# Effects of urbanisation, habitat characteristics, and management on garden pond biodiversity: a citizen science approach

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## Highlights

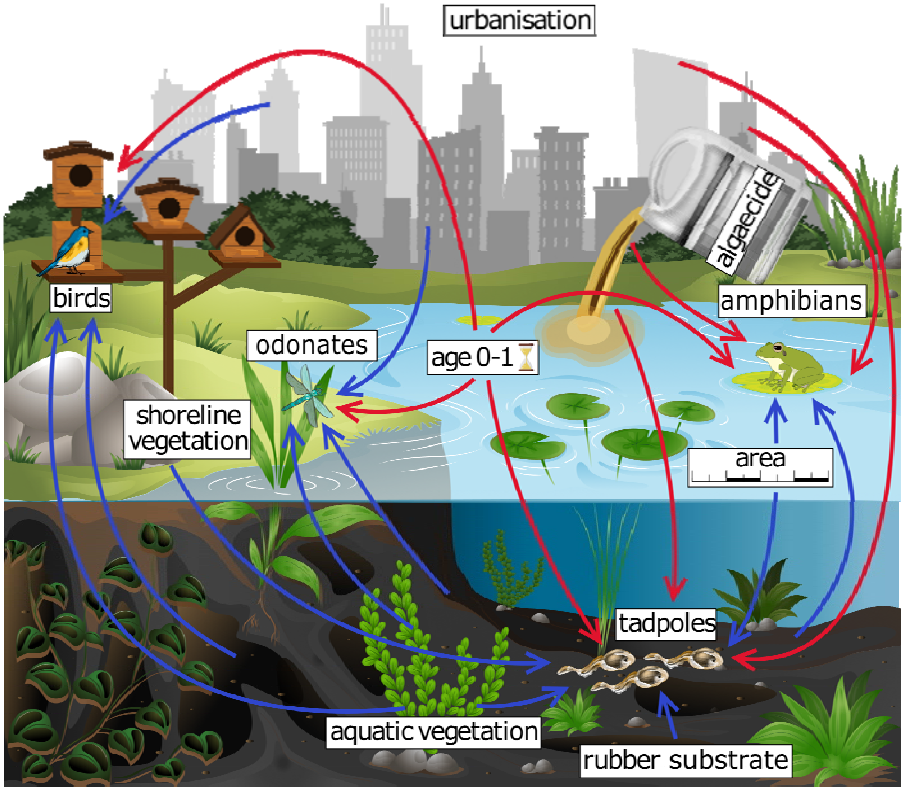
- Over 800 garden pond owners participated in a citizen science project in Hungary.
- Garden ponds can host flagship animal groups, e.g., amphibians, odonates, and birds.
- Pond age, area, and vegetation influenced the occurrence of these animal groups.
- Urbanisation had a negative effect on amphibian communities.
- Algaecide application played a key role in the presence of multiple animal groups.


## Abstract

The rapid expansion of urban areas leads to loss, fragmentation, and degradation of natural habitats, posing a serious threat to biodiversity. While urban ponds might contribute substantially to the biodiversity of urban blue-green infrastructure, the role of garden ponds, one of their most numerous representatives, is still little known. We lack a comprehensive understanding of how local habitat features, different forms of management, and urbanisation might impact the biodiversity of these habitats. This study aimed to reveal the importance of garden ponds via a country-wide online citizen science survey in Hungary, Central Europe. Based on data from over 800 pond owners, we gained knowledge about the prevalence and local frequency of various native animal groups, including amphibians, odonates, and birds, as well as information regarding introduced animals, such as fish. Additionally, we collected data about pond features and management practices. We tested the effect of pond features, pond management, and landscape-level drivers (urbanisation, surrounding wetland coverage) on the presence of conspicuous animal groups (adult amphibians, birds, odonates, and tadpoles) along with species of adult amphibians to identify the potential drivers of the biodiversity of garden ponds. Key pond features like pond age, area, aquatic and shoreline vegetation were the most important factors, while algaecide addition was the most influential management practice negatively affecting the presence of amphibians. Urbanisation had a

negative effect on the presence of adult amphibians and their tadpoles, but surprisingly, it was not negatively associated with the presence of odonates and birds. Our results demonstrate the vital role of garden ponds in urban biodiversity conservation, most notably by providing secondary habitats and contributing to amphibian conservation, as evidenced by the occurrence of 13 species. Emphasizing public involvement is key in developing effective urban biodiversity conservation strategies and recognizing citizens' potential contributions to a better functioning blue-green infrastructure.

**Graphical abstract**




**Graphical abstract:** Summary of the key results from the MyPond survey. Arrows indicate significant relationships (blue: positive, red: negative ) between the presence of animal groups and pond features and management practices)

**Keywords**

Citizen science, Community science, Garden ponds, Urban ponds, Biodiversity, Pond management

## 1. Introduction

Urbanisation is accelerating worldwide, being one of the major drivers of the reshuffling of global biodiversity acting through habitat loss, fragmentation, and degradation (Grooten and Almond, 2018; Stamenković et al., 2019; Tickner et al., 2020). Previous studies have shown that urbanisation often has a negative impact on biodiversity (Concepción, 2021; Danneck et al., 2023; McDonald et al., 2019). It can also create strongly selective environments, leading to a limited species pool in urban compared to natural habitats (Capotorti et al., 2023; Hill et al., 2021; Schueller et al., 2023). Species that can withstand the effects of urbanisation might adapt via genetic (Brans et al., 2018; Brans and De Meester, 2018; Johnson and Munshi-South, 2017) and behavioral changes (Ma et al., 2023; Rivera-Gutierrez et al., 2023; Uchida et al., 2020; Yin et al., 2023), which can foster population persistence and even successful colonization of the habitats in the blue-green infrastructure of urban areas. Consequently, urban habitats can also act as refuges and host considerable biodiversity depending on habitat planning and management (Soanes et al., 2023, 2019). Therefore, it is increasingly important to understand the role of local habitat features and management measures of blue-green infrastructure in our efforts to efficiently conserve and increase urban biodiversity.

Ponds are increasingly recognised as key aquatic habitats, by contributing over-proportionally to regional biodiversity and hosting threatened or endangered species (Céréghino et al., 2007; Williams et al., 2004). While there is no officially recognized international categorization, lentic aquatic habitats that are less than 5 m deep and are between

1 $m^2$ and up to 2-5 ha in size are generally considered ponds (Biggs et al., 2005; Céréghino et al., 2007; Richardson et al., 2022). There is still much uncertainty about the global number of ponds, but it has been estimated that small lakes (< 1 $km^2$) and ponds cover more than 3% of the Earth's surface, and constitute the most widespread type of inland standing waters (Downing et al., 2006). They often represent the locally most abundant aquatic habitats in natural landscapes and even in areas under high agricultural activity (Oertli et al., 2009; Ruggiero et al., 2008), being also among the most numerous components of the blue-green infrastructure in cities (Oertli et al., 2023).

Garden ponds are popular garden features, which can be numerous in urban areas. They are created for various reasons, including aesthetic values, microclimate regulation, keeping ornamental animals, or supporting biodiversity (Oertli et al., 2023). Garden ponds have the potential to offer many ecosystem services, and small ponds are a way to connect to nature, observe wildlife, and also to increase the blue-green surface in urban areas (Peeters et al., 2023). Still, there is only scarce information about the exact number of garden ponds in cities (Hill et al., 2021), and no standard protocol has been established regarding their management to support high biodiversity. Although garden ponds are small, their overall contribution to biodiversity can be quite important (Biggs et al., 2017). For example, they can host threatened taxa like amphibians (Hassall, 2014), which are among the most vulnerable freshwater organisms worldwide (Hamer and McDonnell, 2008). However, due to commercial trade and a lack of knowledge of many exotic species, garden ponds may also act as a source of invasive species thereby threatening native biodiversity (Patoka et al., 2017). For efficient management both suitable for the native species and not facilitating such invasion events, a better understanding of the current management practices and their connection with the wildlife of these secondary habitats would be essential.

Citizen (or community) science, i.e., the involvement of citizens in scientific research and data production, is becoming a valued and necessary research tool for scientists to evaluate or gain knowledge about a wide range of scientific topics (Fraisl et al., 2022), ranging from archeology (Smith, 2014) through ecology (Johansson et al., 2020; Oertli et al., 2023; Peeters et al., 2023) to astrophysics (Memarsadeghi et al., 2022). Citizen science has many shortcomings, such as the lack of standardized methods in the study design or unreliable data collection without expert knowledge. Still, data collected by citizens and later harmonized and validated by experts can greatly improve our understanding of species diversity at large spatial and temporal scales as well as ecological dynamics and the conservation status of species (Steven et al., 2019). For a better understanding of the biodiversity, ecology, and management of garden ponds, citizen science is an essential tool. This is because it allows us to gain data from ponds situated mostly in private gardens and to monitor details in local management based on data reported directly by the owners.

We conducted an online citizen science survey to explore the importance of garden ponds by assessing potential links between the biodiversity and management of garden ponds in Hungary based on data from pond owners. First, based on the resulting large-scale dataset covering a wide gradient in urbanisation across the country, we aimed to reveal the prevalence and local frequency (frequency of sightings) of multiple native aquatic and terrestrial animal groups that visit or use these garden ponds. We focused on taxonomic groups that are conspicuous enough so that they are easily and reliably identifiable by the public (amphibians, birds, odonates) and also collected species data on adult amphibians for which we accompanied our survey with an identification key. In addition, to gain information on potentially invasive exotic species, we collected information on animals deliberately introduced by the owners themselves. Second, in an attempt to identify the potential drivers of native biota, we tested the presence of these organism groups against local pond features and

management practices applied in the garden ponds. We hypothesized that pond management and features have a direct effect on the prevalence and local frequency of multiple animal groups and that urbanisation has an overall negative effect on the presence of these animal groups.

## 2. Materials and Methods

### 2.1. Citizen science survey

An online survey within the citizen science project "MyPond" was launched in 2021 to investigate the biodiversity, local features, and management practices of garden ponds in Hungary (Central Europe). The link to the questionnaire on the "MyPond" website (https://mypond.hu/en/) was distributed via traditional media outlets and social media. The survey consisted of a total of 30 questions: 6 multiple choices, 10 short answers, and 14 closed (yes-no) questions. We collected data on the local features of ponds, including age, area, substrate of the pond (concrete, rubber, plastic, natural), and the presence/absence of aquatic vegetation, shoreline vegetation, and fish. Besides, local management data included circulation, cleaning, draining, leaf removal, and use of algaecide. The biodiversity dataset comprised four animal groups, amphibians (here, we refer to adult amphibians or post-metamorphic juvenile sightings) and their tadpoles (tadpoles were reported separately from adult amphibians), birds, and odonates. The survey contained a link to the amphibian identification guide (drawings) of the Hungarian Ornithological and Nature Conservation Society to help the citizens correctly identify amphibian species (https://www.mme.hu/en/node/4440), which is available as a free smartphone application. Also, there was an option to name the type of birds they had seen in their gardens. The questionnaire is still available on the website and collects data for future purposes. Between 2021 and 2022 (2021 July 6- 2022 September 9), 834 participants filled out the questionnaire,

of which a validated subset of 753 responses was used for statistical analysis (Figure 1). Validation was carried out to exclude duplicates, incomplete data, and any pond with an area over 200 $m^2$, which was based on the frequency distribution of pond areas (the largest was 24000 $m^2$, while most (98%) ponds were smaller than 200 $m^2$).

In the case of the amphibian species dataset, we excluded amphibian species if pond owners made vague statements (e.g. "we have not seen that species in a few years"). However, we included species if the owner reported them as "rarely" seen. Furthermore, entries were excluded from the amphibian species dataset if it only included the name “frog”, “toad”, “newt”, or “tadpoles”, so species identity could not be determined. “Green frogs” were grouped into the *Pelophylax* spp. complex as the three species that comprise this group are morphologically difficult to separate (n = 332). Rare species were also cross-checked with the most up-to-date species distribution maps (https://herpterkep.mme.hu/index.php?lang=en) and retained only if their occurrence had already been proven within the region of the sighting. Species-level data for birds was available from 667 ponds, as those ponds where citizens reported birds only in general but did not specify the species were excluded from this dataset. The full questionnaire can be found in the supplementary information (Table S1).

The resulting datasets included both prevalence (binary; 0, 1) and local frequency (ordinal scale; 0, 1, 2, 3) data of each recorded animal group (amphibians and their tadpoles, odonates, birds). Pond features and management were used as binomial and ratio scale data in the statistical analysis (Table 1).

The area of urban land and wetland coverage as landscape-level drivers were calculated using the Ecosystem Map of Hungary (project KEHOP-430-VEKOP-15-2016-00001, Ministry of Agriculture, 2019). The number of raster pixels (2x2 m) was counted within a 1 km radius circle around each focal pond using the Zonal Histogram tool. The classification of land cover was used as defined by the Ecosystem Map of Hungary (Ministry

of Agriculture, 2019). The wetland coverage category contained pixels of wetlands, marshlands, temporary wetlands, standing waters, and flowing waters, while the urban land category (hereinafter urbanisation) contained pixels of tall buildings, short buildings, sealed roads, dirt roads, railways, other artificial surfaces, and urban green spaces with and without trees. Urbanisation and wetland coverage were then calculated as the proportion of total pixels within the 1 km radius covered by the respective land cover type. All spatial analysis was carried out in QGIS 3.28.1 (QGIS Development Team, 2022).

## 2.2. Statistical analysis

To visualize the prevalence and the local frequency of animal groups, we created barplots and pie charts using the “ggplot2” R package (Wickham, 2016).

To examine the relationship between amphibian community composition and pond features, pond management, and landscape-level drivers (urbanisation and wetland coverage), we performed canonical correspondence analysis (CCA) using the “vegan” R package (Oksanen, 2017). The analysis was based on prevalence data (binomial) of the amphibian species, our only species-level dataset. To normalize the distribution of variables belonging to pond features and landscape-level drivers, we used log transformation for pond area, and square root transformation was applied for wetland coverage prior to the CCA. Pond management variables were included as binomial data. Significant explanatory variables among pond features, management, and landscape-level drivers were identified based on an automatic stepwise (backward and forward) model selection procedure using permutation tests (“ordistep” function, direction = ”both”, n = 999 permutations).

To analyze which pond features, management types, or landscape-level drivers had the strongest effect on the prevalence of each animal group (Table 1), generalized linear models (GLM) were fitted with a binomial distribution and logit link function (hereinafter logistic

regression model). Model selection was carried out based on Akaike's Information Criteria (AIC) with the "MASS" R package (Venables and Ripley, 2002). To further analyze these effects on birds, reported bird types were categorized into three main groups (wading birds, ducks, and other birds, the latter category mostly including songbirds). Visualization was carried out with the "ggplot2" (Wickham, 2016) and "ggbreak" (Xu et al., 2021) R packages.

All statistical analyses and illustrations were made with the R program v 4.2.2 (R Core Team, 2022).

## 3. Results

Based on the prevalence data reported by 753 respondents, odonates (in 96.5% of the ponds) and birds (96.5%) were observed at almost all garden ponds. While the prevalence of amphibian sightings (81.4%) was higher than that of tadpoles, the latter was still observed in close to two-thirds of the ponds (62.1%). Among the amphibian species, *Pelophylax* spp. was the most frequently reported species (29.9%). The most frequently reported birds were songbirds (88.3%, including tits, blackbirds, sparrows, etc.). Within the introduced animal groups, fish were the most frequent (84.4%), while snails, turtles, mussels, and crayfish were all introduced to less than 6% of the ponds, respectively (Figure 2).

Local frequency data of amphibians, birds, and odonates revealed that most (60%, 78.5%, and 86.5%, respectively) of the respondents regularly see these animal groups in their ponds. Tadpoles were regularly present in the smallest share of ponds (40.6%) (Figure 3). Tadpoles were absent from the highest share of ponds (37.8%), but amphibian breeding was regularly observed in over 40% of the ponds detected via tadpole presence (Figure 3).

Participants recorded the presence of 13 amphibian species in garden ponds: three newt species (*Ichthyosaura alpestris*, *Lissotriton vulgaris*, *Triturus dobrogicus*), nine anurans (*Bombina bombina*, *Bufo bufo*, *Bufo viridis*, *Hyla arborea*, *Pelobates fuscus*, *Pelophylax* spp.,

*Rana arvalis*, *Rana dalmatina*, *Rana temporaria*) and one salamander (*Salamandra salamandra*). Amphibian species composition (based on prevalence data, Table 1) was significantly influenced by pond age, substrate, shoreline vegetation, algaecide usage, the introduction of fish, and urbanisation (Figure 4). There was a positive association between *Rana arvalis* and pond age, i.e., it occurred mostly in newly-installed ponds with rubber substrate and shoreline vegetation. *Lissotriton vulgaris*, *Rana temporaria*, and *Rana dalmatina* responded negatively to fish presence and algaecide treatment. *Bufo viridis* was positively associated with urbanisation. *Salamandra salamandra*, *Ichthyosaura alpestris*, *Triturus dobrogicus*, *Bombina bombina*, *Hyla arborea*, and *Pelobates fuscus* were positively associated with large, well-vegetated ponds with a natural substrate, which are only occasionally drained (Figure 4).

Urbanisation was negatively associated with the presence of amphibians and their tadpoles, while it generally did not have a negative effect on the presence of odonates and birds (Figure 5, Table S2). Pond age, area, and rubber substrate were the most frequently significant pond features. Amphibians and their tadpoles, odonates, and birds were less likely to be present in or at newly installed ponds (0-1 year). Pond area had a positive effect on amphibians and their tadpoles. Algaecide had a negative effect on the presence of both amphibians and their tadpoles. There was a positive effect of aquatic vegetation on tadpoles, odonates and birds, however, shoreline vegetation was only significant for the presence of tadpoles (Figure 5, Table S2).

## 4. Discussion

Our citizen science survey provided comprehensive large-scale data on the presence of flagship animal groups of garden ponds, covering an entire European country. Odonates and birds were observed at almost all 753 garden ponds, but amphibians and their tadpoles were also common. Local frequency data revealed that most respondents regularly see these animal

groups in their ponds. The age of the ponds turned out to be a general predictor, with animals more likely to be present in older ponds. In addition, area and rubber substrate were the most important pond features across the animal groups. Among management types, algaecide addition had a negative effect on amphibians and their tadpoles. Urbanisation had an overall negative effect on the presence of amphibians and tadpoles; conversely, odonates and birds showed an unexpected non-negative association. Our data also highlighted that owners introduce various animal groups into their ponds, most frequently fish, with potential consequences for the native biodiversity surrounding garden ponds. Our results demonstrated the crucial role of garden ponds in urban biodiversity and conservation, as they provide important secondary habitats for multiple animal groups in urban areas.

Urbanisation, i.e., the extent of urban landscape within a 1 km radius around the ponds, had disparate effects across the animal groups we investigated. It had a negative effect on the prevalence (presence/absence) of amphibians and their tadpoles in line with our original hypothesis and also corroborated earlier findings on amphibian prevalence and reproduction (Hamer and Parris, 2011; Rubbo and Kiesecker, 2005). Urbanisation is characterized by landscapes fragmented by roads, houses, and buildings that can impede dispersal between ponds and natural upland habitats that are important for amphibians to complete their complex life cycle (Hamer and McDonnell, 2008; Scheffers and Paszkowski, 2012). Urbanisation can also lead to habitat degradation such as the loss of aquatic and shoreline vegetation, which is key for amphibian oviposition and it also provides shelter for amphibians and their larvae (Hamer and McDonnell, 2008). Although urbanisation generally has a negative effect on amphibian diversity, some species are urban adapters (McKinney, 2002), favored by larger body sizes and lower dispersal requirements (they can persist in small habitat patches) (Hahs et al., 2023). For example, *Bufo viridis* was positively associated with urbanisation. This species has a relatively large body size and persists in the center of

European cities and towns (Landler et al., 2023; Mazgajska and Mazgajski, 2020; Sistani et al., 2021). The *Pelophylax* spp. complex had no discernible associations with any of the variables, probably because these species are habitat generalists and can maintain metapopulations in both natural and urban landscapes (Herczeg et al., 2012; Francesco Ficetola and De Bernardi, 2004). Conversely, species associated with natural ponds such as *Ichthyosaura alpestris* were only recorded in the Bakony Mountains (western Hungary) which is a protected forest, and this species is particularly vulnerable to landscape fragmentation due to urbanisation (Emaresi et al., 2011; Van Buskirk, 2012). The sighting of *Salamandra salamandra* also occurred adjacent to a large forested area (Bükk Mountains in northern Hungary) and populations of this species can persist in low-density urban areas provided there is sufficient forest nearby (Kiss et al., 2022).

On the other hand, urbanisation was not negatively associated with the prevalence of odonates and birds in general. These results might seem counter-intuitive at first, although there is evidence that in certain cases urban areas are able to maintain higher odonate species diversity than agricultural lands, due to a network of public, stormwater, or garden ponds that can foster the migration of species (Goertzen and Suhling, 2019; Willigalla and Fartmann, 2012). However, other studies also showed that species richness of odonates increased from the city center to more rural areas, probably due to increasing habitat availability (more water bodies in the rural areas than in cities) (Holtmann et al., 2018; Willigalla and Fartmann, 2012). Here, we only detected the presence of odonates as a group. Therefore, in our case, this pattern could also be explained by a few highly tolerant species occurring in urbanized landscapes, but more detailed follow-up studies will be necessary to link this pattern to species identities and biodiversity. The same might be true for birds, resulting from the presence of more generalist bird species such as blackbirds or sparrows, which are common even in heavily urbanised landscapes (Callaghan et al., 2019; Mennechez and Clergeau,

2006). Furthermore, it has been found that birds were more likely to visit water sources resembling natural waters, such as garden ponds, puddles, or fountains, in urban areas, where other natural water sources are scarce (Tryjanowski et al., 2022), which could have contributed to the pattern we found. Also, wading birds were a group quite frequently (24.3 %) reported from the ponds, which regularly included sightings of grey herons – a species regularly utilising garden ponds for foraging (Jakubas and Manikowska, 2011).

Pond age was overall the most important pond feature shaping the prevalence of animal groups. Newly installed ponds were less visited by wild animals, which can be due to the lack of vegetation that could offer hiding and breeding places to aquatic and semi-aquatic animal groups (Huikkonen et al., 2020). Additionally, colonization time might be another factor as animals need time to find and occupy newly installed ponds in the urban landscape (Cayuela et al., 2020; Coccia et al., 2016; Unglaub et al., 2021). Among the amphibian species, *Rana arvalis* was strongly associated with newly installed ponds that this species can potentially colonize while moving relatively long distances through the landscape (Brzeziński and Mętrak, 2014). Altogether, amphibians and their tadpoles were significantly associated with older ponds, correlating with a greater period for species to locate and colonize these ponds (Moor et al., 2022). Many amphibian species prefer well-vegetated or large ponds (Arntzen et al., 1997; Péntek et al., 2017; Rannap et al., 2013), which was supported by our results that several species such as *Bombina bombina, Pelobates fuscus, Triturus dobrogicus* were positively associated with aquatic vegetation in our ponds. Due to the larger size of the rubber-lined ponds, rubber substrate had a significantly positive effect on the presence of amphibians and their tadpoles, also odonates, birds, and wading birds (Hamer et al., 2023).

Algaecide addition was the most important form of pond management, influencing the presence of animal groups, particularly amphibians and their tadpoles. The application of algaecides in ponds was negatively associated with the prevalence of amphibians and their

tadpoles. This might be related to widely used substances of chemicals produced to reduce algal growth such as copper, which can inhibit tadpole growth and reduce survival (Christenson et al., 2014). It has been shown experimentally that tadpoles decrease algal abundance due to grazing, which suggests that creating ponds that are suitable for amphibians could provide natural bioremediation in garden ponds and eliminate the need to use algaecides (Dvorsky et al., 2023). However, other animal groups like odonates or birds did not have a significant negative association with algaecide addition. Birds use these habitats quite differently (e.g. for drinking or bathing) (Gibbons et al., 2023) than amphibians, who spend most of their lifecycle in the water. So birds may be less affected by the quality of water. Regarding odonates, there can be a number of highly tolerant urban species that might even withstand elevated levels of copper in the water (Tollett et al., 2009), which could have contributed to their presence under algaecide addition.

Exotic animals are frequently introduced by the owners of garden ponds for ornamental purposes (Hassall, 2014). According to our results, fish were the most frequently introduced animals (e.g. goldfish), being consequently present in 84% of ponds. In comparison to our finding, a study in the UK reported that only ~35% of the garden pond owners stocked their ponds with fish (Loram et al., 2011), which was only a third of what we found in Hungary. Besides fish, turtles and several invertebrates (snails, mussels, and crayfish) were also reported. Previous studies found that aquaria and garden ponds may act as sources of invasive species (Chucholl, 2013; Patoka et al., 2014; Soes et al., 2011; Van Den Neucker et al., 2017), e.g. the red-eared slider (*Trachemys scripta elegans*) (Tietz et al., 2023), water hyacinth (*Pontederia crassipes*) (Olden et al., 2021), signal crayfish (*Pacifastacus leniusculus*) (Chucholl et al., 2021). In this sense, without the indispensable knowledge and education about invasive species, garden pond owners and garden centers can

pose a threat to native biodiversity. This highlights the importance of outreach activities targeting pond owners, encouraging more conscious management choices.

We also found that the introduction of fish was negatively associated with all recorded amphibian species. Fish are important predators of all amphibian life stages and a negative relationship between fish and amphibian populations has been demonstrated for many European amphibians (Hartel et al., 2007; Van Buskirk, 2005). Despite the introduction of fish into 85% of ponds, amphibian reproduction was observed in 60% of the ponds, indicating that some species are able to co-exist with fish (Hamer et al., 2021; Kloskowski et al., 2020). In another study focusing on local pond features in the same set of ponds, it was also found that the introduction of fish was a significant predictor of garden pond design and within-pond features including management practices (Hamer et al., 2023). This result implies a potential conflict between creating ponds with the main aim of keeping ornamental fish and the potential of garden ponds to support native biodiversity.

To this date, there was no information available about the biodiversity of garden ponds in Hungary, similar to the rest of Eastern Central Europe. This also means a limitation in the implications of our study, given that we can not compare our questionnaire data to earlier or other regional datasets as a reference. Another potential caveat is that even with our best efforts for a validated dataset, there is the potential for species misidentification (especially with amphibians). To overcome this, we collected data on taxa that can easily be identified, and are considered flagship groups of pond diversity (Oertli et al., 2002). Concurrently, the high number of ponds in our analyses provides robust data for the general patterns that can be observed in these secondary habitats that could inform pond owners on management activities being more beneficial for the local pond biota.

With the globally accelerating rate of urbanisation and the related loss and alteration of aquatic habitats, a sound knowledge of the ecological roles of garden ponds is crucial. For

this, citizen science projects can be important tools by providing access to private properties and data with high spatial coverage. The potential of the approach is well-illustrated by the high level of engagement in the present survey, with over 800 completed forms. Based on communication with the respondents, many had a high interest in the habitat quality and biodiversity of their garden ponds. This suggests there is a high potential to change peoples' perspectives on the "ideal" garden pond via evidence-based outreach activities. We suggest the promotion of pond installations in urban areas by highlighting relevant facts about invasive species and the most suitable local features and management types to maximise local biodiversity. For effective biodiversity conservation in urban areas, where natural habitats are under constant pressure from degradation and mismanagement, public input and engagement are essential, for which citizen science can provide essential tools.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## CRediT authorship contribution statement

*Zsuzsanna Márton*: Data curation, Formal analysis, Visualization, Writing - original draft, Writing - review & editing

*Barbara Barta*: Conceptualization, Methodology, Data curation, Writing - review & editing

*Csaba F. Vad*: Conceptualization, Methodology, Writing - review & editing

*Beáta Szabó*: Formal analysis, Writing - review & editing

*Andrew J. Hamer*: Data curation, Formal analysis, Writing - review & editing

*Vivien Kardos*: Methodology, Visualization, Writing - review & editing

*Csilla Laskai*: Methodology, Writing - review & editing

*Ádám Fierpasz*: Methodology, Writing - review & editing

*Zsófia Horváth*: Conceptualization, Methodology, Writing - review & editing, Supervision

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**Data availability**

Data will be deposited in the Figshare database upon acceptance of the article.

**Table 1** Data types in the validated dataset

| Main variable groups | Recorded variables | Data type |
|---|---|---|
| **Biodiversity - prevalence** | **amphibians and their tadpoles, birds, odonates** | Binomial (0, 1) |
| **Biodiversity - local frequency** | **amphibians and their tadpoles, birds, odonates** | Ordinal (0, 1, 2, 3, corresponding to no, singular, occasional, and frequent sightings per pond) |
| **Pond management** | **circulation, cleaning, draining, leaf removal, algaecide** | Binomial (0, 1) |
| **Pond features** | **age, area, substrate (concrete, rubber, plastic, natural), aquatic vegetation, shoreline vegetation, fish presence** | Ratio scale data |

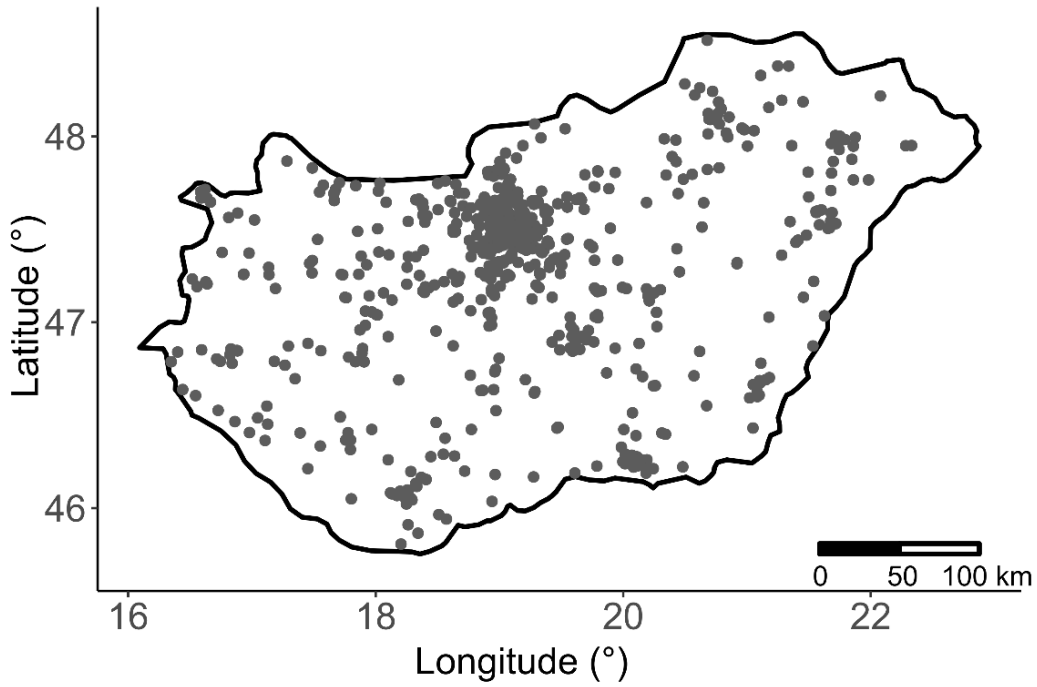


**Figure 1** Location of the 753 garden ponds in Hungary used in the analyses. (Map was created with R v. 4.2.2)

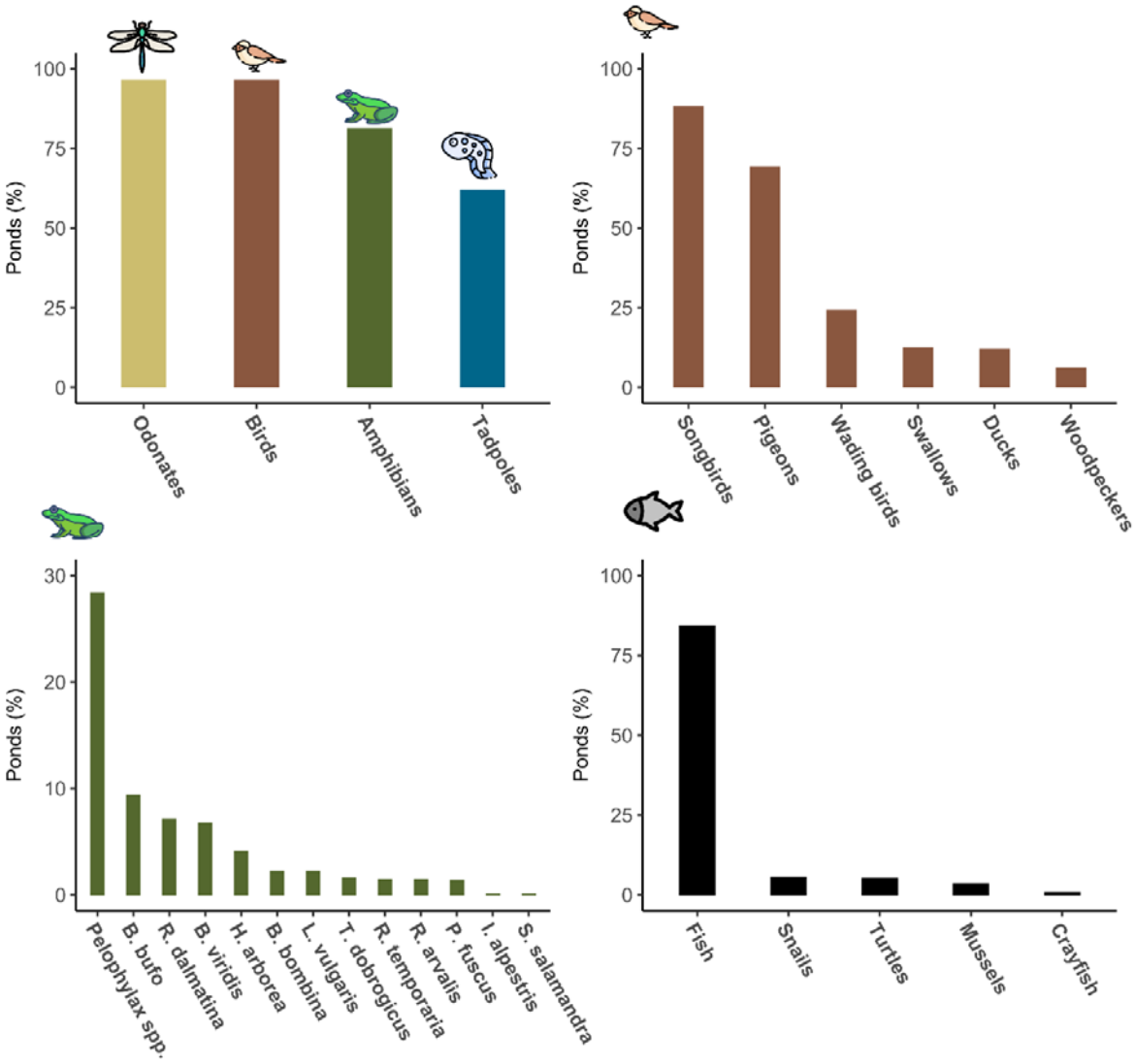


**Figure 2** Percentage of all ponds with the occurrence of the animal groups reported by the citizens. Samples sizes were n=667 in case of types of birds (top right), and n=753 in the other three datasets.

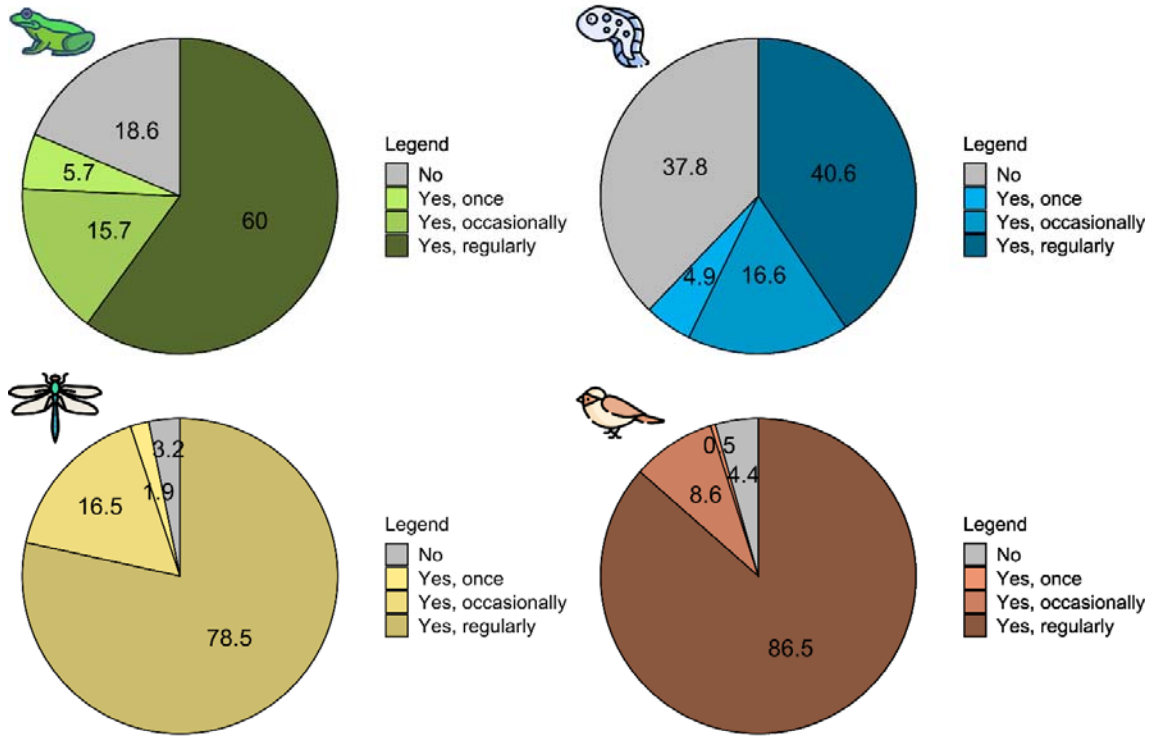


**Figure 3** Share (%) of each response on the local frequency of animal groups (amphibians and their tadpoles, odonates and birds) in garden ponds (n=753)

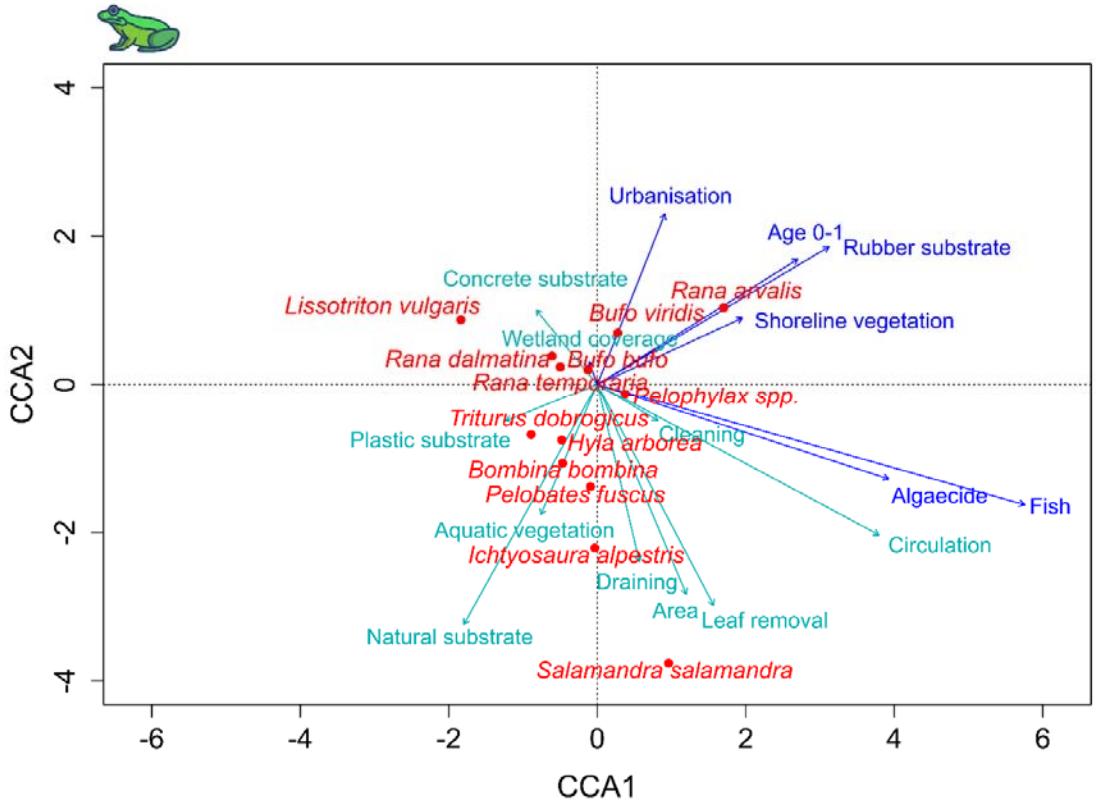


**Figure 4** Canonical correspondence analysis (CCA) biplot based on the reported prevalence of amphibian species, environmental predictors, and level of urbanisation (red points: species scores, dark blue arrows: significant predictors, light green arrows: all other predictors). The analysis is based on data from 332 ponds where participants recorded amphibian species data correctly.

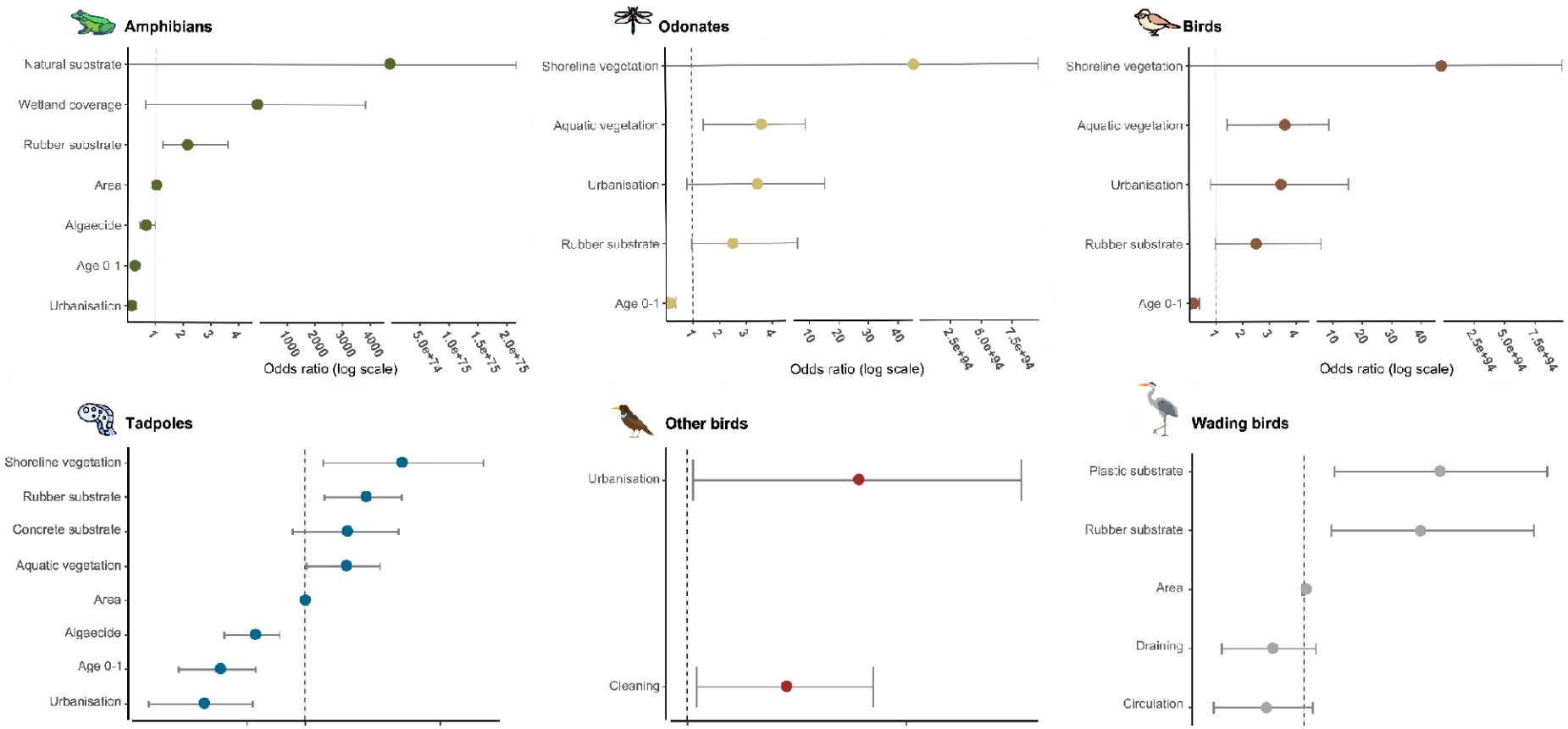
Amphibians
Natural substrate
Wetland coverage
Rubber substrate
Area
Algaecide
Age 0-1
Urbanisation
1
2
3
4
1000
2000
3000
4000
5.0e+74
1.0e+75
1.5e+75
2.0e+75
Odds ratio (log scale)
Odonates
Shoreline vegetation
Aquatic vegetation
Urbanisation
Rubber substrate
Age 0-1
1
2
3
4
10
20
30
40
2.5e+94
5.0e+94
7.5e+94
Odds ratio (log scale)
Birds
Shoreline vegetation
Aquatic vegetation
Urbanisation
Rubber substrate
Age 0-1
1
2
3
4
10
20
30
40
2.5e+94
5.0e+94
7.5e+94
Odds ratio (log scale)
Tadpoles
Shoreline vegetation
Rubber substrate
Concrete substrate
Aquatic vegetation
Area
Algaecide
Age 0-1
Urbanisation
Other birds
Urbanisation
Cleaning
Wading birds
Plastic substrate
Rubber substrate
Area
Draining
Circulation

**Figure 5** Summary of the best-fit logistic regression models (based on AIC) odds ratio and their 95% confidence interval testing the relationship between the prevalence of animal groups and pond features and management. Samples sizes were n=753 for amphibians, odonates, birds, and tadpoles, and n=667 for other birds and wading birds.

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