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TRAPA NATANS L. AS A PART OF MACROPHYTE BIODIVERSITY ECOLOGICAL ESTIMATION

P.I. Ilicheva[1], I.I. Vasenev[2], Ye.B. Taller[3]

[1, 2, 3] *Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Moscow, Russia*
[1] *polinailicheva@yandex.ru,* [2] *vasenev@rgau-msha.ru,* [3] *etallereb@rgau-msha.ru*

Abstract. As urban territories grow in population and size, water ecosystems suffer from anthropogenic impact on hydrological conditions and macrophyte biodiversity. The research goal is to analyze the seasonal changes (May – September 2020–2024) in aquatic plant diversity, rare species as *Trapa natans* (July 2022–2024), in connection with air temperature changes and ecological levels of water quality by saprobity index Sladecek (1963) and Kokin (1982) in Moscow urban ponds. The study was carried out by using the standard methods of identification and description of macrophyte diversity in Verhni Chernivskiy pond, Severniy Polyanskiy pond and Saltykovskiy pond which are located in urban parks: Landscape Park of South Butovo and Butovo Forest Park. It was estimated that the annual, seasonal changes and the anthropogenic effect have permanent impact on the macrophyte species and their quantity. In 2021 we identified 38 species of macrophytes in the studied urban ponds due to warm spring temperatures and appropriate water level in the ponds owing to abundant rainfall. But in 2023 and 2024 the aquatic plant biodiversity decreased and the saprobity index shows the water quality class as satisfactory clean in Saltykovskiy pond and Severniy Polyanskiy pond that could be caused by increasing transport and new road building impact on these areas. Also, in 2023 water caltrop number had been reducing in all recording points in Verhni Chernivskiy pond because of a cold summer, higher water level in the pond and competition with other macrophytes. Providing monitoring organization and ecological assessment mitigates recreational impact on Landscape Park of South Butovo and Butovo Forest Park and keeps high macrophyte diversity level, in particular *Trapa natans* and *Nymphaea Candida*, that lead to the water ecosystems sustainability in Moscow.

Keywords: aquatic plants, water ecosystems, saprobity index, water caltrop, species diversity, urban ecosystems

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ЭКОЛОГИЧЕСКАЯ ОЦЕНКА БИОРАЗНООБРАЗИЯ МАКРОФИТОВ, В ЧАСТНОСТИ *TRAPA NATANS* L.

П. И. Ильичева[1], И. И. Васенев[2], Е. Б. Таллер[3]

[1, 2, 3] *Российский государственный аграрный университет – МСХА имени К. А. Тимирязева, Москва, Россия*
[1] *polinailicheva@yandex.ru,* [2] *vasenev@rgau-msha.ru,* [3] *etallereb@rgau-msha.ru*

Аннотация. Многократное ускорение процесса урбанизации приводит к повышению уровня антропогенной нагрузки на водные объекты, нарушению водного режима, ухудшению состояния водоемов, а также к уменьшению уровня биологического разнообразия макрофитов. Изучение сезонной динамики биоразнообразия водных растений позволяет оценить влияние климатических и антропогенных факторов на видовой состав растительности. Цель работы – изучить сезонные изменения биоразнообразия макрофитов, в частности рогульника плавающего (июль 2022–2024 гг.), с учетом индекса сапробности по Сладечеку (1963) и Кокину (1982) в Верхнем Черневском пруду, Салтыковском пруду и Северном Полянском пруду за период с мая по сентябрь 2020–2024 гг. Исследования проводились по общепринятым методикам в водных объектах, находящихся на территориях Ландшафтного парка Южное Бутово и Бутовского лесопарка в Москве. Выявлена взаимосвязь между годовыми и сезонными колебаниями и видовым и количественным составом водных растений, что обусловлено абиотическими факторами и жизненными циклами растений. В сезонной динамике биоразнообразия макрофитов отмечается повышение количества видов от мая к июлю-августу и постепенное

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снижение к сентябрю. В 2021 гг. было установлено максимальное количество видов водных растений (38 вида) благодаря благоприятным температурным условиям весной и количеству осадков для развития растений. В 2023–2024 гг. отмечено снижение биоразнообразия макрофитов и ухудшение значения качества воды по индексу сапробности (по Сладечеку (1963), Кокину(1982)) – умеренно-загрязненная вода в Салтыковском и Северном Полянском прудах, что связано с увеличением транспортной нагрузки и началом строительства дороги в непосредственной близости с водоемами. Анализ динамики популяции рогульника плавающего в Верхнем Черневском пруду на территории Ландшафтного парка Южное Бутово показал максимальное значение в 2024 г. и снижение в 2023 г., что соответствует естественным колебаниям численности вида. Проведение мониторинга и комплексной экологической оценки по снижению антропогенной нагрузки на водные объекты на территориях Ландшафтного парка Южное Бутово и Бутовского лесопарка поможет сохранить устойчивость водоемов в урбоэкосистемах и высокий уровень биоразнообразия макрофитов, в частности рогульника плавающего и кувшинки белой.

Ключевые слова: водные растения, водоемы, сапробность, рогульник плавающий, разнообразие видов, урбоэкосистемы

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Introduction

In the last decades biodiversity loss has increased because of enormous growth of urban ecosystems. There are different ways of direct and indirect impacts on biodiversity in big cities with its designs, planning and government, for instance: habitat loss, fragmentation and degradation of pristine areas, species interactions, invasive taxa, pollution or altered climate [21, 27]. The main problem of cities is a biodiversity conservation as a large part of the world's population moves from rural to urban areas and there are significant changes in the link between human activities, biodiversity and in ways of creating biodiversity conservation policies [28]. One of the most popular solutions in aquatic plant biodiversity conservation is the creation of buffer zones taking into consideration proper spatial extent from the pond edge [14] such places could be landscape parks or urban forests. It is necessary to provide conditions for fauna and flora diversity as well as recreation facilities for people.

It is predicted that anthropogenic effect will be a major cause of species extinctions in the next 100 years but whether it will be featured in changing biotic interactions, limited physiological tolerance to high/low temperatures or other factors not stated. In many studies the probable causes vary widely and there is no a straightforward relationship between local biodiversity level and temperature dynamics [16]. However, it is implicated that the different species interact with each other, especially in resource availability, and there is a correlation between water pollution and biodiversity level [1, 11].

Also much research study the spread of invasive species in big cities [35] but we focused on the rare taxa *Trapa natans* as a part of biodiversity level in city water ecosystems. This macrophyte was in the Russian Red List and now only several regions of our country keep it, for example in: the Kaluga region [4], the Novosibirsk region [13], the Amur region [3] and the Republic of Altai [38]. However, in North America and Australia this taxon is considered an invasive species [17, 34]. *Trapa natans* could be a good and representative ecological indicator of macrophytes biodiversity and climate changes [36]. Water chestnut is an annual plant, forming its rosettes from a large number of rhombic mosaic leaves floating on the water surface. The underwater leaves are thread-like, the stem is attached to the ground by thread-like roots and last year's nut, like an anchor. Viability of its fruits in silt lasts up to 10, or even 50 years. Nuts dried or frozen below –8... –10 °C lose their viability [38]. These nutritious nuts are used in different national cuisines as a staple food, fertilizer and in traditional medicine, for instance: in India and China. Water chestnut grows in ponds, lakes and channels with weak flowage. This macrophyte spots in non-polluted nutrient-rich waters and does not stand salinity [26].

It is known that changes in climate, vegetation and land use are related to the sensitivity of biodiversity that is why it is important to conduct ecological investigations in this sphere [30, 31].

Materials and methods

The article is based on the results of field studies of seasonal dynamics of macrophyte diversity with *Trapa natans* as a part of this assessment and the correlation with the water pollution calculated by the Sladecek (1963) and Kokin (1982) saprobity index. Research was conducted in three urban ponds in Landscape Park of South Butovo and Butovo Forest Park (Fig. 1) from May to September in 2020–2024. Severniy Polyanskiy pond and Saltykovskiy pond are located in Butovo Forest Park. This area is a forest park which is situated on the vast territory of South and North Butovo districts in Moscow. Verhni Chernivskiy pond is in Landscape Park South Butovo which was opened after reconstruction in 2018.

Fig. 1. Airphotos of urban ponds in Landscape Park of South Butovo (*A*) with recording points (*C*) of *Trapa natans* and Butovo Forest Park (*B*)

Verhni Chernivskiy pond is a part of a cascade of three ponds which are located on the territory of former village Chernevo near the end of the land-based metro line. The weirs are on the rivers Koryuska and Chernevka. This pond has earth dams 2–3 m high with a drain into the well and further underground water header. There are banks with low coast gabions and tracks with special pavement. This pond is usually used for recreational purposes and fishing (generally the crucian carp and perch). In 2000 the permanent stream of the river Koryushka started from Verhni Chernivskiy pond, but now after the development of the South Butovo district it can be sometimes dried up and upper of this place. Before the Landscape Park of South Butovo reconstruction the pond was 280 m in the western direction and reached width of 70 m, but the upper part was extremely narrow and shallow. In 2018 during park reconstruction, it was organized special actions for bottom clearing, bank strengthening and creating places for recreation of city residents. Nowadays Verhni Chernivskiy pond has nearly the same levels, but on average wider and deeper (1.4 ha). In the east part there is an island of 10 × 20 m [23]. Severniy Polyanskiy pond and Saltykovskiy pond are located on the southern edge of Butovo Forest Park between the South and North Butovo districts. Severniy Polyanskiy pond is at the turning of the highway which is crossing this urban forest. This pond is sickle-shaped and has definitions 60 m long, 20 m wide and area is 0.2 ha. The road plays the role of the dam. Spring runoff goes over the road to the southeast and collecting water from a system of wooded hollow it gives the start to springhead of the river Gvozdyanka. The banks are natural and water-logged. Nowadays it is not used for any purposes [23]. Saltykovskiy pond is 115 m long, extending in a south-eastern direction, narrowing to the upper part, width up to 55 m, area is 0.6 ha. The weir is at the springhead of the river Gvozdyanka, the flow is surficial, water comes out closer to the top of the pond from the north-eastern bank and flows around the pond. The earth dam is up to 1.5 m high, the banks are natural and water-logged in the upper part. This pond is usually used for fishing and other recreational events [23].

The investigations were made using the standard methods of identification, description and mapping of higher aquatic species diversity [5, 6, 9, 12]. During the ecological assessment it was necessary to find out the correlation between the quality of water bodies, macrophyte biodiversity and its seasonal dynamics. In Verhni Chernivskiy pond there were 6 recording points, in Saltykovskiy pond and Severniy Polyanskiy pond were 5 of them.

The Sladecek (1963) and Kokin (1982) saprobity index was used to determinate the impact of water quality on the level of aquatic plant biodiversity. This method describes the degree of water pollution of the pond by indicating the macrophytes which have special saprobic indicator value and they are classified on a score-scale to preference for saprobic water quality. The most sensitive to water pollution aquatic plants are on the top of the list while certain others are on the bottom. This test is a complex of physiological properties of this water plant, which determines its ability to develop in water with some organic matter content and with some degree of pollution [32]. Higher biodiversity level of macrophytes supports a better quality of water that is why this method has positive results for contaminated urban water ecosystems.

Using these ecological indicators could help to deal with the anthropogenic effect challenges, keeping balance in high diversity level, social and economic development of big cities. The statistical assessment of the obtained data was carried out using a Microsoft Excel programme.

Results and discussion

By the results of the study of macrophyte biodiversity in 6 recording points of Verhni Chernivskiy pond and 5 recording points of Severniy Polyanskiy pond and Saltykovskiy pond in the territories of Landscape Park of South Butovo and Butovo Forest Park were identified 38 dominant species of macrophytes from 25 families (Cyperaceae, Typhaceae, Potamogetonaceae, Ranunculaceae, Ceratophyllaceae, Lemnaceae, Sparganiaceae, Alismataceae, Salicaceae, Lamiaceae, Equisetaceae, Hydrocharitaceae and others) and 30 genera (*Carex*, *Ranunculus*, *Typha*, *Potamogeton*, *Elodea*, *Spirodela*, *Ceratophyllum*, *Lemna*, *Sparganium*, *Alisma*, *Salix*, *Equisetum*). The studied plants are in the division of Magnoliophyta.

Ranking the identified macrophytes by ecological groups, it was found out that the dominating species are from hydrogelophytes (24 %) and hygrogelophytes (38 %). Among hydrogelophytes were identified river horsetail (*Equisetum fluviatile* L.), bulrush (*Typha latifolia* L.), lesser bulrush (*Typha angustifolia* L.), common water-plantain (*Alisma plantago-aquatica* L.), simplestem bur-reed (*Sparganium erectum* L.), arrowhead (*Sagittaria Sagittifolia* (L.) and others. Hygrogelophytes were presented 14 species of aquatic plants that include a three-part beggarticks (*Bidens tripartita* L.), great water-parsnip (*Sium latifolium* L.) and toad rush (*Juncus bufonius* L.) and others.

The monthly average temperature (Fig. 2) in May 2024 was about +13 ºC which is 1 ºC below the average climatic points but at the same time light frosts were recorded which were also in May 2022. The monthly average in September 2024 was +18 ºC that was much warmer and it was 6 ºC above the norm. The hottest summers were in 2021 and 2022, the coldest one was in 2023. The monthly average rainfall in July 2020 was 170 mm which was 86 mm more than the average climatic points. And in August 2022 only 4 mm of rainfall fell out that was 74 mm less than the average points. The wettest season was in 2020 while the lowest rain level during the research period was in 2022.

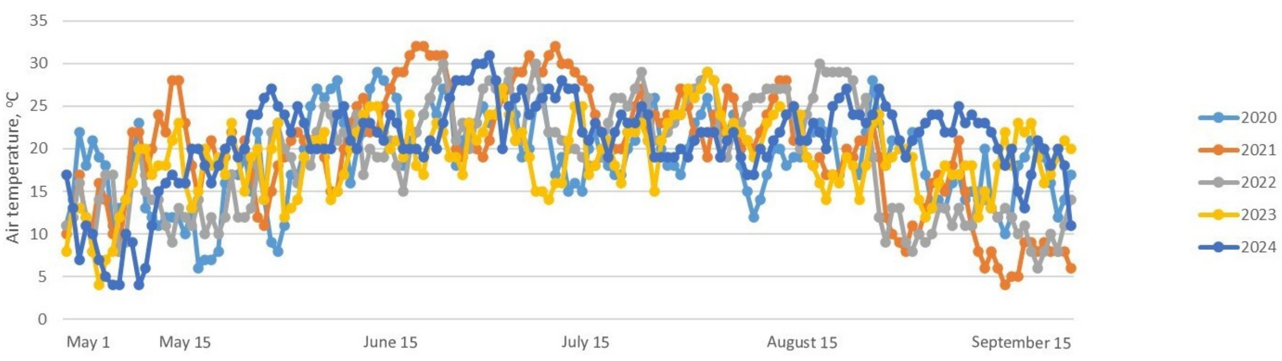

Fig. 2. Air temperature dynamics

The seasonal diversity of macrophytes shows an increase in species from May to July – August and a gradual decline by September. Annual and seasonal changes have permanent impact on the aquatic plant species and their quantity due to abiotic factors and plant life cycles [8].

In 2021 in Verhni Chernivskiy pond and Saltykovskiy pond was recorded the highest level of biodiversity with 38 identified species due to the favourable temperature and rainfall conditions, for instance: swamp sawgrass (*Cladium mariscus* (L.) Pohl), white waterlily (*Nymphaea candida* J. Presl & C. Presl), longroot smartweed (*Persicaria amphibia* (L.) Delarbre), common duckweed (*Lemna minor* L.), small bur-reed (*Sparganium natans* L.), three-part beggarticks (*Bidens tripartita* L.), yellow loosestrife (*Lysimachia vulgaris* L.) and other species. But since 2023 macrophyte number has been reducing that could be caused by the increasing recreational and transport impact. In Saltykovskiy pond such species as bittersweet (*Solanum dulcamara* L.), grass rush (*Butomus umbellatus* L.) and yellow waterlily (*Nuphar lutea* (L.) Sm.) were changed by the increased population of more pollution-resistant species: arrowhead (*Sagittaria sagittifolia* L.), bulrush (*Typha latifolia* L.), Canadian waterweed (*Elodea canadensis* Michx.) and horsetail (*Equisetum fluviatile* L.). In 2024 dominated aquatic plant species in Verhni Chernivskiy pond were simplestem bur-reed (*Sparganium erectum* L.), yellow waterlily (*Nuphar lutea* (L.) Sm.), water caltrop (*Trapa natans* L.) and hornwort (*Ceratophyllum demersum* L.).

As for invasive species, in 2020 was recorded only several zones with rootless duckweed (*Wolffia arrhiza* (L.) Horkel ex Wimm.) near the banks of Severniy Polyanskiy pond but in 2024 the total projective coverage of this macrophyte was 50–60 %. Species richness fell from 18 species to 11 where the dominating association was *Wolffia arrhiza* (L.) Horkel ex Wimm. and *Lemna minor* L. (Fig. 3) because of the started road building in the nearest pond area without any barriers and special protective equipment.

Fig. 3. Macrophyte biodiversity: *Trapa natans* (*A*) associations with yellow waterlily and with simplestem bur-reed (*B*); *C* – *Nymphaea candida*; *D* – *Wolffia arrhiza* and *Lemna minor* association

It is interesting that nowadays its distribution is not specified so it is considered as a rare taxon which marked in 5 Russian regions: Bryansk region, Kursk region, Voronezh region, Moscow region, Lipetsk region [2; 10; 33]. Typically, rootless duckweed occurring in the temperate, subtropical and tropical regions of Europe, Africa, western Asia, North and South America. It is known that it is a progressive aquatic plant and increases its range and number rapidly. The further spread of *Wolffia arrhiza* (L.) Horkel ex Wimm. in Moscow water ecosystems is expected.

According to the results of the Sladecek (1963) and Kokin (1982) saprobity index calculations, Verhni Chernivskiy pond is in the ß-mezotrophic category with its value 1.79 for the 3 water quality class which means satisfactory clean water. As well as Saltykovskiy pond with 1.78 points and Severniy Polyanskiy pond (1.89) are included in the same ß-mezotrophic category for the 3 class of water quality (satisfactory clean water).

Among the plants belonging to macrophytes in Verhni Chernivskiy pond we found rare plants – water caltrop (*Trapa natans* L.) (Fig. 3) and white waterlily *(Nymphaea candida* J. Presl & C. Presl) (Fig. 3) which are listed in the different editions of the Red List. White waterlily (*Nymphaea candida* J. Presl & C. Presl) is marked in two recording points of the aquatic plants research in July 2022–2024, it was likely planted during the reconstruction of the park. And the water chestnut was found out in 3 recording points (Fig. 1) which were located in 2 different associations: with yellow waterlily (*Nuphar lutea* (L.) Sm.) and with simplestem bur-reed (*Sparganium erectum* L.) (Fig. 3) in the zone 1 and in simplestem bur-reed association in the zone 2. In the zone 3 *Trapa natans* L. was dominated taxa as other species of macrophytes were not practically recorded. Also there were formed small spots of water chestnut of individual specimens which were located at a distance of 2–3 m from each other in the pond in order to avoid competition with other aquatic plants.

Interestingly, despite the increasing number of yellow waterlily (*Nuphar lutea* (L.) Sm.) as the main competitor in the 1st recording point, it was noted its positive role in water caltrop associations. Its roots support silt accumulation and hold the water chestnut fruits providing favourable conditions for the vegetation of *Trapa natans* L.

Comparing results, it was obtained that the water caltrop population changes during 2022–2024 because of the temperature variations, different amount of rainfall and the natural cycles in the population of the species. Since 2023 the number of water chestnut had been reducing in all recording points, it could be caused by a higher water level in the pond and competition with other macrophytes. In 2022 spring temperature was lower than the average climatic points and with light frosts so the growing season started later. The diameter of the rosette, the number and width of the leaves of the water chestnut also have changes throughout the years of research. In 2024 it was recorded the maximum number of leaves and rosettes due to the favourable weather conditions. In 2022 it was a long and cold spring so the plant quantity, rosette and leaf size became lower. The growing season started later so the leaves were not in their final growth as well as the diameter of the rosettes did not reach its maximum size at the time of the study. It was estimated that all the associations showed slight visible damage. Water caltrop plants were in the vegetation stage but plants in the bud and blooming stages were found too. According to the literature, blooming period of this macrophyte is from July to August and fruiting stage is from late August to September in Central Russia [3].

Conclusion

An ecological assessment of the seasonal diversity of macrophytes was conducted in water bodies in the territories of Butovo Forest Park and Landscape Park of South Butovo in Moscow. It was established the correlation between increasing level of water pollution and decreasing in aquatic plant biodiversity level. The maximum species diversity was recorded in July and August over the period of research. In 2021 were over 25 species identified in each Verhni Chernivskiy pond and Saltykovskiy pond that was the highest meanings of macrophyte biodiversity. Severniy Polyanskiy pond also had the best numbers in this year it could be caused by warm spring temperatures and appropriate water level in the urban ponds due to the abundant rainfall. Whereas in 2023 and 2024 the aquatic plant biodiversity was the lowest and the Sladecek (1963) and Kokin (1982) saprobity index became nearer to the contaminated water in Severniy Polyanskiy pond because of the road building in its immediate area without any special non-polluted barriers. Also in this pond the invasive *Wolffia arrhiza* (L.) Horkel ex Wimm. was found that is not studied well in Russia and further research is expected. During the study period in each year such dominated aquatic species were found out in each urban pond: common duckweed (*Lemna minor L.*), Canadian waterweed (*Elodea canadensis Michx.*), bulrush (*Typha latifolia L.*) and hornwort (*Ceratophyllum demersum L.*), these macrophytes are typical to urban water ecosystems. As for the water caltrop (*Trapa natans L.*) population in Verhni Chernivskiy pond, the maximum number of leaves and rosettes was in 2024 due to the favourable weather conditions. The main sources of anthropogenic impact are transport, road building and increased recreational load. That is why it is necessary to organize ecological activities to clean the urban ponds, monitor and assess the level of macrophyte biodiversity.

Список литературы

1. Анищенко Ю. Д., Анищенко О. В., Зуев И. В. [и др.]. Оценка антропогенного воздействия на экосистему р. Енисей в черте г. Красноярска на основе элементного анализа макрофитов и воды // Журн. Сиб. федер. ун-та. Биология. 2023. № 16. С. 87–108.
2. Бочкин В. Д., Майоров С. Р., Насимович Ю. А. [и др.]. Дополнения к адвентивной флоре Москвы и Московской области // Бюллетень Московского общества испытателей природы. Отдел биологический. 2014. Т. 119, вып. 6. С. 63–65.
3. Болотова Я. В. Распространение видов рода Trapa L. (Trapaceae) на территории Амурской области (российский Дальний Восток) // Вестник Северо-Восточного федерального университета им. М. К. Аммосова. 2014. Т. 11, № 2. С. 22–28.
4. Булавинцева А. Г. Вторая находка *Trapa natans* L. (Lythraceae) в Калужской области // Бюллетень Московского общества испытателей природы. Отдел биологический. 2014. Т. 119, вып. 3. С. 68–69.
5. Глушенков О. В., Глушенкова Н. А. Школа гидроботаники: теория и практика учебных гидроботанических исследований : учеб.-метод. пособие. Чебоксары, 2013. 176 с.
6. Глушенков О. В., Глушенкова Н. А. Растения пресных вод. Карманный определитель. Чебоксары, 2013. 132 с.
7. Капитонова О. А. Флора водоемов и водотоков г. Тобольска (Тюменская область): основные характеристики и их анализ // Журнал Сибирского федерального университета. Биология. 2023. № 16. С. 430–453.
8. Кокин К. А. Экология высших водных растений. М. : МГУ, 1982. 160 с.
9. Лисицына Л. И., Папченков В. Г., Артеменко В. И. Флора водоемов волжского бассейна. Определитель сосудистых растений. М. : КМК, 2009. 219 с.
10. Панасенко Н. Н., Анищенко Л. Н., Романова Ю. Н. *Wolffia arrhiza* (L.) Horkel ex Wimm. В Брянской области // Вестник Брянского государственного университета. 2012. № 4. С. 203–204.
11. Рябова В. Н., Васильева В. А. Восстановление растительности рекультивированных прудов Лугового парка (водоподводящая система фонтанов г. Петергофа) // Biological Communications (Вестник СПбГУ). 2014. Сер. 3. Вып. 4. С. 49–66.
12. Таллер Е. Б., Яшин М. А., Тихонова М. В., Бузылев А. В. Лабораторный практикум по экологии. Часть I. Биоиндикация : учеб. пособие. М. : ДПК Пресс, 2021. 106 с.
13. Визер А. М., Киприянова Л. М. Находка водяного ореха *Trapa natans* L. s. l. (Trapaceae) в Новосибирской области // Turczaninowia. 2010. Т. 13, вып. 3. С. 67–69.
14. Akasaka M., Takamura N., Mitsuhashi H., Kadono Y. Effects of land use on aquatic macrophyte diversity and water quality of ponds // Freshwater Biology. 2010. № 55. P. 909–922.
15. Barney J. N., Tharayil N., DiTommaso A., Bhowmik P. C. The biology of invasive alien plants in Canada. 5. *Polygonum cuspidatum* Sieb. & Zucc.[= *Fallopia japonica* (Houtt.) Ronse Decr.] // Canadian Journal of Plant Science. 2006. № 86. P. 887–906.
16. Cahill A. E., Aiello-Lammens M. E., Fisher-Reid M. C. [et al.]. How does climate change cause extinction? // Proceedings of the Royal Society B: Biological Sciences. 2013. № 280. P. 20121890.
17. Chorak G. M., Dodd L. L., Rybicki N. [et al.]. Cryptic introduction of water chestnut (*Trapa*) in the northeastern United States // Aquatic Botany. 2019. № 155. P. 32–37.
18. Hassall C. The ecology and biodiversity of urban ponds // WIREs Water. 2014. № 1. P. 187–206.
19. Hegland S. J., Nielsen A., Lázaro A. [et al.]. How does climate warming affect plant-pollinator interactions? // Ecol. Lett. 2009. № 12 (2). P. 184–195.
20. Lande V. W. Biomonitoring of water environment in rivers, ponds and lakes // Journal of Global Biosciences. 2021. № 10. P. 8458–8477.
21. Maclean I. M. D., Wilson R. J. Recent ecological responses to climate change support predictions of high extinction risk // Proc. Natl. Acad. Sci. USA. 2011. № 108. P. 12337–12342.
22. Markovic G., Vicentijevic-Markovic G., Tanaskovic S. First record of water chestnut (*Trapa natans* L., Trapaceae, Myrtales) in Central Serbia // Journal of Central European Agriculture. 2015. № 16. P. 436–444.
23. Nasimovich Yu. A. The basin of the River Pahra in the south of Moscow. 1991–2009. URL: http://temnyjles.narod.ru/Reki3-20.htm (дата обращения: 21.02.2025).
24. O'Briain R., Corenblit D., Gurnell A. Interacting effects of climate change and invasions by alien plant species on the morphodynamics of temperate rivers // WIREs Water. 2023. № 10. P. e1649.
25. Pecl G. T., Araujo M. B., Bell J. D. [et al.]. Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being // Science. 2017. № 355.6332. P. eaai9214.
26. Phartyal S. S., Rosbakh S., Poschlod P. Seed germination ecology in Trapa natans L., a widely distributed freshwater macrophyte // Aquatic Botany. 2018. № 147. P. 18–23.
27. Pinho P., Casanelles-Abella J., Luz A. C. [et al.]. Research agenda on biodiversity and ecosystem functions and services in European cities // Basic and Applied Ecology. 2021. № 53. P. 124–133.

28. Puppim de Oliveira J. A., Balaban O., Doll C. N. H. [et al.]. Cities and biodiversity: Perspectives and governance challenges for implementing the convention on biological diversity (CBD) at the city level // Biological Conservation. 2011. № 144. P. 1302–1313.
29. Pyšek P. Alien and native species in Central European urban floras: a quantitative comparison // Journal of Biogeography. 1998. № 25. P. 155–163.
30. Sala O. E., Chapin III F. S., Armesto J. J. [et al.]. Global biodiversity scenarios for the year 2100 // Science. 2000. № 287. P. 1770–1774.
31. Seto K. C, Güneralp B., Hutyra L. R. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools // Proc Natl Acad Sci USA. 2012. № 109. P. 16083–16088.
32. Sladecek V. System of water quality from the biological point of view // Arch. Hydrobiol. Ergeb. Limnol. 1973. № 7. 218 p.
33. Starodubtseva E. A., Grigoryevskaya A. Ya., Lepeshkina L. A., Lisova O. S. Alien species in local floras of the Voronezh region nature reserve fund (Russia) // Nature Conservation Research. 2017. № 2. P. 53–57.
34. Tall L., Caraco N., Maranger R. Denitrification hot spots: dominant role of invasive macrophyte *Trapa natans* in removing nitrogen from a tidal river // Ecological Applications. 2011. № 21. P. 3104–3114.
35. Turbelin A., Catford J. A. Chapter 25 – Invasive plants and climate change // Climate Change (Third Edition). Elsevier, 2021. P. 515–539.
36. Walusiak E., Krztoń W., Cieślak E. [et al.]. Native recovery or expansive threat? Past and predicted distribution of *Trapa natans* L. s. l. on northern limit of species' range, Handout for species management // Ecological Indicators. 2024. № 158. P. 111349.
37. Wiens J. J. Climate-related local extinctions are already widespread among plant and animal species // PLOS Biol. 2016. № 14. P. e2001104.
38. Zarubina E. Yu. [et al.]. Long-term dynamics of vegetation cover of Lake Manzherokskoye (Republic of Altai) under high antropogenic load on the reservoir and its basin // Ecosystem Transformation. 2024. № 7. P. 119–137.
39. Zhao X., Li F., Yan Y., Zhang Q. Biodiversity in Urban Green Space: A Bibliometric Review on the Current Research Field and Its Prospects // International Journal of Environmental Research and Public Health. 2022. № 19. P. 12544.

References

1. Anishchenko Yu.D., Anishchenko O.V., Zuev I.V. et al. Assessment of anthropogenic impact on the Yenisei River ecosystem within the city of Krasnoyarsk based on elemental analysis of macrophytes and water. *Zhurn. Sib. feder. un-ta. Biologiya = Journal of Siberian Federal University. Biology*. 2023;(16):87–108. (In Russ.)
2. Bochkin V.D., Mayorov S.R., Nasimovich Yu.A. et al. Additions to the adventive flora of Moscow and the Moscow region. *Byulleten' Moskovskogo obshchestva ispytateley prirody. Otdel biologicheskiy = Bulletin of Moscow Society of Naturalists. Biological series*. 2014;119(6):63–65. (In Russ.)
3. Bolotova Ya.V. Distribution of species of the genus Trapa L. (Trapaceae) in the Amur region (Russian Far East). *Vestnik Severo-Vostochnogo federal'nogo universiteta im. M.K. Ammosova = Vestnik of North-Eastern Federal University*. 2014;11(2):22–28. (In Russ.)
4. Bulavintseva A.G. The second find of Trapa natans L. (Lythnraceae) in the Kaluga region. *Byulleten' Moskovskogo obshchestva ispytateley prirody. Otdel biologicheskiy = Bulletin of Moscow Society of Naturalists. Biological series*. 2014;119(3):68–69. (In Russ.)
5. Glushenkov O.V., Glushenkova N.A. *Shkola gidrobotaniki: teoriya i praktika uchebnykh gidrobotanicheskikh issledovaniy: ucheb.-metod. posobie = School of hydrobotany: theory and practice of educational hydrobotanical research: study guide*. Cheboksary, 2013:176. (In Russ.)
6. Glushenkov O.V., Glushenkova N.A. *Rasteniya presnykh vod. Karmannyy opredelitel' = Freshwater plants. pocket guide*. Cheboksary, 2013:132. (In Russ.)
7. Kapitonova O.A. Flora of reservoirs and watercourses of Tobolsk (Tyumen region): main characteristics and their analysis. *Zhurnal Sibirskogo federal'nogo universiteta. Biologiya = Journal of Siberian Federal University. Biology*. 2023;(16):430–453. (In Russ.)
8. Kokin K.A. *Ekologiya vysshikh vodnykh rasteniy = Ecology of higher aquatic plants*. Moscow: MGU, 1982:160. (In Russ.)
9. Lisitsyna L.I., Papchenkov V.G., Artemenko V.I. *Flora vodoemov volzhskogo basseyna. Opredelitel' sosudistykh rasteniy = Flora of the Volga basin reservoirs. Guide to vascular plants*. Moscow: KMK, 2009:219. (In Russ.)
10. Panasenko N.N., Anishchenko L.N., Romanova Yu.N. Wolffia arrhiza (L.) Horkel ex Wimm in the Bryansk region. *Vestnik Bryanskogo gosudarstvennogo universiteta = The Bryansk State University Herald*. 2012;(4):203–204. (In Russ.)
11. Ryabova V.N., Vasil'eva V.A. Restoration of vegetation of reclaimed ponds of Lugovoy Park (water supply system of fountains of Peterhof). *Biological Communications (Vestnik SPbGU) = Biological Communications (Vestnik of Saint Petersburg University)*. 2014;(Ser.3(4)):49–66. (In Russ.)
12. Taller E.B., Yashin M.A., Tikhonova M.V., Buzylev A.V. *Laboratornyy praktikum po ekologii. Chast' I. Bioindikatsiya: ucheb. posobie = Laboratory practical training in ecology. Part I. Bioindication: study guide*. Moscow: DPK Press, 2021:106. (In Russ.)

13. Vizer A.M., Kipriyanova L.M. Finding of the water chestnut Trapa natans L. s. l. (Trapaceae) in the Novosibirsk region. *Turczaninowia*. 2010;13(3):67–69. (In Russ.)
14. Akasaka M., Takamura N., Mitsuhashi H., Kadono Y. Effects of land use on aquatic macrophyte diversity and water quality of ponds. *Freshwater Biology*. 2010;(55):909–922.
15. Barney J.N., Tharayil N., DiTommaso A., Bhowmik P.C. The biology of invasive alien plants in Canada. 5. Polygonum cuspidatum Sieb. & Zucc.[= Fallopia japonica (Houtt.) Ronse Decr.]. *Canadian Journal of Plant Science*. 2006;(86):887–906.
16. Cahill A.E., Aiello-Lammens M.E., Fisher-Reid M.C. et al. How does climate change cause extinction? *Proceedings of the Royal Society B: Biological Sciences*. 2013;(280):20121890.
17. Chorak G.M., Dodd L.L., Rybicki N. et al. Cryptic introduction of water chestnut (Trapa) in the northeastern United States. *Aquatic Botany*. 2019;(155):32–37.
18. Hassall C. The ecology and biodiversity of urban ponds. *WIREs Water*. 2014;(1):187–206.
19. Hegland S.J., Nielsen A., Lázaro A. et al. How does climate warming affect plant-pollinator interactions? *Ecol. Lett*. 2009;(12):184–195.
20. Lande V.W. Biomonitoring of water environment in rivers, ponds and lakes. *Journal of Global Biosciences*. 2021;(10):8458–8477.
21. Maclean I.M.D., Wilson R.J. Recent ecological responses to climate change support predictions of high extinction risk. *Proc. Natl. Acad. Sci. USA*. 2011;(108):12337–12342.
22. Markovic G., Vicentijevic-Markovic G., Tanaskovic S. First record of water chestnut (Trapa natans L., Trapaceae, Myrtales) in Central Serbia. *Journal of Central European Agriculture*. 2015;(16):436–444.
23. Nasimovich Yu.A. *The basin of the River Pahra in the south of Moscow*. 1991–2009. Available at: http://temnyjles.narod.ru/Reki3-20.htm (accessed 21.02.2025).
24. O'Briain R., Corenblit D., Gurnell A. Interacting effects of climate change and invasions by alien plant species on the morphodynamics of temperate rivers. *WIREs Water*. 2023;(10):e1649.
25. Pecl G.T., Araujo M.B., Bell J.D. et al. Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science*. 2017;(355.6332):eaai9214.
26. Phartyal S.S., Rosbakh S., Poschlod P. Seed germination ecology in Trapa natans L., a widely distributed freshwater macrophyte. *Aquatic Botany*. 2018;(147):18–23.
27. Pinho P., Casanelles-Abella J., Luz A.C. et al. Research agenda on biodiversity and ecosystem functions and services in European cities. *Basic and Applied Ecology*. 2021;(53):124–133.
28. Puppim de Oliveira J.A., Balaban O., Doll C.N.H. et al. Cities and biodiversity: Perspectives and governance challenges for implementing the convention on biological diversity (CBD) at the city level. *Biological Conservation*. 2011;(144):1302–1313.
29. Pyšek P. Alien and native species in Central European urban floras: a quantitative comparison. *Journal of Biogeography*. 1998;(25):155–163.
30. Sala O.E., Chapin III F.S., Armesto J.J. et al. *Global biodiversity scenarios for the year 2100*. *Science*. 2000;(287):1770–1774.
31. Seto K.C, Güneralp B., Hutyra L.R. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc Natl Acad Sci USA*. 2012;(109):16083–16088.
32. Sladecek V. System of water quality from the biological point of view. *Arch. Hydrobiol. Ergeb. Limnol*. 1973;(7):218.
33. Starodubtseva E.A., Grigoryevskaya A.Ya., Lepeshkina L.A., Lisova O.S. Alien species in local floras of the Voronezh region nature reserve fund (Russia). *Nature Conservation Research*. 2017;(2):53–57.
34. Tall L., Caraco N., Maranger R. Denitrification hot spots: dominant role of invasive macrophyte Trapa natans in removing nitrogen from a tidal river. *Ecological Applications*. 2011;(21):3104–3114.
35. Turbelin A., Catford J.A. Chapter 25 – Invasive plants and climate change. *Climate Change (Third Edition)*. Elsevier, 2021:515–539.
36. Walusiak E., Krztoń W., Cieślak E. et al. Native recovery or expansive threat? Past and predicted distribution of Trapa natans L. s. l. on northern limit of species' range, Handout for species management. *Ecological Indicators*. 2024;(158):111349.
37. Wiens J.J. Climate-related local extinctions are already widespread among plant and animal species. *PLOS Biol*. 2016;(14):e2001104.
38. Zarubina E.Yu. et al. Long-term dynamics of vegetation cover of Lake Manzherokskoye (Republic of Altai) under high antropogenic load on the reservoir and its basin. *Ecosystem Transformation*. 2024;(7):119–137.
39. Zhao X., Li F., Yan Y., Zhang Q. Biodiversity in Urban Green Space: A Bibliometric Review on the Current Research Field and Its Prospects. *International Journal of Environmental Research and Public Health*. 2022;(19):12544.