the others have decreased (48.8%) or failed (45.6%).

4.2. Indirect PAs' design – the establishment of the proposed area as other PA's part (appending). Moscow PAs' appendings have been entirely designated to compensate excluding parts within the current PA which a planned PA adjoined. Any appending aimed at the true PAs' expansion is unknown.

The high share of non-designed PAs reveals a disparity between the eco-positive strategy of the Moscow government and the actual state of proposed PAs: green areas with almost no prohibitions were mostly overused by recreation activities and various third-party stakeholders and consequently deteriorated.

Therefore, the essential results of our study are as follows:

•Adverse transformations affected a larger area than positive ones (53.8% of a total PA area compared to 22.6%).

•Adverse and positive transformations of PAs contributed by various components unevenly (Fig. 6). Positive transformations contributed by PAs' design (49.5%) mostly, while adverse ones – by easing of restrictions on land use (60.3%) and failures in the design of new PAs (22.8%) (Fig. 6). Adverse transformations are reflected mostly in downsizing of zones with the strictest prohibitions on land use (-68% on average), low share of designed PAs (54%), decrease in proposed PAs' area (up to 88%) through the period 2005-2022.

•Adverse vegetation transformations (2005-2021) affected areas where planned PAs have been failed. Semi-natural urban forests have been partially replaced by woodland plantations (+86.5%). Fragile grasslands declined considerably (-38.3%) within areas included in PAs. Barren areas increased within lands reserved for PAs' design (+40.4% of 2001 value).

DISCUSSION

It is proposed to expand the PADDD framework based on the multi-step qualitative and quantitative approach, including analysis of new PAs' design and its failures. Compared to worldwide statistics, the most common PADDD type is downgrading, making up 90% of the total transformations' number (Golden Kroner et al. 2019). There are multiple causes of downgrading dominance in Moscow as well:

• Direct law bans on downsizing without compensation (total PA's areas must not lower);

• Direct law bans on PAs' degazettment except for the vanishing of basic natural, cultural or historical objects;

• Active engagement of locals in continuous recreation, leading to a high interest in the sustainable condition of PAs. More complicated downgrading actions are much more difficult to reveal in law acts than degazettment or downsizing. Thus, government entities prefer this type of PA4D in case of some planned construction of transport, engineering, leisure, and sport facilities due to the shortage of free space.

As our study is the first implementation and advancement of this framework in megapolis, a few limitations should be clarified.

Some subtypes and levels are strongly related to the management system of the city analyzed: PAs' categories, number of zones, presence of inland nature monuments embedded into other larger PAs, existence of protecting buffer green areas but applied to separated nature monuments only, set of zones etc. Some of these features may be not elicited in other cities.

Detailed typology of urban ecosystems with subtypes delimitated by dominating tree species, succession stages, moisture gradients, levels of recreational pressure etc. or

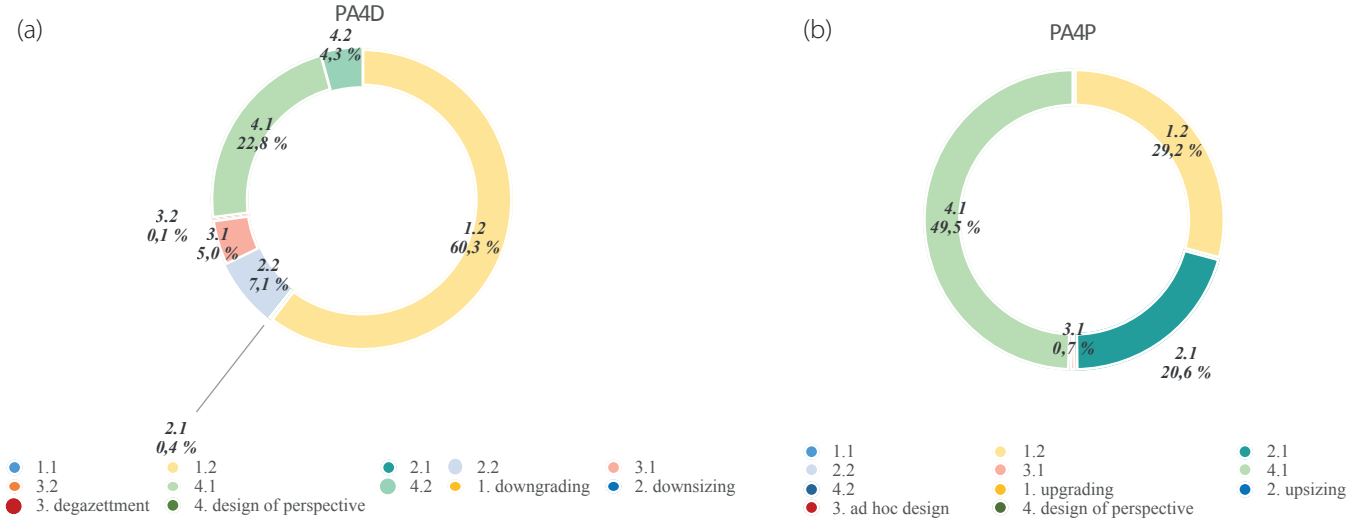

Fig. 6. PA4D (a) and PA4P (b) ratios.

Estimated by the authors on the basis of the Bulletin of Moscow, data hubs IAIS OGD and Russia Protected Areas

exhaustive land use maps have not been implemented as no unified and actual typology has been devised and applied to all study objects. At the same time, any spatial data following such typology may be harnessed for advanced analysis of transformations in other cities, e.g., covered by Urban Atlas 2018[10] or Saint-Petersburg (Khramtsov et al. 2016).

Moreover, not all transformations were mapped accurately as PAs' borders and zones are given sometimes as text descriptions or figures instead of coordinates in legislative acts, especially in older legislative acts. Another assumption regarding downgrading is that zones and zonal differences in restrictions on land use have not been articulated in acts of the 1990s and early 2000s, except Elk Island National Park.

Moscow has no open-access data about planned PAs' gestation (just proposed/scientific research was conducted/final establishment procedures etc.), but a model of PA's transformations should be advanced by it if possible.

It is important to mention that the 30-m spatial resolution of Landsat satellite imageries might be not sufficient to reveal small transformations of land cover within included or excluded areas that may be represented by narrow strings, e.g., overlapping cadastral parcels. At the same time, Sentinel-2 imageries with a spatial resolution of 10 m (bands B2, B3, B4, B8)[11] could not be used in studies covering lengthy periods as these sensors were launched in 2015 only. We assume that local field observations of these target areas would be more efficient and accurate to reveal actual land cover that may be quite dynamic.

The exact volume of transformations within protected areas of New Moscow adjoined to the city after 2012 has not been estimated. Instead of designing PAs new "specially protected green areas", covering more than 40% of converted space, have been established followed by less strict prohibitions and a high share of natural and semi-natural ecosystems, disturbed to a lesser extent than PAs which are closer to the city centre. To date, it is possible to downsize such areas in compliance with legal acts (TEEB-Russia 2021). PAs designed before 2012 are under ambiguous status currently – they have not been either degazetted or listed in official documentation anymore. This fact implies considerable limitations to a continuation of PAs' transformations analysis within actual Moscow boundaries.

Overall, it is necessary to note that the analyzed typology of Moscow PAs' transformations is quite conventional and may be improved through comparisons with other megapolises abundant in natural heritage.

CONCLUSIONS

The multidisciplinary approach, combining various methods from the fields of nature conservation, GIS, urban planning and environmental law, has been used to assess grave challenges for protected areas in megapolis. The outcomes of our study should develop an ecological awareness about the future of nature in cities as urban liveability may be considerably compromised by reducing of large green cores and corridors in the context of ecosystem services, global climate change, biodiversity decline, physical health and even mental crisis of urban dwellers (Peen et al., 2010).

By now, the biotopes' ability to supply ecosystem services is dramatically reducing, even though positive transformations have been also revealed. Regarding the planning of nature conservation, reserves for new PAs are extremely limited. Since 2005 a lot of severely transformed landscapes of a rather low biodiversity have been declared as protected areas. Such actions might be considered restoration of vegetation and water bodies, but the experience of recent years is rather questionable. The laying of new walkways accompanied by severe environmental disturbances as well as the construction of sport and entertainment facilities on the ruderal grasslands have become a core of so-called "land improvement" (TEEB-Russia 2021).

The typology of PAs' transformations devised is considered to be quite dynamic in future (as an illustration, cases of upgrading from the protecting buffer zone to a protected area are possible in future as the first protecting zones of nature monuments were established in 2020 only).

This study may be advanced by the following surveys:

- spatial comparison of our results with more detailed land cover dynamics, including data from forest inventories;
- implementation of PA4D-PA4P model into analysis of protected areas in New Moscow and other cities, covering marine areas as well;
- conjunction of legislative transformation analysis with field observations of urban ecosystems to reveal local trends;
- implementation of typology units (especially derived from downsizing) to management analysis of national parks beyond urban areas, as national parks commonly tend to be maintained through spatial zoning and a diverse set of restrictions on land use;
- economic evaluation of ecosystems' losses in the framework of ecosystem services;
- design of tradeoff model that should be applied in any cases of legislative transformations within protected areas.

All PAs' peculiarities mentioned above may be reflected in all cities of emerging and developed countries managed by state-led systems of spatial planning. Because of the greater disadvantages of emerging countries in environmental policy and the late design of PAs' networks, exploring the fourth component of PA4D seems to be more significant there. Moreover, current global and regional economic challenges will likely jeopardize PAs' design. Subsequently, our study may be continued provided that data on PAs of other cities are available. Besides that, such surveys may be focused on protected areas in cities not only with state-led systems of spatial planning, but market-led and conformative ones (Berisha et al. 2021; Bulkeley et al. 2021) as well to elicit differences and develop new ways to safeguard natural heritage.

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[11]European Space Agency. Sentinel Online. Available at: https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/resolutions/spatial

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