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Biodiversity of specially protected and unprotected urban water bodies: case of the water fleas (Crustacea: Cladocera) of Moscow City (Russia)

Биоразнообразие городских водоемов, имеющих охранный статус и не имеющих его: пример ветвистоусых ракообразных (Crustacea: Cladocera) города Москвы (Россия)

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КЛЮЧЕВЫЕ СЛОВА: городская экология, анализ списков видов, зоопланктон, Европа.

ABSTRACT. We analysed zooplankton samples collected in small water bodies in the territory of “Old Moscow” in autumn months of 2020 and 2021; also, additional material from collections dating back to 1998 was examined. Of the 148 studied water bodies, at the time of sampling, 70 were located within the boundaries of the specially protected natural areas of the city, 78 were located outside them. A total of 47 species of water fleas (Crustacea: Cladocera) were identified, 40 species were found in unprotected and 40 — in protected water bodies. The fauna of both protected and unprotected areas demonstrates a high similarity, while the number of species per water body for protected areas is significantly higher. Especially remarkable is absence of a correlation between the species richness and water body size in unprotected area; in contrast, such correlation is significant in protected areas. We propose a “lottery model” to explain a paradoxical situation of correlation absence between species diversity and the surface area in unprotected water bodies.

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РЕЗЮМЕ. В работе проанализированы пробы зоопланктона, отобранные в малых водоемах на территории «Старой Москвы» в осенний период в 2020–2021 гг. с прибавлением материала из коллекций, собранного с 1998 г. Из 148 изученных водоемов, на момент отбора проб 70 располагались в границах ООПТ города Москвы, 78 — за их пределами. Всего нами выявлено 47 видов ветвистоусых ракообразных, по 40 видов в водоемах, имеющих и не имеющих охранный статус. Фауны обоих типов водоемов демонстрируют высокое сходство, в то время как количество видов на водоем для охраняемых территорий значимо выше. Примечательно отсутствие корреляции между видовым богатством и размером водоема на неохраняемых территориях; напротив, на охраняемых территориях такая корреляция значима. Мы предлагаем «лотерейную модель» для объяснения парадоксальной ситуации отсутствия корреляции между видовым разнообразием и площадью водоема в неохраняемых водоемах.

Introduction

Anthropogenic activities in the industrial period have led to a strong (and cumulative) pressure on terrestrial and aquatic ecosystems [Matthews, 2016]. Multiple stressors include, among others, human-mediated climate change, pollution by toxic substances, an increase in nutrient input due to agriculture and urban development, hydrological alterations, and invasive species introduction [Lanka *et al.*, 2024]. Consequently, freshwater ecosystems experience deterioration, demonstrating the decline of ecosystem services provided, such as reduced local biodiversity and poor water quality. The global urban population exceeded the rural population already in 2008. It is expected by the United Nations experts, that two thirds of the world population will live in urban areas by 2050 [Anonymous, 2025a]. It means that the study of urban landscapes and the water bodies within them is becoming an increasingly important part of our understanding of a life in human-transformed environment. Extensive literature describes various patterns that determine the biological diversity in cities.

Cities worldwide are characterised by unique human stressors that induce species filtering based on stressor traits, potentially leading to biodiversity loss [Fournier *et al*., 2020]. Species richness in a city is influenced by contradictory factors [Klausnitzer, 1987; Elmqvist *et al*., 2013; Feoktistova *et al*., 2013; Szulkin *et al*., 2020]. For some taxonomic groups, even a greater species richness has been shown in anthropogenic landscapes as compared to natural ones [Dearborn, Kark, 2010]. A loss of species richness takes place in urban territories, since the habitat are changed under anthropogenic pressure. At the same time, invasive and synanthropic species add a city fauna. Changes in urban water bodies can have a various nature; also, basically new habitats are created in the cities. Traditionally, maximum attention in urban ecology is focused on anthropogenic pollution, first of all, chemical (nitrates, metals, surfactants), thermal [Szulkin *et al*., 2020], and light [Klausnitzer, 1987] ones. Most recent reports on urban biodiversity have focused on higher plants [Dylewski *et al*., 2023], insects [Fournier *et al*., 2020], mammal and avifauna [Tikhonova *et al*., 2009; Ventura *et al*., 2024; Garizábal-Carmona *et al*., 2024] and soil communities [Yurkova *et al*., 2009].

Less attention is paid to inhabitants of urban water bodies, namely zooplankton, although it is used routinely as a model for understanding of anthropogenic impacts on aquatic ecosystems [Pinel-Alloul, Mimouni, 2013; Mimouni *et al*., 2015; Chen, 2020; Evgrafov *et al*., 2023]. It is demonstrated that urban ponds with a low level of human disturbance harbor richer zooplankton communities relative to highly disturbed ones both in temperate and tropical areas [Jantawong *et al*., 2024]. However, different groups of zooplankton could demonstrate opposing trends when eutrophication level increases [Chen, 2020].

Water fleas (Crustacea: Branchiopoda: Cladocera) represent one of the most numerous groups of microscopic invertebrates inhabiting freshwater bodies. They are used as models in biological monitoring of ecosystems and in toxicological tests [Smirnov, 2017; Korovchinsky *et al*., 2021a]. Cladocera respond well to bottom-up factors, such as changes in water quality and nutrients, algal blooms, and aquatic vegetation and top-down factors, induced by fish and macroinvertebrate predation [Gelinas, Pinel-Alloul, 2008]. Cladoceran resting eggs are resistant to drying or freezing, they also serve as a source for rapid pond re-colonization. Ability to reproduce parthenogenetically allows cladocerans to increase their number very rapidly [Korovchinsky *et al*., 2021a]. Cladocerans are among key animal groups for pond restoration: large-bodied daphnids are efficient grazers of algae and may strongly enhance water transparency in shallow lakes and ponds [Peretyatko *et al*., 2010; Chen, 2020].

Moscow is the capital and largest city of Russia, "with a population estimated at over 13 million residents within the city limits, over 19.1 million residents in the urban area, and over 21.5 million residents in its metropolitan area" [Anonymous, 2025b]. The extensive system of specially protected natural areas in Moscow occupies up to 18% of the territory of "old Moscow" [Sobolev, 2022]. It obviously does not provide protection from all types of pollution to the same extent, but it is aimed at solving two virtually interrelated problems [Anonymous, 2025c]:

(1) Preservation of valuable natural habitats and communities, rare and endangered species of plants or animals, other objects of living and inanimate nature and, at the same time,

(2) Implementing the legal functions in order to increase the recreational potential of territories for public health [Anonymous, 2025d].

Moscow Urban Development City Plan until 2035 [Anonymous, 2016] uses the term "natural framework" to designate these legal functions, and incorporates territories with different protection regimes. The "natural framework territories" are opposed to the "urbanized framework territories", and (together with the "recreational framework territories") form a "natural-recreational framework". The duality of the functions of urban protected areas, which combine the roles of a refugium for species inhabiting urbanized territory [Klausnitzer, 1987] and recreational facilities, leads to the fact that both legally required measures to preserve the existing environment and measures to adapt the environment to recreational needs are carried out there [Anonymous, 2025e]. This duality creates a special interest for studying species diversity of urban protected areas.

Most studies of urban fauna of Moscow City also are focused on plant, soil communities, or avifauna [Avilova, 2009; Gorbacheva *et al*., 2021]. At the same time, the territory of Moscow has only recently attracted the attention of carcinologists [Mityaeva *et al*., 2024]; only some aspects of the cladoceran diversity in Moscow have yet been discovered.

The aim of this work is to compare the species diversity and composition of water fleas found in small water bodies in the city of Moscow in specially protected and unprotected areas of the city.

Material and methods

We have analysed 155 qualitative samples collected from 148 water bodies in the territory of "Old Moscow" (historical territory of Moscow city before expansion of administrative borders in 2012) in the period from 1998 to 2021 during autumn months (September and October). Results of our provisional examination of most these samples were published in our previous paper [Mityaeva *et al*., 2024]. Additionally, samples from 36 water bodies were added to our analysis (Fig. 1). The protocol of collection and processing of the samples was described in Mityaeva *et al*. [2024].

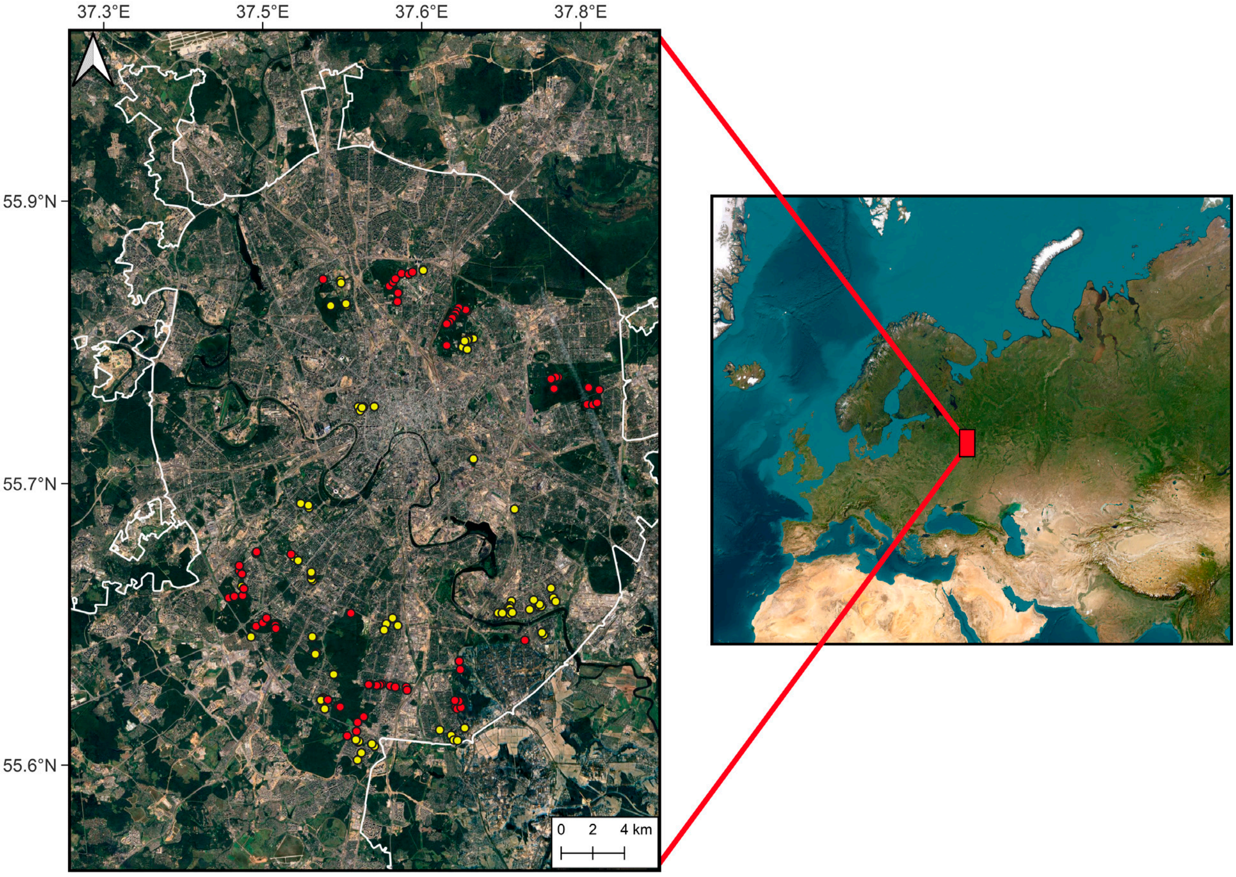

Fig. 1. Map of the sampled water body positions in Moscow City. Protected water bodies are marked by red, unprotected by yellow.

Рис. 1. Карта расположения исследованных водоемов на территории города Москвы. Охраняемые водоемы отмечены красным, неохраняемые — желтым.

Only the taxa identified to the species level were incorporated in our analysis. A species list for each sample was formed initially, then the taxa collected at different times in the same locality were combined in a single species list. Finally, a total matrix of records/locality was combined (Supplementary Table 1). The species were classified into two main groups by ecological preferences based on published data [Korovchinsky *et al.*, 2021a, b]: plankton-neustonic (PL) and benthic-phytophilous (BP). The results are presented in Table 1.

All water bodies were subdivided into those belonging to specially protected natural areas (“protected”) or located outside the boundaries of specially protected natural areas (“unprotected”). The status of each water body was checked based on the list of specially protected natural areas on the Moscow Government website [Anonymous, 2025c]. As a result, 70 water bodies were classified as protected (Fig. 2), and 78 as unprotected (Fig. 3). Visualisation of sampling points and estimation of the surface area of each water body was made in QGIS 3.40.0 packet with an accuracy of up to hundreds of square meters. Full information on the studied water bodies is presented in Supplementary Table 2.

A well-known biogeographical pattern linking the number of species in an ecosystem with its area [Preston, 1962] could influence greatly the results of our comparison. Differences in the average area (decimal logarithm) of the studied protected and unprotected water bodies were tested by Mann-Whitney test.

A total matrix of presence/absence per each water body was formed in Microsoft Excel 2013 and then processed in different statistical packages. The species richness was estimated in the EstimateS 9.1 package [Colwell, Elsensohn, 2014]. The species accumulation curves as a function of sampling effort (number of

Table 1. Species found in Moscow, with ecological preferences and presence in unprotected/protected areas.

Таблица 1. Виды ветвистоусых ракообразных, обнаруженные водоемах Москвы, их экологические предпочтения и присутствие в водоемах без охраняемого статуса/охраняемых водоемах.

Species	preferences	unprotected	protected
Acroperus angustatus Sars, 1863	BP		+
Acroperus harpae (Baird, 1834)	BP	+	+
Alona guttata Sars, 1862	BP	+	+
Alonella excisa (Fischer, 1854)	BP	+	+
Alonella exigua (Lilljeborg, 1853)	BP	+	+

Table 1 (continued).
Таблица 1 (окончание).

Species	preferences	unprotected	protected
Biapertura affinis (Leydig, 1860)	BP	+	+
Bosmina (*Bosmina*) *longirostris* (O.F. Müller, 1776)	PL	+	+
Camptocercus rectirostris Schödler, 1862	BP	+	+
Ceriodaphnia dubia Richard, 1894	PL	+	
Ceriodaphnia laticaudata P.E. Müller, 1867	PL	+	+
Ceriodaphnia pulchella Sars, 1862	PL	+	+
Ceriodaphnia quadrangula (O.F. Müller, 1785)	PL	+	+
Ceriodaphnia reticulata (Jurine, 1820)	PL		+
Ceriodaphnia rotunda Straus, 1820	PL	+	
Chydorus sphaericus (O.F. Müller, 1776)	BP	+	+
Coronatella rectangula (Sars, 1862)	BP	+	+
Daphnia (*Ctenodaphnia*) *magna* Straus, 1820	PL	+	
Daphnia (*Daphnia*) *cucullata* Sars, 1862	PL	+	+
Daphnia (*Daphnia*) *curvirostris* Eylmann, 1887	PL	+	
Daphnia (*Daphnia*) *galeata* Sars, 1864	PL	+	+
Daphnia (*Daphnia*) *longispina* O.F. Müller, 1776	PL	+	+
Daphnia (*Daphnia*) *pulex* Leydig, 1860	PL	+	+
Diaphanosoma brachyurum (Liévin, 1848)	PL	+	+
Disparalona rostrata (Koch, 1841)	BP	+	+
Flavalona costata (Sars, 1862)	BP		+
Graptoleberis testudinaria (Fischer, 1851)	BP	+	+
Ilyocryptus agilis Kurz, 1878	BP	+	+
Ilyocryptus cuneatus Štifter, 1988	BP	+	+
Ilyocryptus sordidus (Liévin, 1848)	BP	+	
Leptodora kindtii (Focke, 1844)	PL		+
Leydigia (*Neoleydigia*) *acanthocercoides* (Fischer, 1854)	BP	+	
Macrothrix laticornis (Jurine, 1820)	BP	+	+
Megafenestra aurita (Fischer, 1849).	PL		+
Moina brachiata (Jurine, 1820)	PL	+	+
Moina macrocopa (Straus, 1820)	PL	+	
Oxyurella tenuicaudis (Sars, 1862)	BP		+
Pleuroxus aduncus (Jurine, 1820)	BP	+	+
Pleuroxus laevis Sars, 1862	BP		+
Pleuroxus trigonellus (O.F. Müller, 1776)	BP	+	+
Pleuroxus truncatus (O.F. Müller, 1785)	BP	+	+
Pleuroxus uncinatus Baird, 1850	BP	+	+
Polyphemus pediculus Linnaeus, 1758	BP	+	+
Pseudochydorus globosus (Baird, 1843)	BP	+	+
Scapholeberis mucronata (O.F. Müller, 1776)	PL	+	+
Sida crystallina (O.F. Müller, 1776)	BP	+	+
Simocephalus serrulatus (Koch, 1841)	BP	+	+
Simocephalus vetulus (O.F. Müller, 1776)	BP	+	+

PL — plankton-neustonic species; BP — benthic-phytophilous species.

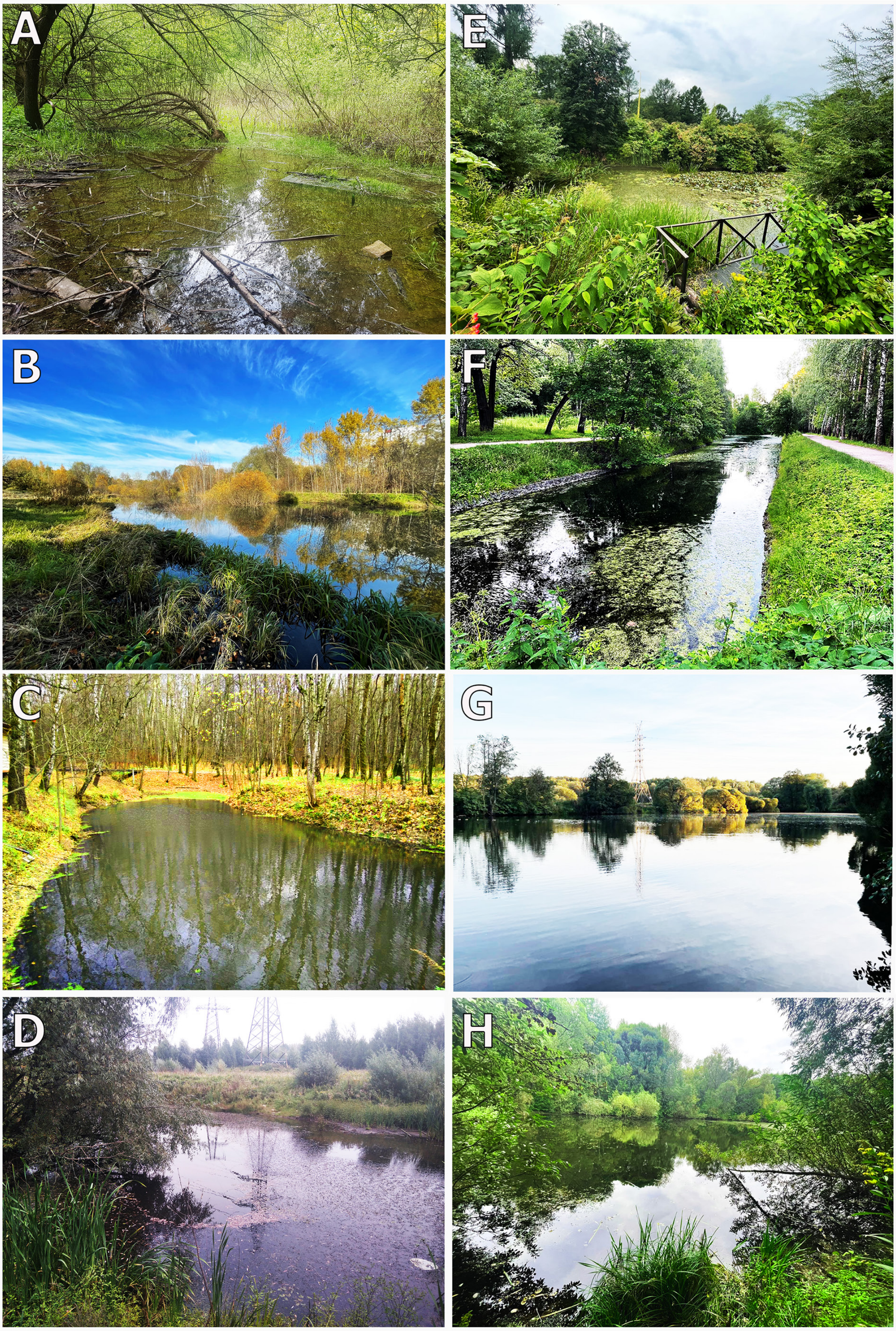

Fig. 2. Examples of protected water bodies in Moscow City. A — unnamed pond, "Bittsevsky les", Bittsevsky lesopark; B — Ochakovka River floodplain, Troparyovsky Forest Park, Troparyovsky Forest Park; C — 1st Pond on Biryulevsky brook, Biryulevsky dendropark; D — unnamed pond, Brateevskaya Poyma; E — unnamed pond, MSU Botanical Garden; F — Third Putyaevsky Pond, Sokolniki Forest Park; G — Sovkhozny pond, Izmailovsky Park; H — Pashkovsky Pond, Troparyovsky Forest Park.

Рис. 2. Примеры охраняемых водоемов в г. Москва. A — Безымянный пруд, Битцевский лесопарк; B — пойма реки Очаковки, Тропаревский лесопарк; C — Первый пруд на Бирюлевском ручье, Бирюлевский дендропарк; D — безымянный пруд, Братеевская пойма; E — безымянный пруд, Ботанический сад МГУ; F — Третий Путяевский пруд, лесопарк Сокольники; G — Совхозный пруд, Измайловский парк; H — Пашковский пруд, Тропаревский лесопарк.

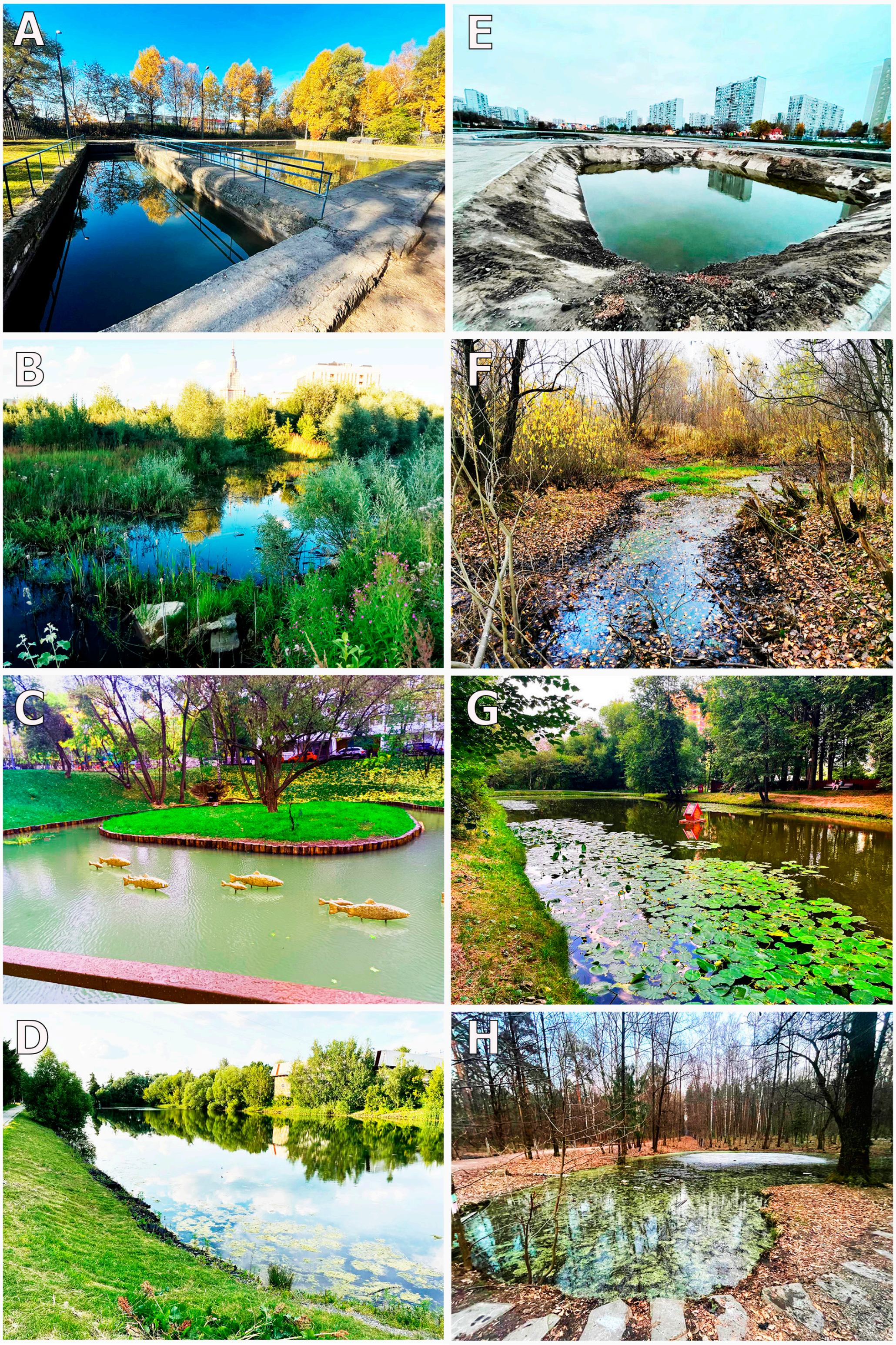

Fig. 3. Examples of unprotected water bodies in Moscow City. A — unnamed pond, the area of 44 km of Moscow Circular Road; B — unnamed pool, neighborhood of the MSU Library; C — Second Warsaw Pond, Warsaw Ponds; D — Middle Farms Pond, K.A. Timiryazev Russian State Agricultural Academy of Agricultural Sciences; E — unnamed pond, Brateevskaya Street; F — unnamed pond, South of Vostryakovsky Cemetery; G — 2nd Vorontsovsky Pond, Vorontsovsky Park; H — Olenie Lake, Timiryazevsky Park.

Рис. 3. Примеры неохраняемых водоемов в пределах г. Москвы. A — безымянный пруд в районе 44 километра МКАД; B — безымянный пруд в районе Библиотеки МГУ, Ленинские Горы; C — Второй Варшавский пруд, Варшавские пруды; D — Средний Фермерский пруд, РГАУ-МСХА имени Тимирязева; E — безымянный пруд, Братеевская улица; F — безымянный пруд, юг Востряковского кладбища; G — Второй Воронцовский пруд, Воронцовский парк; H — Оленье Озеро, Тимирязевский парк.

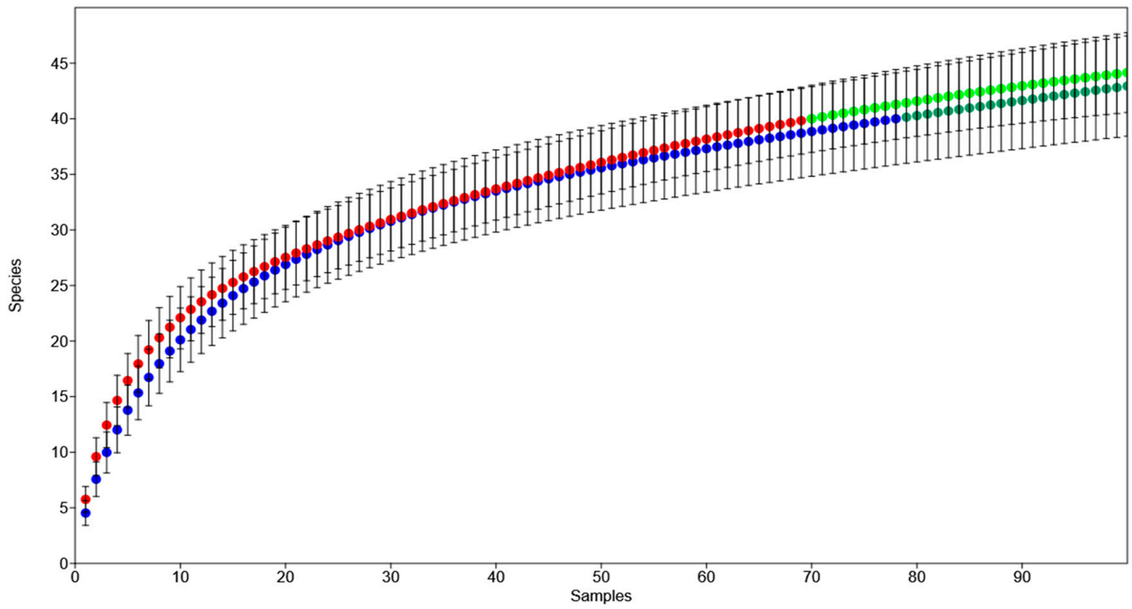

Fig. 4. Curves of accumulation of species abundance depending on the number of studied water bodies. The expected number of species and the standard deviation according to the extrapolation method [Colwell, Elsensohn, 2014]. Protected water bodies are marked in red, unprotected in blue. Extrapolation (green dots) of both curves to the number of samples equal to one hundred added.

Рис. 4. Кривые накопления видового обилия в зависимости от числа исследованных водоемов. Приведено ожидаемое число видов и стандартное отклонение по методу экстраполяции [Colwell, Elsensohn, 2014]. Охраняемые водоемы отмечены красным, неохраняемые синим. Зелеными точками отмечена экстраполяция кривых накопления до размера выборки в сто проб.

samples taken) were constructed using five different algorithms: Chao 1, Chao 2, Jackknife 1, Jackknife 2 and Bootstrap. The best model was selected by the smallest variance of the predicted values for each step. Nonparametric tests were used to assess the species composition; a simple linear regression model (OLS algorithm) was used to estimate the relationship between the number of species and the water body surface area. Confidence intervals in all cases were calculated based on permutation tests with 9999 repetitions. Construction of diagrams, calculation of summary statistics, nonparametric tests, and regression analysis were performed in PAST 5.02 [Hammer *et al*., 2001].

Results

Totally, we analysed 756 records (Suppl. Table 1) belonging to 47 (Table 1) species from 148 water bodies (Suppl. Table 2).

The curves of species accumulation for protected and unprotected water bodies trend in a similar manner, both reaching a plateau, which allows us to regard the territory as adequately studied. However, when extrapolating to an equal sample size of one hundred samples, the gap remains insignificant (within the standard deviation of estimates) (Fig. 4). Predictions of nonparametric models of the maximum number of species were different significantly; the best in terms of minimal dispersion was the Bootstrap model, predicting 44 species for unprotected water bodies, and 45 species for protected water bodies.

The number of species found in protected and unprotected water bodies is exactly the same, namely 40; 70% of the species forming the total list are found in both protected and unprotected water bodies (Fig. 5A). Differences were minimal according to the taxa ecological preferences: 16 planktonic and 24 benthic in unprotected, and 14 planktonic and 26 benthic species in protected water bodies were found (Fig. 5B). The average number of species per water body for protected water bodies was significantly higher, 5.76±0.46 *vs.* 4.52±0.37 (Mann-Whitney test z=1.8553, p=0.0382, Fig. 5C). The indices of phylogenetic diversity [Clarke, Warwick, 1998] were almost equal for both types of water bodies, 2.821 (confidence interval 2.624–2.959) for unprotected and 2.835 (2.630–2.948) for protected water bodies.

At the same time, no significant differences were found in average surface of studied protected and unprotected water bodies (3.66±0.09 and 3.57±0.07, respectively; Mann-Whitney test z=0.8931, p=0.3731) (Fig. 5D), therefore, any regularities cannot be explained by differences of the water body size in protected and unprotected water bodies.

The regression model demonstrated a significant positive relationship between the number of species and the logarithm of water body area (Fig. 5E), although with a small strength (n=148, r=0.25, r^2=0.06, F=10.44 p=0.0014), for protected water bodies this relationship was slightly stronger (n=70, r=0.32, r^2=0.10, F=7.659

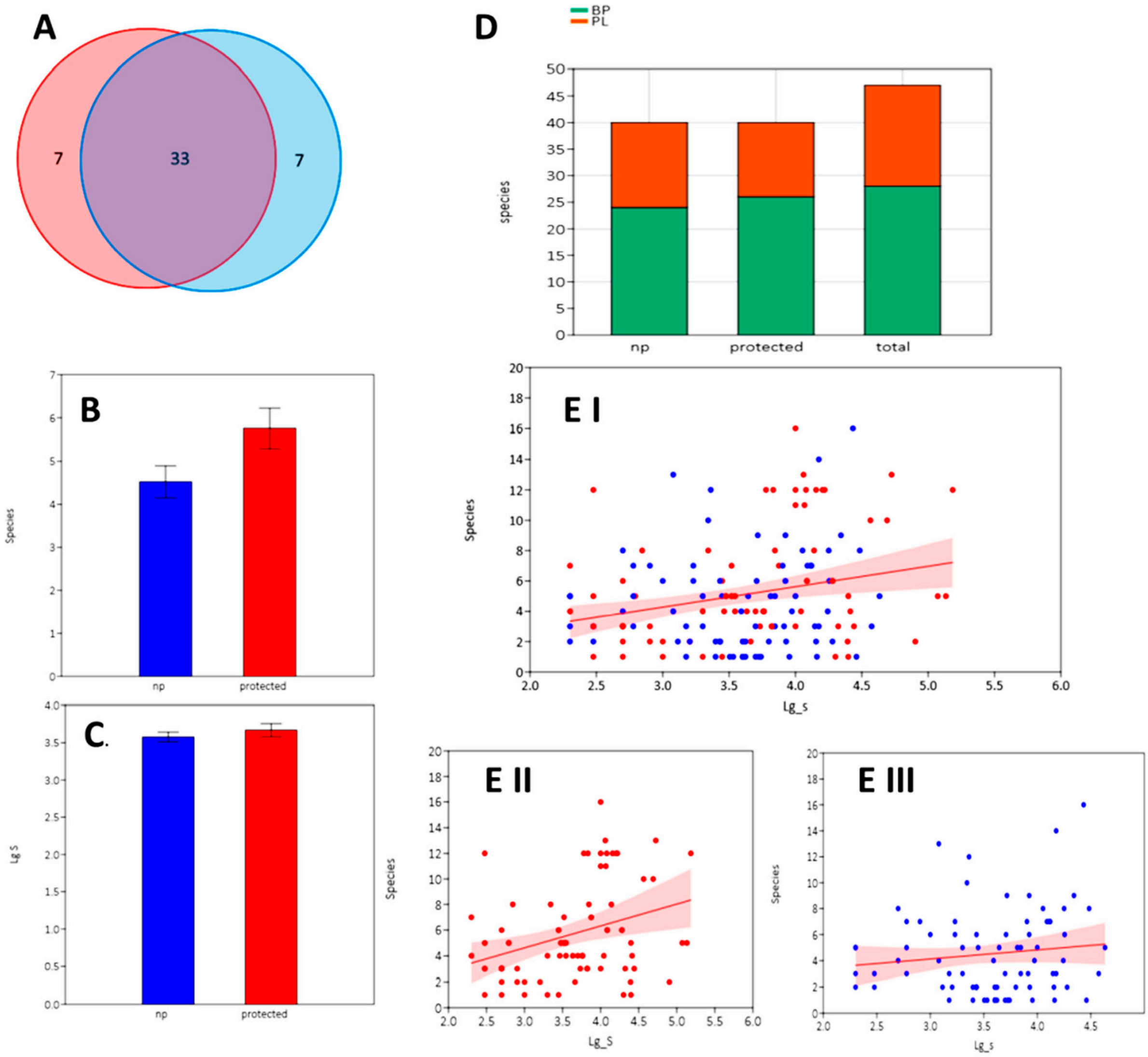

Fig. 5. Analysis of the fauna of water bodies. Protected water bodies are marked in red, unprotected in blue. A — overlap of the species lists of protected and unprotected water bodies; B — average number of species per water body and the range of standard deviation; C — average area of water bodies (decimal logarithm) and the range of standard deviation; D — composition of fauna by ecological preferences (PL — plankton-neustonic species, BP — benthic-phytophilous species); E — the relation between number of species and water body area (decimal logarithm): I — for all water bodies, II — for protected, III — for unprotected water bodies.

Рис. 5. Анализ фаун водоемов. Охраняемые водоемы отмечены красным, неохраняемые синим. A — пересечение видового состава охраняемых и неохраняемых водоемов; B — среднее число видов на водоем и диапазон стандартного отклонения; C — средняя площадь водоемов и диапазон стандартного отклонения (десятичный логарифм); D — состав фаун по образу жизни (PL — планктон-нейстонные виды, BP — бентосно-перифитонные); E — зависимость числа видов от площади водоема (десятичный логарифм); I — для всех водоемов, II — для охраняемых, III — для неохраняемых.

p=0.0063), and for unprotected water bodies it was absent (n=78, r=0.1238, r^2=0.015, F=1.164, p=0.2766).

Discussion

Increase in the number of studied water bodies as compared to Mityaeva *et al*. [2024] led to a small increase in the number of identified species in our general list (47 vs. 45 taxonomic units — 39 species and 6 genera in the previous study). New records for the city of Moscow are *Diaphanosoma mongolianum*, *Eurycercus lamellatus*, *Flavalona costata*, *Ilyocryptus cuneatus*, *I. sordidus*, *Leptodora kindtii*, *Leydigia acanthocercoides* and *Megafenestra aurita* which are relatively common species in North Eurasia [Korovchinsky *et al*., 2021a]. No non-indigenous taxa are detected, although biological invasions are very usual among the cladocerans [Kotov *et al*., 2022].

Surprisingly for us, a total pool of the cladoceran species was almost the same in protected and unprotected water bodies. Most probably, it is only a portion of a total regional species pool for Moscow Area after the "filtering effect of the city" [Fournier *et al*., 2020]. We expect that the total species number in the city is smaller as compared to rural territories, as it is usual for the cladoceran populations [Paz *et al*., 2018; Lanka *et al*., 2024]. Unfortunately, we do not have an accurate species list for whole Moscow Area to date. Published species lists are known for other regions of Europe with the size comparable to that of Moscow Area: 77 species in Belgium [Forró *et al*., 2003]; 67 species in Slovakia [Hudec, 2010]; 66 branchiopods (mainly cladocerans) in Sicily [Marrone, 2006]; 61 species were detected in the Zeya River basin, Russian Far East [Kotov *et al*., 2011]. Not surprisingly, accurate species lists of the Cladocera are absent for other European cities.

Within Moscow City itself, "the environmental filtering from a regional to an urban species pool" [Fournier *et al*., 2020] was minimal. Total species lists of protected and unprotected water bodies were minimally different in our study (see phylogenetic diversity indices). Our conclusions contradict to the data of Martins *et al*. [2019] which have compared "preserved" and "constructed" areas in the Campus of Federal University of Rio Grande and found "a clear difference between the two areas, both in environmental characteristics and in the composition of taxa". Also, the rate of plankton-neustonic/benthic-phytophilous species was equal in protected and unprotected territories of Moscow. Such homogeneity can have several explanations, based both on the properties of the water bodies themselves and on the properties of taxonomic groups inhabiting them.

The water system of protected areas of Moscow City is, in reality, closely integrated with the unprotected urban framework of the city. Streams and rivers that form lakes and ponds both within and outside protected areas may be significantly polluted along their entire length [Savushkina *et al*., 2018; Evgrafov *et al*., 2023]. Some rivers may start in a protected area, flow through a collector and form ponds outside a protected area, and then form ponds in another protected area. Also, chemical pollution is transferred with precipitation and surface runoff [Savushkina *et al*., 2018].

Contradictory functions of urban protected areas lead e.g. to periodical human-mediated disasters for the water communities: for the purpose of aesthetic improvement, water bodies are cleaned, and coastal strip and even water body bottom could be concreted, just like water bodies outside the protected areas [Anonymous, 2025e]. As a result of such clearing, ecosystem degradation and loss of invertebrate biodiversity could take place e.g. due to the habitat destruction and loss of the propagule bank in bottom sediments. Such reconstructions are especially harmful for truly benthic cladocerans [Kotov, 2006] because just their homes are virtually absent in concreted water bodies.

At the same time, in recent years, new technologies have been used during the reconstruction of water bodies in recreational areas of Moscow. They are aimed at bringing the appearance of the water body as close as possible to the natural one [Anonymous, 2025e]. Natural materials are used: sloping banks with crushed stone backfill, as well as so-called "bioplateau" areas are constructed, including aquatic plant introduction. Together with the water transfer from the water bodies unaffected by the reconstruction, belonging to the same water system, this can lead to an acceleration of the rate of restoration of zooplankton biodiversity in the reconstructed reservoirs. Installation of water plants is one of conventional ways for biological manipulation of ecological restoration of lake water [Peretyatko *et al*., 2010; Chen, 2020].

Despite aforementioned homogeneity effects, we observe a statistically significant excess of the number of identified species per water body within the boundaries of protected areas, regardless of their sizes. Especially remarkable is absence of a correlation between the species richness and water body size for unprotected area; in contrast, such correlation is significant in protected areas. Note that Martins *et al*. [2019] also "did not find positive correlation between pond area and richness" in urban waters. They explained such phenomenon referring to Scheffer *et al*. [2006] who wrote that "we could expect some increase in species diversity for most invertebrate groups in ecosystems with a high density of macrophytes", but such macrophytes are less numerous or absent in unprotected water bodies.

For zooplankton species, every single water body is an island surrounded by impassable terrain (similar to the idea of islands of natural landscape in the midst of urbanized territory [Klausnitzer, 1987; Szulkin *et al*., 2020]. Based on MacArthur and Wilson's theory of island biodiversity and Levins's [1969] metapopulation, the power function has formed the basis for several important theoretical models of the species-area relationship [Preston, 1962; MacArthur, Wilson, 1967]. Although an island area is usually the single strongest predictor of species number, area typically accounts for only half of the variation in species richness [Boecklen, Gotelli, 1984]. Therefore, phenomena of difference in species-area relationship between protected and unprotected water bodies needs explanation.

We propose a "lottery model" to explain a paradoxical situation of correlation absence between species diversity and surface area in unprotected water bodies (Fig. 6). Presence of a large species number in a larger water body is explained by a greater chance of a larger target colonisation by every single species from the regional pool. However, their survival depends on complexity and diversity of the habitats in the target water body, which is different in protected and unprotected areas. Disturbed larger water bodies still have a greater chance of colonisation as compared to smaller ones, but zooplankton species diversity stays low due to lack of habitat diversity in large, but anthropogenically disturbed, water bodies. Thus, observed species number difference may be interpreted as a result of difference in survival rates while dispersal rates for protected and unprotected water bodies are similar.

In general, such differences reflect a lower heterogeneity of unprotected water bodies in terms of important parameters for species diversity: the period of existence (including after reconstruction), levels of various types of pollution (not only chemical, but also of other nature), which requires further study. Note that increasing of the water body surface in unprotected area do not provide new ecological niches in contrast to protected water bodies where size increase provides such niches e.g. by adding patches of different macrophytes, differentiation

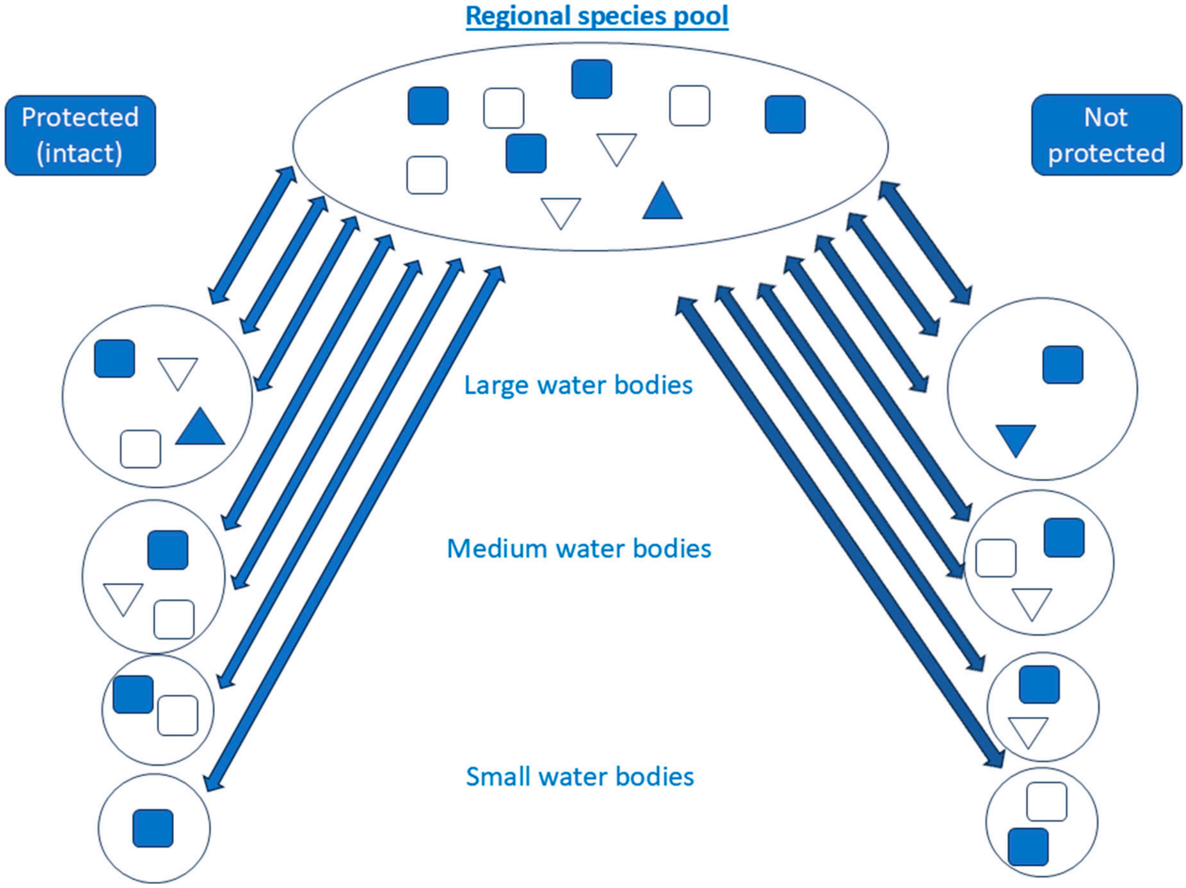

Fig. 6. "Lottery model" of species placement from regional species pool into water bodies of different size.
Рис. 6. «Лотерейная модель» заселения водоемов разного размера из регионального пула видов.

of the floating leaf zone and open littoral, appearance of a real open pelagic zone. In addition, it can be assumed that in protected areas any water bodies are less often reconstructed, are protected at least from some types of pollution. As a result, more complexly-structured biotopes are formed, which is indirectly indicated by a larger number of benthic-phytophilous species found in them.

Moscow microcrustaceans remain insufficiently studied. In particular, recent publications [Mityaeva *et al*., 2024] indicated a small number of thermophilous species. Such situation could be explained by the time of our sampling campaigns: the autumn period. Just protected water bodies seem to be more promising sources of new records for urban fauna. It is also important to continue the research of temporary water bodies and swamps, containing specific cladoceran taxa and communities [Kotov, Taylor, 2019; Aksenova *et al*., 2023].

Conclusion

We do not observe statistically significant differences between the autumn cladoceran fauna of water bodies within and outside the protected areas, except for the average number of species per water body. Such homogeneity of fauna can be explained by both the shared water system throughout the city and good dispersal abilities of the water fleas. At the same time, the difference in the number of species per water body and absence of the correlation between species number and water body surface in unprotected area indirectly indicate a greater anthropogenic pressure in the latter, not fully compensated for by easy dispersal. Further studies can shed light on the mechanisms of maintaining biodiversity in urban water bodies in our changing world.

The anticipated rise in anthropogenic pressure on aquatic ecosystems, driven by the expansion of urban service activities, is likely to have detrimental effects on the species richness of the crustaceans across Moscow. This increased pressure on water bodies should be considered an unfavourable factor, warranting further research to evaluate the implications of rehabilitation initiatives (such as water body clean-up) on the biodiversity of aquatic ecosystems within specially protected natural areas.

Compliance with ethical standards

CONFLICT OF INTEREST: The authors declare that they have no conflict of interest.

Ethical approval: No ethical issues were raised during our research.

Supplementary data. The following Excel-tables are available online.

Supplementary Table 1. Species presence by localities.

Supplementary Table 2. Studied water bodies coordinates, area and protection status.

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