Evaluating threats to urban park ecosystems in megacities: a case study of effective environmental management strategies in Kyiv, Ukraine

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Abstract. A systematic assessment of the park ecosystems environmental threats has not yet been conducted. To address this knowledge gap, we focused on assessing ecological threats to parks in megacities, exemplified by Kyiv, Ukraine, against the backdrop of rapid urbanization and climate change. As the world's population increasingly resides in urban areas, the importance of parks as biodiversity hotspots and providers of ecosystem services becomes crucial. The aim of this research is to evaluate the ecological threats to park ecosystems in megacities, using the example of Kyiv, Ukraine, and explore possible links and long-term consequences of their impact. The research categorizes and evaluates 41 ecological threats, including salinization, war pollution, and desertification, impacting parks. A systematic approach combining integral analysis and expert assessments was employed in methodology. Findings reveal a complex interplay of threats, with physico-chemical impacts and pollution scoring highest in intensity and spatial distribution. The study highlights the need for adaptive management strategies, rapid threat assessments every 2-3 years, and collaboration with urban green space management authorities to safeguard biodiversity and ecosystem services amidst urban expansion and environmental challenges.

Keywords: Biodiversity, heat island, general threat index, parks, urban ecosystem, urbanization.

1. Introduction

Currently, 56% (4.4 billion) of the world's population resides in urban areas, and by 2050, this number is projected to reach seven billion (Pandey & Ghosh, 2023). Consequently, the study of urban ecology and ecology within cities, along with future forecasting, will become increasingly pertinent (Wilby & Perry, 2006; Giovacchini et al., 2024).

At present, the most serious threats to biodiversity in cities include climate change, urbanization, habitat degradation and/or loss, overexploitation of biological resources, biological invasion, and the spread of problematic species (Hulme, 2011; Salafsky &

Wollenberg, 2000; Giovacchini et al., 2024; Wilby & Perry, 2006; Pandey & Ghosh, 2023; Solarz et al., 2023), as well as the consequences of intensive agricultural practices, water pollution, and mismanagement. Climate change may exacerbate these issues through increased competition from exotic species, the spread of diseases and pests, summer drought stress on wetlands and forests, and rising sea levels threatening rare coastal areas (Wilby & Perry, 2006; Pandey & Ghosh, 2023).

In our research, a park ecosystem is defined as a natural or anthropogenic, semi-natural, and human-subsidized ecosystem with a tree stand or woody-shrub phytocoenosis, within which natural components, landscape complexes, and small architectural forms and structures can be spatially organized and harmonized into a system connected by a road and transport network, creating a specific architectural landscape object. Its natural resilience and structure are maintained by humans to ensure the ecologically balanced development of the urban ecosystem (Miroshnyk et al., 2023). Therefore, diagnosing disturbances in their condition, as well as the existence and preservation of ecological functions, poses a complex task.

Park ecosystems (PE) serve as distinct biodiversity hotspots within urban ecosystems, contributing to their stabilization, improvement of microclimate, and prevention of undesirable phenomena (such as floods, landslides, soil erosion, formation of significant surface depressions, fires, smog, etc.) by interrupting built-up and heavily transformed landscapes with semi-natural ecosystems. In cities, they can be utilized to counter climate-related threats to biodiversity, improve flood control and air quality, as well as mitigate the impact of heat islands in cities (Wilby & Perry, 2006; Sparks et al., 2011; Pandey & Ghosh, 2023). PE provide ecosystem services in cities, including regulating and supporting ecosystem services, reducing critical emissions into the environment, and influencing soils, water resources, landscapes, and biodiversity. They have the greatest potential for mitigating the consequences of climate change and adaptation to some loss of forest environment conditions (Cao et al., 2021; Pandey & Ghosh, 2023). PE provide unique ecosystem services for biodiversity conservation in cities (Cao et al., 2021), ensuring landscape continuity, air purification, urban ecosystem stabilization, and are also crucial for public health preservation. Biodiversity in the PE of Kyiv is significant, with many protected species of insects, including bees, and birds (Miroshnyk et al., 2023), indicating the importance of PE as providers of pollinator services and ecosystem stabilization.

Over the 20 years, urbanization in Kyiv has increased by 14%, while the temperature within the city has risen by 5°C compared to its outskirts (Ukraine. Urbanization Review, 2015; Boychenko et al., 2017). Therefore, it is necessary to assess the strength of the impact, duration of influence, and scale of threats to park ecosystems in megacities, using the example of Kyiv, as well as explore opportunities for expanding park areas for more effective biodiversity conservation, developing urgent solutions, and further managing urban systems.

Anthropogenic pressure has led to an increase in the ratio of species extinction processes to evolutionary diversification. Human activity has altered the balance – the rates of species extinction have increased by 1000 times, and this figure could rise to 10,000 compared to background levels, as species under threat of extinction are dying due to anthropogenic pressure. Evolutionary change principles should be considered by scientists, taking into account the stressful conditions in which organisms find themselves due to direct and indirect consequences of climate change and habitat fragmentation. The application of the concept of evolutionary resilience, studying evolutionary processes at the ecosystem level, should contribute to the conservation of biodiversity and landscapes (Sgrò et al., 2010).

Preservation of biodiversity and disappearing habitats in the face of climate change is an important direction of ecological research to fulfill the strategy of conserving all life on Earth (Olson et al., 2002; Salafsky et al., 2008) and the EU Biodiversity Strategy 2030 for sustainable development strategies. Anthropogenic impact deeply fragments landscapes worldwide, altering the quality and connectivity of habitats (Noss, 1999; Balvanera, 2001; Haddad et al., 2014; Haddad et al., 2015; Upal et al., 2015; Wilson et al., 2015). Scientists have conducted assessments of global threats to understand where risks arise, the speed, intensity of their development, and to find out predictions for preventive measures (Salafsky & Wollenberg, 2000; Midgley et al., 2002; Upal et al., 2015; Assessment and Directions, 2003; Giovacchini et al., 2024).

The intensity of some threats in urban ecosystems is heightened, such as industrial and biological pollution, physical destruction (Giovacchini et al., 2024; Firoozi et al., 2025), destruction and threats due to war (Shupova & Kratenko, 2025), changes in soil-lithogenic base compared to natural ecosystems, while some are not immediately destructive, such as poaching, deforestation, and peatland drainage.

Theoretical principles for assessing and preventing threats to biodiversity in Ukraine have been developed by O.V. Dudkin, An.V. Yena, V.V. Lavrov, and others (Assessment and Directions, 2003). They evaluated threats to biodiversity in Crimea in various aspects by Yu.R. Shelyag-Sosonko, Ya.P. Didukh, and others (Shelyag-Sosonko, 1998; Blinkova, 2012); V.I. Shcherbak and others focused on hydroecosystems using the example of the Shatsky National Natural Park (Shcherbak et al., 2013). However, an assessment of threats to park ecosystems has not been conducted. Therefore, **the aim** of this research is to evaluate the ecological threats to park ecosystems in megacities, using the example of Kyiv, Ukraine, and explore possible links and long-term consequences of their impact.

2. Materials and methods

The methodology for assessing threats to park ecosystems uses a systematic, structural, and interdisciplinary approach, enabling the consideration of the urban ecosystem as a multi-level and unified whole with the coordinated functioning of all its elements, with parks being its structural components. To investigate the impact and relationships of ecological threats on the state of PE, and to identify the spatial dynamics of threat impacts, methods of integral and comparative analysis, impact ranking, analytical and mathematical processing of factual data were utilized. Threat classification was conducted according to the Danish approach (Stein, 2002; Assessment and Directions, 2003) with adaptation to the research objects (Miroshnyk et al., 2019 Table 1) and considering the general classification of the World Conservation Union–Conservation Measures Partnership (IUCN-CMP) (Salafsky et al., 2008), where a direct threat is defined as immediate (anthropogenic) activity that has caused, or may cause destruction, degradation, and/or deterioration of the biota habitat and natural processes. Our compiled list of major ecological threats consists of 41 factors, which are tentatively divided into 6 groups: I) 1–4 – disruption of hydrological regime; II) 5–13 – mechanical impact on biodiversity; III) 14–23 – physico-chemical impact; IV) 24–35 – changes in soil-lithogenic base; V) 36–37 – pollution; VI) 38–41 – disturbing and other factors.

Table 1. Types of threats to PE biodiversity

Group	Types of threats
I. Disruption of hydrological regime	1. Salinization
	2. Swamp formation
	3. Flooding (Flood)
	4. Drainage
II. Mechanical impact on biodiversity	5. Grazing
	6. Mowing
	7. Recreational pressure
	8. Fires
	9. Logging, destruction of plants by other means
	10. Collection of berries and medicinal plants
	11. Poaching

	12. Afforestation of areas unsuitable for crops
	13. Plowing
III. Physico-chemical impact	14. Municipal and household waste and wastewater
	15. Landfills
	16. Railway, automotive, aviation transport
	17. Power lines
	18. Industrial pollution
	19. Agricultural pollution (especially from animal husbandry and aquaculture)
	20. Military pollution
	21. Main and other pipelines
	22. Radioactive contamination
	23. Energy, noise, electromagnetic pollution
IV. Changes in the edapho-lithogenic basis	24. Erosion
	25. Quarries
	26. Desertification
	27. Sely
	28. Landslides
	29. Abrasion
	30. Soil extraction
	31. Extraction of minerals (sand, gravel, peat, etc.)
	32. Water intake from reservoirs
	33. Railways, highways, airports
	34. Residential construction and urban areas
	35. Industrial zones
V. Pollution	36. Biological pollution (alien species)
	37. Genetic pollution
VI. Disturbing and other factors	38. Disturbing factor
	39. Land encroachment
	40. Climate change due to urbanization (climate aridity, extremely high and extremely low temperatures, etc.)
	41. Fragmentation of species habitats

Threat 1 – Salinization. This threat refers to salinization caused by anti-icing agents in winter. In Kyiv, many trees along roadsides die due to this threat.
Threat 20 – War pollution: This considers the consequences of military actions in Ukraine, such as physical destruction of plantings and mechanical damage to trees due to explosions and fires, shrapnel wounds to trees leaving traces for many years, significant soil and substrate disturbances due to bombings, destruction of dams and reconstruction of hydroecosystems affecting significant areas for tens of square kilometers, consequences of significant internal population migration resettling in regions where there are no bombings, there by redistributing recreational pressure to PE in Ukrainian cities.
Threat 26 – Desertification. It indirectly considers the impact of urbanization. In large cities, the temperature inside is 1.5-5 degrees higher than in the surrounding area (heat island effect), modeling climate change and warming associated with it, which causes, for example, plant flowering in winter, wintering of migratory birds in megacities, processes of synanthropization and adventization of vegetation, etc.
Threat 29 – Abrasion. This includes soil erosion processes from unprotected slopes and the process of destroying shores and removing rocks in the coastal zone of water bodies by waves and surf.
Threat 34 – Residential construction and urban areas: Illegal construction on coastal and protected areas (e.g., construction on the slopes of the Dnipro River and territories of national parks).
Threat 36 – Biological pollution (alien species). This considers introduced tree species (such as *Ailanthus altissima* (Mill.) Swingle, *Robinia pseudoacacia* L., *Quercus rubra* L.), which can interfere with local plant successions for Italy (Giovacchini et al., 2024) as well as for Kyiv. It is known that invasions of alien species can contribute to the occurrence of extreme climatic events (Diez et al., 2012; Solarz et al., 2023), which are characteristic of megacities.

Since it is difficult to isolate the impact of each factor on ecosystems and consider interactions both within ecosystems and between them and the surrounding natural environment, the authors (Assessment and Directions, 2003; Stein, 2002; Giovacchini et al., 2024) propose evaluating each ecological threat in points according to three criteria: intensity of action, spatial distribution, and assessment of the time factor of the threat. The intensity of action is assessed as follows: 1 – weak, 2 – moderate, 3 – significant, 4 – strong, 5 – very strong; spatial distribution of the factor: 1 – local, 2 – within a certain type of ecosystems, 3 – regional, 4 – common for the research area, 5 – global. The time factor of the threat was assessed as: 1 – the ecosystem recovers quickly, almost immediately after the removal of the influence; 2 –

within a year, 3 – within 10 years, 4 – recovery is unsatisfactory, 5 – does not recover at all. For the quantitative assessment of the overall impact of threats on PE and comparison of the intensity and scope of their impact, the overall hazard index was calculated as the product of points of intensity, spatial distribution, and the time factor of the threat (Blinkova, 2012).

The next step involved calculating the class interval size using the formula (Shoukri & Pause, 1999):

$$C = \frac{[(X_{max} - X_{min}) \cdot \lg 2]}{\lg N}$$

where: X_{max} is the maximum value of the general index; X_{min} – the minimum value of the general index; N is the sample volume, corresponding to the number of values of the general index within the interval (min ÷ max) (Fig. 1). Construction of charts was carried out with the help of M. Excel, Statistica 10 programs.

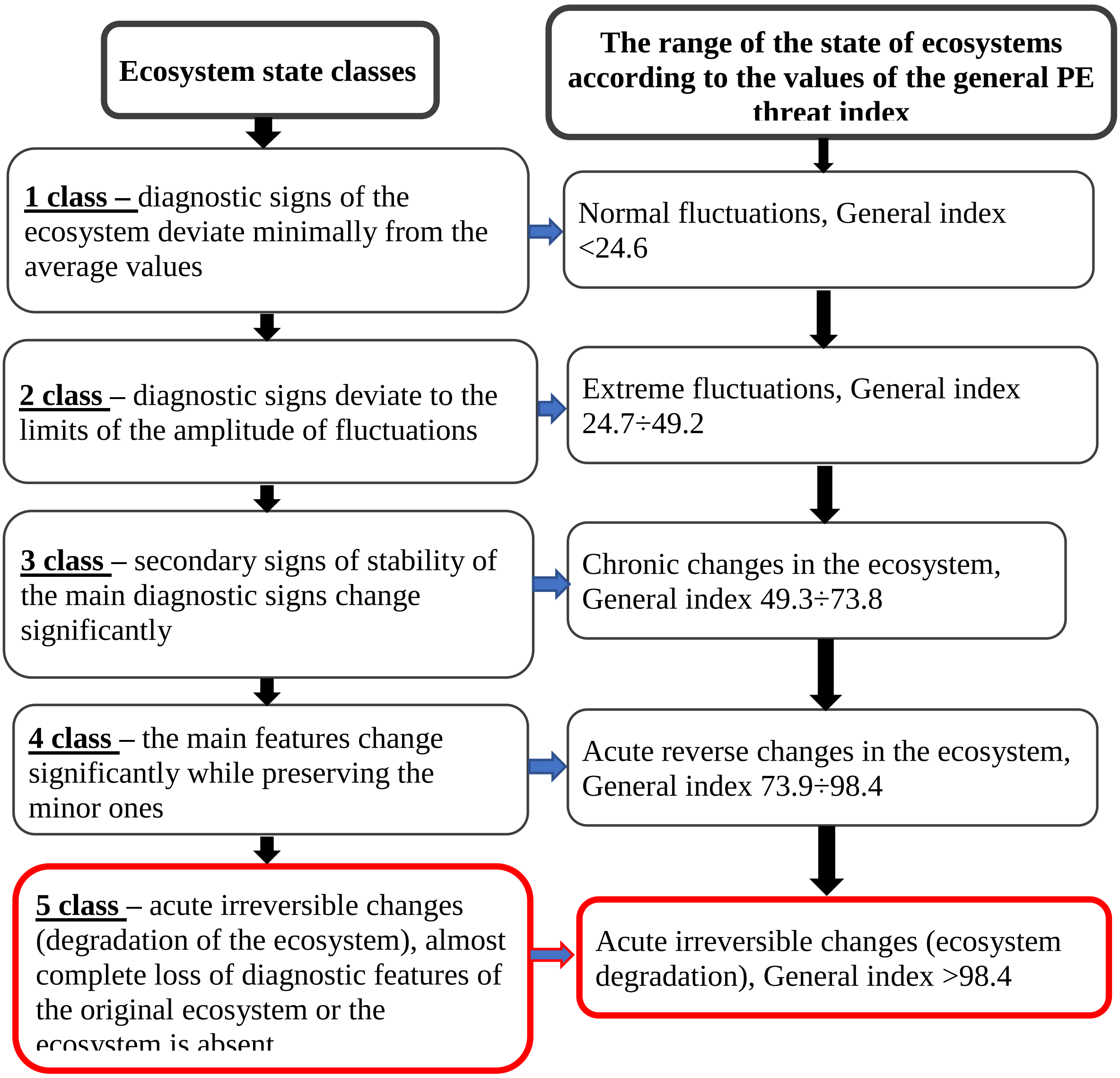

Figure 1. Classes of ecosystem condition based on the values of the general index of threats to Pes

3. Results

The characteristics of urban green spaces serve as indicators of the ecological balance of the urban environment and act as stabilizers of its condition. Assessing these characteristics requires a systematic and multi-criteria approaches. However, as complex systems, parks are subject to the laws governing such systems, exhibiting both simple (additive) and complex (non-additive) properties. It is usually difficult to assess the extent of damage and the limits of ecosystem resilience. This is due to the cumulative and additive effects of threats on urban green spaces, combined with variations in the speed and ability of these ecosystems to recover after impacts, which depend on the sensitivity threshold of the most vulnerable biota components. Addressing this issue involves employing expert assessments (Assessment and Directions, 2003; Giovacchini et al., 2024) to decompose the problem into components, which are then given a numerical rating. The sum or product of these ratings enables the comparison of objects or the state of an object across different time intervals (Fig. 2).

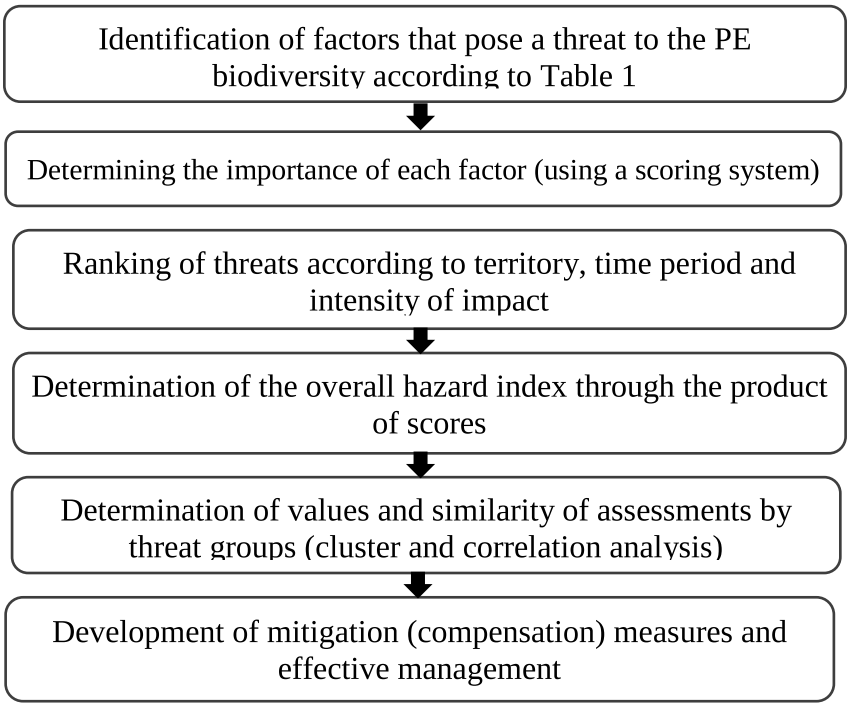

Figure 2. Algorithm for assessing threats to PEs biodiversity

The characteristics of intensity of action, temporal factor, and spatial spread do not have clear synchronization (Fig. 3). For instance, the most intense factors, such as flooding and recreational pressure, are often short-term, while the impact of power lines and main pipelines is the least pronounced.

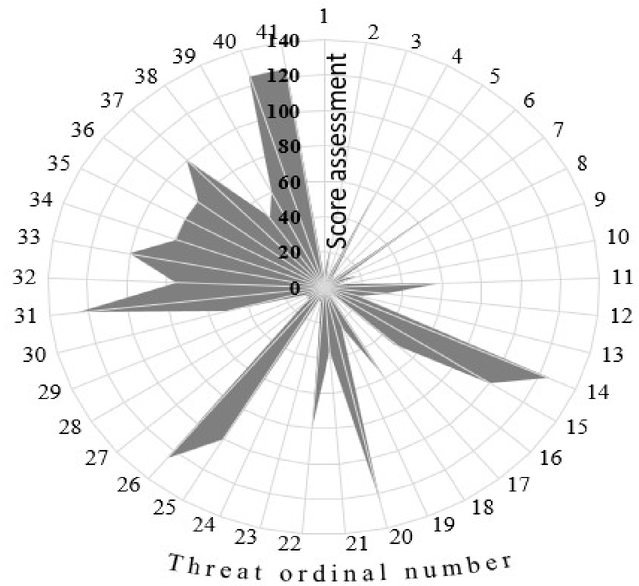

Figure 3. General Index of Environmental Threats Hazard for Pes

The analysis by threat groups revealed a shift of values to the right towards specific impacts on the environmental components (pollution, disturbing factor, changes in the edapho-lithogenic base) (Fig. 3). The groups of threats scored the highest number of points for the intensity of influence: physico-chemical impact, changes in the edapho-lithogenic base, disturbing and other influences (4.2–4.8 points); for spatial distribution: disturbing and other factors, pollution (4.5–5.0 points); for the time factor: disturbing and other factors, pollution (4.0–4.5 points) (Fig. 4, 5).

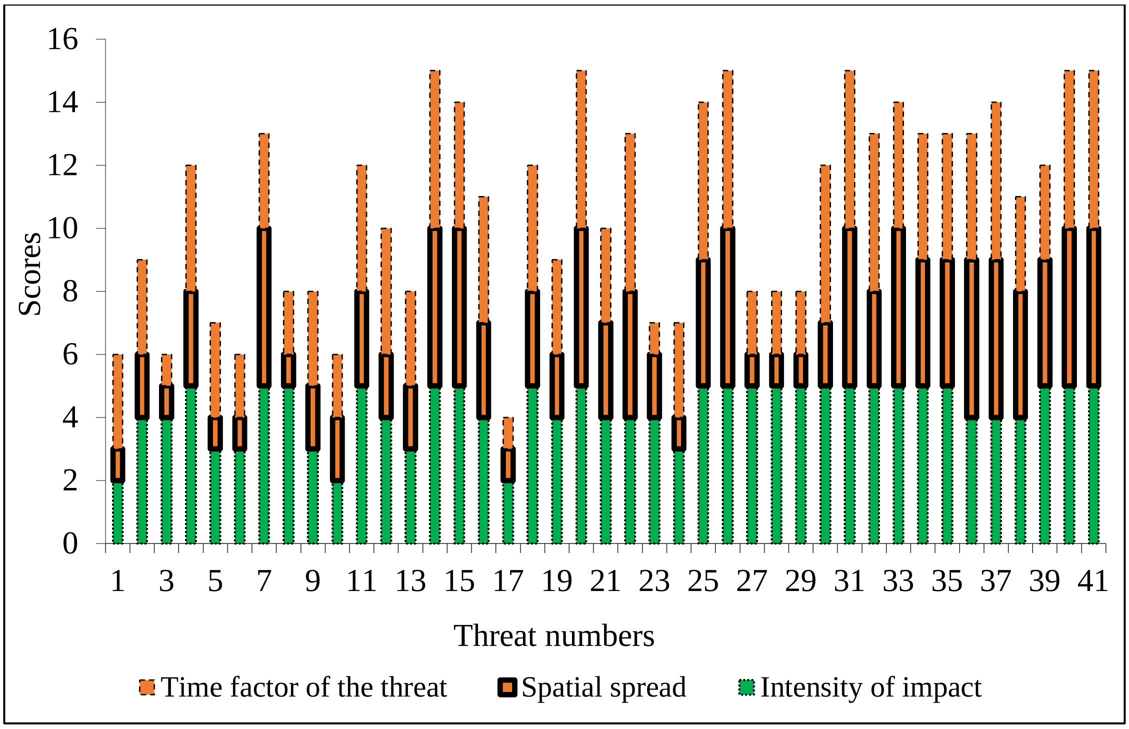

Figure 4. Rating of the intensity of action, spatial distribution, and temporal factor of threats

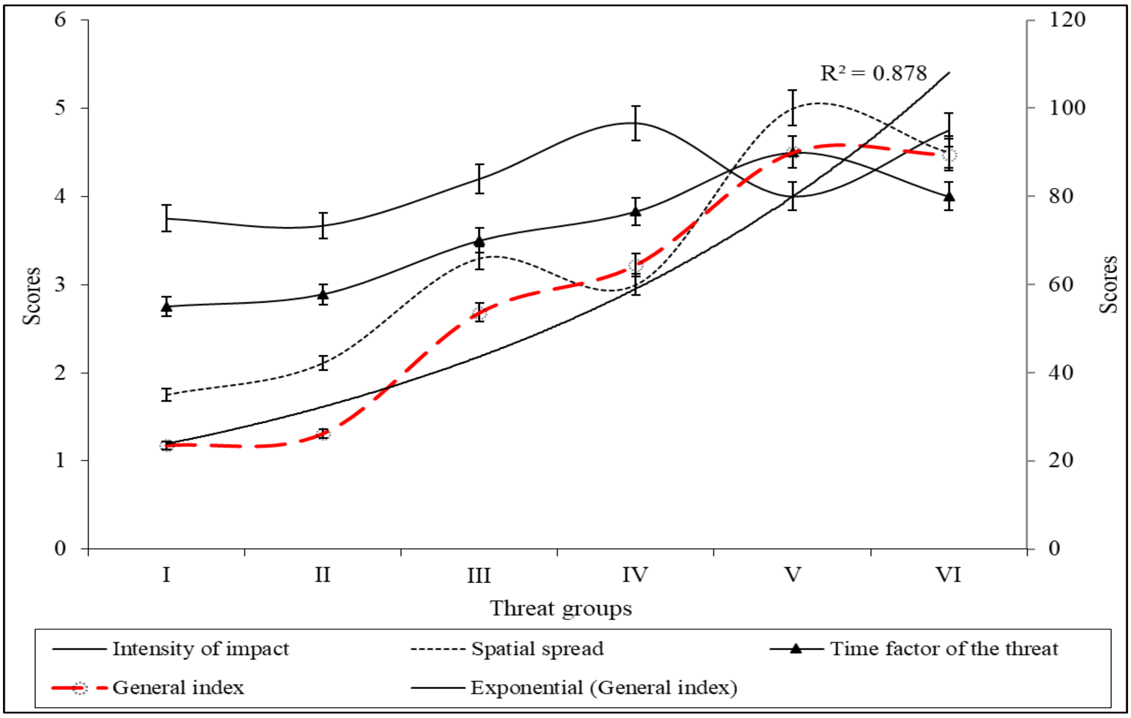

Figure 5. Characterization by Threat Groups: I - disruption of hydrological regime; II - mechanical impact on biodiversity; III - physico-chemical impact; IV - alteration of soil-lithogenic base; V - pollution; VI - disturbing and other factors

According to the overall hazard index, the most intensive impacts specific to urban ecosystems include phenomena such as drainage (caused by lowering the groundwater level), recreational pressure, municipal solid waste and wastewater, desertification, extraction of natural resources (sand, gravel, peat, etc.), urban climate changes due to urbanization (climate aridity, extremely high and extremely low temperatures, etc.), and habitat fragmentation for species (Fig. 3).

Based on the values of the overall threat index, we assessed the range of ecosystem conditions (Fig. 1). Class 1 includes 16 threats (39%), the main of which are associated with groups of hydrological regime disturbances and mechanical impacts on biodiversity. Class 2 comprises 4 threats (9.8%), including afforestation of areas unsuitable for crops, railway, automotive, and aviation transport, major pipelines, and disturbing factors (recreational pressure-induced disturbance).

Class 3 encompasses 5 threats (12.2%) – drainage, poaching, industrial pollution, soil extraction, land grabbing. Since Class 3 is the threshold of irreversibility of processes, when the removal of pressure (changes in intensity or reduction of exposure time) 25 threats (61%) ecosystems can restore their condition. Class 4 includes 5 threats (12.2%) that cause acute reversible changes in the ecosystem – recreational pressure, radioactive pollution, industrial zones, biological pollution (adventive species).

Class 5 includes 10 threats (24.3%) causing acute irreversible changes (ecosystem degradation), characterized by maximum index values. These include municipal solid waste and wastewater, military pollution, quarries, desertification, extraction of natural resources (coal, peat, iron ore, etc.), railways, highways, airports, genetic pollution, urban climate changes due to urbanization (aridity, etc.), habitat fragmentation for species.

To avoid the manifestation of the law of critical values of the factor and the limiting factor principle, which is an inevitable negative effect of aggregating integral indices when they are applied to assess complex open biological ecosystems, it is recommended (Shoukri & Pause, 1999) to use Euclidean distance as a claster analisis metric space (Fig. 6). According to the conducted cluster analysis, the most intensive impact is exerted by threat groups such as physico-chemical impact, pollution, changes in the edapho-lithogenic base, disturbing factors, and other factors (Fig. 6).

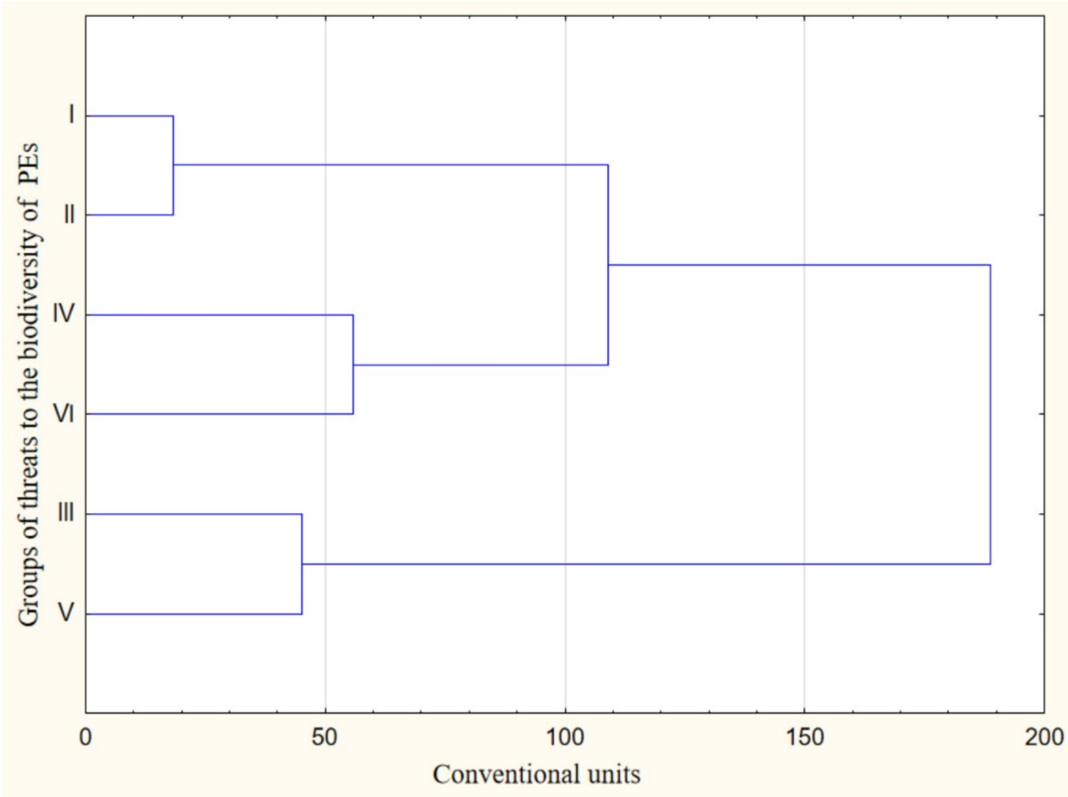

Figure 6. Clustering based on the values of the overall index of threat danger to PEs

The relationship between intensity, spatial distribution, and temporal duration of threats is highly complex; as these connections strengthen, the cumulative impact of threats increases (Fig. 7). If the intensity of the impact is strong but the duration is short, or if the spatial distribution is significant but the intensity is weak, then ecosystems quickly recover after the negative influence is removed. An exception is the unpredictability of the consequences of military impact, as mined areas of the environment will recover rapidly due to the absence of disturbance factors. At the same time, excessively strong impacts from bombings that lead to the disruption of deep soil layers or the destruction of dams and cause changes in the landscape hydrological regime will have consequences for decades.

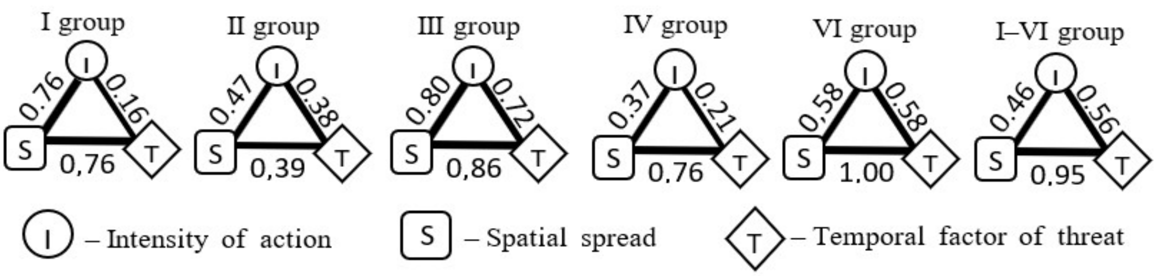

Figure 7. Correlation criteria for assessing threats to PEs

Regarding correlation relationships along two vectors – by threat groups and characteristics – in the II group of threats, the connections between intensity, time, and spatial factor are weak. In all other groups, the strongest correlations are between spatial distribution and the temporal factor (0.8–0.95), while the weaker ones are with the intensity of the threat (0.16–0.56). The strongest correlation, based on overall values (I–VI groups), is between spatial distribution and the temporal factor of threats.

The distance to intensive influencing factors, location in densely populated areas or on the outskirts of cities, the type of PE (plain, sloping, floodplain-terraced, floodplain), class (forest parks, garden-parks, botanical gardens), and the character of plantings reflecting the level of stability and resilience of the ecosystem are all conditions that should be taken into account when assessing the consequences.

4. Discussion

Assessing environmental threats in urban ecosystems is complex due to multiple interacting factors and varied ecosystem responses. Indirect and combined effects are especially difficult to isolate. Understanding emergent ecosystem properties such as stability, resistance, inertia, self-organization is essential for predicting and managing responses to these threats.

Human activities in cities, such as replacing dead trees with new plantings, establishing new parks, artificial irrigation, have a supportive effect, although they do not have a decisive impact on the state of the environment.

Social-economic threats also exert direct and indirect negative influences – violations of laws regarding land alienation for construction, changes in ownership, safety requirements for construction, corruption, poverty, inadequate levels of environmental education, educational activities, administrative management imperfections, ultimately leading to catastrophic reductions in greenery in cities, the loss of environmental quality, and the deterioration of urban systems, especially in megacities.

It is recommended to organize a network of paths to prevent uncontrolled recreation (Giovacchini et al., 2024). However, if the urban green spaces are located in densely populated areas of a megacity, this may provide little assistance, and uncontrolled visitor recreation, excessive workload can lead to significant disturbances, soil compaction, and reduction in canopy density.

Among threats considered insignificant, grass cutting on urban green spaces (lawns) has been mentioned (Giovacchini et al., 2024). However, based on our data, this is an intensive threat hindering the regeneration of urban greenery and stable functioning due to the structural disruption of understory vegetation, promoting synanthropization and adventization of the plant cover, reducing insect and bird biodiversity by destroying habitats and food sources (Miroshnyk et al., 2022).

We have assessed the degree of military influence, the risk of escalation of military actions, the level of internal migration, and indirectly the state of urban green spaces in two cities in Ukraine – Chernihiv and Vinnytsia (Miroshnyk, 2023). Significant transformative impacts of military actions on urban green spaces have been identified.

The analysis of threats has a significant drawback – due to the lack of analytical data, expert judgments may be biased due to subjectivity. The strengths of threat assessment include low cost, high speed, and uniformity, considering the specificity and difficulties of assessing large open ecosystems. It is also important that threat assessment provides a preliminary rapid evaluation for making quick decisions in management and planning, as well as feedback on the effectiveness of decisions made. Such rapid assessment can be conducted every 2-3 years, which promotes adaptive and effective management. It will enable timely forecasting changes and preventing catastrophic events, contributing to the preservation of biodiversity and the provision of other ecosystem services. We recommend conducting a threats assessment for urban green spaces every 2-3 years and collaborating with institutions responsible for urban green space management for better planning of conservation and management measures, creating new urban green spaces in newly developed areas of Kyiv (for example, the Obolon district), and better and timely response to destructive processes in urban green spaces (such as slope collapses due to water erosion, drying of plantings due to diseases and pests, etc.).

5. Conclusions

Thus, the main ecological threats to park ecosystems in megacities have been formulated and evaluated using the example of Kyiv, Ukraine. Some methodological aspects regarding threat assessment criteria have been deepened. Classes of each threat severity have been identified, and the overall threat index has been calculated. The characteristics of the intensity of impact, the temporal factor, and the spatial distribution factor do not have clear synchronization. The analysis revealed that the most critical threats to urban park ecosystems include municipal waste, military pollution, desertification, and habitat fragmentation – each scoring high in intensity, spatial extent, and long-term impact. Additionally, factors like salinization and grazing, though less severe individually, contribute cumulatively to ecosystem degradation. The application of cluster analysis allows somewhat mitigating the negative effects of the aggregated threat severity index. According to its results, the most intensive impact is exerted by threat groups such as physical-chemical impact, pollution, changes in the soil-lithogenic base, disturbing factors, and others (including the impact of military actions).

The correlation between the intensity, spatial distribution, and temporal factor of threats is highly complex: as the tightness of the connection increases, the cumulative effect of threats grows. The presence of a correlation relationship has been proven, based on overall values (I–VI groups), between spatial distribution and the temporal factor of threats.

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