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RESEARCH ARTICLE

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Ecological characterisation of urban ponds in the Netherlands: a study based on data collected by volunteers

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Abstract

Blue space in the urban environment can positively contribute to public health and well-being. Many urban freshwater systems, however, are exposed to anthropogenic stressors, resulting in deteriorated water quality and biodiversity. Private garden ponds are essential elements of this blue space but little is known about their water quality since they are not monitored by water professionals. The Dutch citizen science initiative Waterdiertjes.nl focusses on biological water quality assessment using macroinvertebrates and launched a campaign to investigate garden ponds in 2021. The campaign yielded macroinvertebrate recordings in 60 garden ponds and limited additional information on dimensions, and presence of water vegetation and fish. Volunteers also investigated 92 public urban ponds in 2021. Combining both data allowed for evaluation of the similarity between both pond types. Analyses were also performed to discover the importance of pond dimensions and presence of aquatic vegetation or fish for the macroinvertebrate biodiversity and water quality. Multivariate analyses showed a considerable overlap in macroinvertebrate community composition between garden and public urban ponds. Results showed high variability in taxon richness, total macroinvertebrate density and water quality scores A significant, non-linear relation was observed between pond depth and macroinvertebrate taxon richness with the highest richness at a depth of 0.5-1m. Submerged vegetation correlated significantly with taxon richness with little vegetation having the lowest richness. Presence of fish or floating vegetation was not significantly related to taxon richness, total density and water quality scores possibly due to unnatural conditions that underlie in garden ponds. Since water professionals and academic scientists do not monitor garden ponds, citizen science may provide valuable data on water quality and biodiversity in these waters. The present initiative showed that volunteers can successfully monitor understudied ecosystems and gather data on temporal and spatial scales complementary to professional data that lead to new (ecological) insights.

Highlights

- A citizen science project was launched to investigate private garden ponds and public urban ponds in the Netherlands in 2021
- Private garden ponds are in general smaller with more floating vegetation than public urban ponds
- Garden and public urban ponds largely share macroinvertebrate communities but also may harbour specific communities
- Water depth and to a lesser extent submerged vegetation appeared to be more important for macroinvertebrates in urban ponds than presence of fish or floating vegetation
- Citizen science can generate valuable data and information that professionals can't or usually won't obtain

Keywords: biodiversity, citizen science, garden ponds, macroinvertebrates, Netherlands, public ponds, urban ecology, urban environment, volunteers, water quality

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Introduction

Blue spaces in the urban environment contribute to the quality of life through positively affecting public health and well-being (Vaeztavakoli et al. 2018, White et al. 2020). There are multiple pathways that link water to public health in cities (Rietveld et al. 2016) but essentially urban waters provide ecological and social ecosystem services (Costadone et al. 2021). The ecosystem services which can be supplied by an urban water clearly depend on the quality of the water in the blue spaces (Zhao and Wang 2021). In urban environments, freshwater systems are exposed to a variety of anthropogenic stressors that may all have a deteriorating effect on the water quality such as eutrophication (Toor et al. 2017), hydrological changes (Fletcher et al. 2013), and recreation (Venohr et al. 2018). Urban water systems have long been regarded as just storage systems of water without any other value but this view has changed over the last decades (Teurlincx et al. 2019). Many urban surface water bodies like ponds, lakes, and drainage channels are small but those small water bodies can have an important contribution to biodiversity (Biggs et al. 2017).

Citizen science, the involvement of volunteers in science projects, has been expanding over the past decades. Progressively more community initiatives have been undertaken to monitor the surrounding environment. Although volunteers can contribute to science projects at different levels (Shirk et al. 2012, Senabre Hidalgo et al. 2021), most citizen science projects focus on generating data and information. According to the UN, not only is the volunteers' participation crucial for monitoring the progress of a number of the UN Sustainable Development Goals (SDG) (UN 2015, Bishop et al. 2020), it will also become essential in the reporting on SDG (Fritz et al. 2019). The European Water Framework Directive also encourages citizens to provide input, expertise and time to help protect fresh waters (EC 2003).

Monitoring of water quality is in many countries legally tasked to professionals working at water authorities. In the European Union, these professionals are responsible for determining, maintaining and improving the water quality according to the Water Framework Directive (WFD) (EC 2003). Regional water authorities in the Netherlands have a long tradition in monitoring abiotic conditions and presence and abundance of plant and animal species. These observations are used for water quality assessment and reporting, strictly following the EU WFD (Pot 2021). In the Netherlands, the citizen science project Waterdiertjes.nl was launched in 2018 with the aim to engage volunteers in water quality monitoring and to present their results on a nationwide map. In the Dutch project, volunteers may collect macroinvertebrates in a nearby surface water, identify and count the number of specimens. The British Freshwater name trail (Orton et al. 1996) is used as identification key to limit the level of identification in order to involve as much volunteers as possible (Fore et al. 2001, Rae et al. 2019). After the identification and counting of the animals, the information is uploaded to the website 'Waterdiertjes.nl'. The web application then calculates a water quality score (Peeters et al. 2022) based on the information provided and sends this score back to the volunteer as a reward. A comparison has been made between data collected in the Netherlands by professionals and volunteers and this showed that only a minority of the samplings by professionals was in the urban environment (roughly 10% of yearly investigations) while volunteers sampled more frequently (roughly 20% of their samples) (Peeters et al. 2022). Since only a limited number of private garden ponds has been monitored in the past in the Netherlands (Peeters et al. 2022), knowledge on the biodiversity and water quality of these aquatic systems in the urban environment remains very limited.

Small ponds are in general more biodiverse than larger lakes possibly due to the lack of large fish (Scheffer et al. 2006). Although ponds in the urban environment are degraded compared to ponds in nature areas (Biggs et al. 2005, Zamora-Marín et al. 2021), they still significantly contribute to the urban's regional biodiversity (Indermuehle et al. 2004, Davies et al. 2008, Loram et al. 2011, Biggs et al. 2017). In their study, Hill et al. (2019) indicated that local environmental conditions are the primary drivers of macroinvertebrate biodiversity. Because of the many functions submerged plants perform e.g. changing physical and chemical environment, providing habitat (Thomaz 2021), they are considered crucial for the ecological functioning of ponds (Scheffer 1998, Cristina et al. 2009). The presence of vegetation positively promotes the diversity of other groups as periphyton, invertebrates, and fish (Declerck et al. 2005, Briggs et al. 2019) leading to a higher water quality. Contrary, the presence of benthivores feeding fish species such as pumpkinseed sunfish or carp can have a strong negative effect on the macroinvertebrate biodiversity (Van Kleef et al. 2008, Bonneau and Scarnecchia 2015). Additionally, the presence of small fish may also negatively impact macroinvertebrate communities (Leu et al. 2009). As a result, the presence of fish may lead to a lower macroinvertebrate diversity and water quality. Garden ponds have been constructed for various reasons such as for their aesthetic value or to support biodiversity or ornamental fish (Hill et al. 2021). The differences in underlying reasons for constructing garden ponds may thus lead to considerable variability in species richness and water quality of those ponds.

To further explore the water quality in urban ponds and possible impacts of vegetation and fish, the citizen science program Waterdiertjes.nl invited volunteers to monitor their own garden pond and to provide additional data on pond dimensions, vegetation and fish in 2021. The objective of this study is to analyse the data of garden ponds in combination with data available on public urban ponds to evaluate water quality and biodiversity patterns and to unravel the importance of dimensions, vegetation, and fish in these ponds. We hypothesize that private garden ponds will have a higher water quality and higher biodiversity than public urban ponds because they are less exposed to deteriorating environmental stressors like sewage overflow, nutrient enrichment by waterbirds and litter. Furthermore, we expect that depth

Table 1. Requested additional variables with their classes used during the 2021 garden pond campaign of Waterdiertjes.nl.

Dimensions		Vegetation cover		Fish
Depth (class)	Width (class)	Submerged (Class)	Floating (Class)	Presence (Yes/No)
< 0.5m	0 – 1 m	Hardly (< 10%)	Hardly (< 10%)	Small fish (< 5 cm)
0.5 - 1.0m	1 – 5 m	Little (10 – 25%)	Little (10 – 25%)	Larger fish (> 5 cm)
> 1.0m	5 – 15 m	Moderate (25 -75%)	Moderate (25 -75%)	
		Abundant (> 75%)	Abundant (> 75%)	

will have a positive effect since deeper ponds can provide more different habitats and warm up less quickly. Also, we assume that the presence of submerged vegetation contributes positively due to offering food, oxygen, and shelter while complete coverage by floating vegetation and the presence of fish will negatively affect diversity and water quality.

Materials & Methods

Data preparation

Waterdiertjes.nl does not provide extensive written guidelines on sampling procedures but some audio-visual material is available. Volunteers are stimulated to use a simple hand-net and white tray, to sample existing habitats, and to collect minimally 50 individuals. We retrieved all macroinvertebrate data from the website[1] that was related to the 2021 garden pond campaign in the Netherlands as well as data from public urban ponds from the same year. In a few cases, multiple volunteers investigated together the macroinvertebrates from a water system and uploaded their own recorded animals. In those cases, all recordings from the same day in the same pond were regarded as one observation and were merged together.

Season may influence macroinvertebrate community composition (Álvarez-Cabria et al. 2010) and to evaluate its importance a variable ‘season’ was created. Samples taken in March, April and May were assigned to Spring, June through August to Summer, September – November to Autumn and December, January and February to Winter.

The number of recorded taxa was counted and water quality score was calculated using the collected number of individuals per taxon and their indicator value (see Appendix S1) following (Peeters et al. 2022). In short, the counts and assigned water quality score are used to calculate the overall (weighted average) Citizen Science Water Quality (WQ_{cs}) sample score:

$$WQcs = \frac{\sum_{i=1}^{5} i \cdot n_i}{\sum n_i}$$

With n_i = number of individuals belonging to water quality class i, *i* = water quality indication ranging from 1 (very bad) to 5 (good)
The WQ_{cs} score ranges between 1 and 5 and this range is divided in five quality classes, being very bad (score 1-1.8), insufficient (1.8-2.6), moderate (2.6-3.4), reasonable (3.4-4.2) and good (4.2-5.0).

The requested additional information was related to the dimensions of the pond, coverage of submerged vegetation, coverage of floating vegetation (including free floating plants and rooted plants with floating leaves), and presence of fish (Table 1). Since there were very few recordings of the lowest two vegetation cover class, these were combined into one class ‘Little’.

Data analysis

The macroinvertebrate species community was analysed with multivariate analysis techniques using the software Canoco 5 (Ter Braak and Šmilauer 2012) to evaluate the importance of season. A Redundancy Analysis (RDA) with logarithmically transformed counts and season as explanatory variable showed that ‘season’ significantly contributed to explaining part of the observed pattern. To separate out this significant effect, ‘season’ was defined as covariate (Ter Braak and Šmilauer 2012) in a subsequent analysis. To link the results to the ordering of the samples with taxon richness, total density and water quality score, these variables were treated as supplementary variables in the principal components analysis (PCA). Supplementary variables themself do not determine the ordination but are related afterwards by regression to the ordination results (Ter Braak and Šmilauer 2012). To find patterns between macroinvertebrate community composition and the incomplete requested additional information, samples in the ordination diagram from the PCA were labelled with values for the variables depth, width, submerged and floating vegetation and fish.

Univariate Generalized Linear Models (GLMs) were applied to evaluate whether pond depth and width, vegetation and fish had a significant contribution in explaining taxon richness, total density and water quality score. First the contribution and significance of season was tested followed by the other variables. A normal distribution with identity as link was used for the water quality scores while for the number of taxa and total number of collected individuals a Poisson distribution with a log-link was applied. To overcome overdispersion, the Pearson chi-square estimate of the scale parameter was used to obtain more conservative variance estimates and significance levels following (McCullagh and Nelder 1983). The Wald Chi-Square test was used to evaluate the significance of the model with $p \leq 0.05$ being significant and $0.05 < p < 0.10$ being

[1] https://www.waterdiertjes.nl accessed on 2022-02-04

regarded as a trend. The reduction in deviance was used to assess the contribution of a model to the explanation of the variance (Peeters and Gardeniers 1998). The deviance reduction (R) of a variable included in the GLM was calculated from the deviance without and with the variable in the model:

$$R = \left(1 - \frac{D_{with}}{D_{without}}\right) * 100\%$$

Where R = reduction in deviance, D_{with} = deviance of model with variable and $D_{without}$ = deviance of model with that variable.

Pearson's chi-square tests (Field 2013) were used to test whether differences in frequency distribution over the classes of the environmental variables were significantly different between garden and public urban ponds.

All these analyses were done using IBM SPSS version 25 (IBM Corp 2017).

Results

General characteristics

Data were available from 60 garden ponds and 92 public urban ponds. Additional information on dimensions, presence of vegetation and presence of fish was provided in roughly 40% of the ponds (see Appendix S2). Inventories were done throughout the Netherlands between April and November with 70% of the observations in September and October.

Environmental conditions

Table 2 shows that there are some differences in environmental conditions between garden and public urban ponds. Most ponds had an intermediate depth of 0.5-1.0 m. The studied public urban ponds had greater width than garden ponds and this difference was significant (Table 2). Approximately 1/3 of the ponds had no fish at all and in more than 50% of the ponds small fish was present. Both submerged and floating plants were frequently present covering a considerable part of the pond. No significant differences between public urban and garden ponds were found in coverage of submerged vegetation but coverage of floating vegetation was significant lower in public urban ponds (Table 2).

Water quality

Water quality in garden and public urban ponds in the Netherlands ranged from very bad to good (Fig. 1). The majority of ponds had a moderate or reasonable water quality while a smaller fraction had a very bad or good water quality. The distribution of the observations over the water quality classes was not significantly different (Chi-Square 3.281, df 4, p 0.524) between public urban and garden ponds although public urban ponds had relatively fewer observations in the good quality class.

Macroinvertebrate taxa

The number of macroinvertebrate taxa collected varied between 1 and 20, most frequently 5 to 8 taxa were collected (Fig. 2a). In 25% of the samples only

Table 2. Overview of the counts of the different classes of the variables depth, width, fish and vegetation for garden and public urban ponds and results of Chi-Square test for significant differences.

Variable	Class	Garden ponds (n)	Public urban ponds (n)	Chi-Square X^2	df	p-value
Depth	0-0.5m	8	5	4.054	2	0.151
	0.5-1.0m	11	22			
	>1m	10	8			
Width	0-1m	6	1	28.919	3	<0.001
	1-5m	13	5			
	5-15m	6	11			
	>15m	-	22			
Fish	No fish	10	12	3.901	33	0.282
	Small fish	6	12			
	Small & large fish	10	5			
	Large fish	5	4			
Submerged vegetation	Little	4	12	4.551	2	0.117
	Moderate	15	11			
	Abundant	6	5			
Floating Vegetation	Little	8	20	11.654	2	0.001
	Moderate	15	4			
	Abundant	4	3			

1 or 2 taxa were collected and observations with more than 17 taxa were rare. The abundance of the macroinvertebrates reported ranged from 1 to 254 individuals (Fig. 2b) with 57% of the samples having an abundance between 9 and 64 individuals and roughly 15% of the samples having more than 50 individuals.

Community analysis

A first RDA with season as explanatory variable showed that sampling period explained significantly 6.5% of the variation in the macroinvertebrate community structure (Monte Carlo Permutation Test with 999 permutations, pseudo-F = 4.5, p=0.002). A PCA with the variable 'season' as covariate and the variables 'Taxon richness', 'Total density', and 'water quality score' as supplemental variables showed that the ordering of the samples along the first ordination axis correlates largely with taxon richness and total density and less with water quality score (Fig. 3). The figure also clearly shows that the position of the garden ponds partially overlap with the position of the public urban ponds and those overlapping samples are characterized by low species richness and low total density. Furthermore, Fig. 3 also shows that there is a distinct group of garden ponds in the upper half of the diagram and a distinct group public urban ponds in the lower part of the diagram. This separated group of public urban pond is characterized by higher abundance of Baetidae, Hydracarina, Oligochaeta and to a lesser extend Hirudinea, Corixidae and Chironomidae. Contrary, a distinct group of garden ponds had larger amounts of Lymnaeidae, Hydrometridae, Gerridae, Gyrinidae, Planorbarius and Planorbidae. Labelling the position of the samples with values for the different variables showed that depth, fish, submerged, and floating vegetation did not show a pattern that corresponded with the ordination scores (Fig. S1). Based on pond width, the group of samples in the bottom part can be distinguished as have been taken in larger public urban ponds with a moderate depth and little floating vegetation.

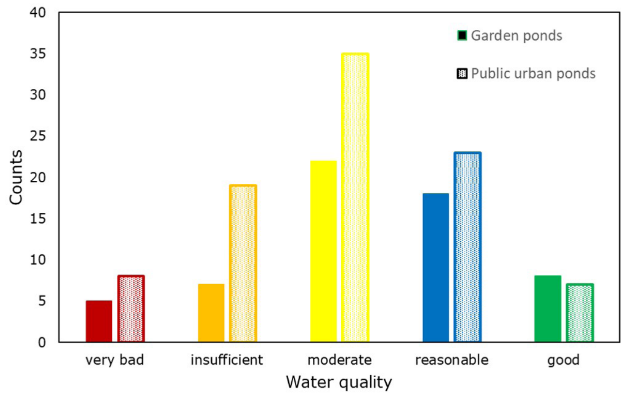

Figure 1. Water quality in garden (solid bars) and public urban (open bars) ponds in the Netherlands in 2021 based on the presence and abundance of macroinvertebrates following the methodology of Peeters et al. (2022).

Importance explanatory variables

Results of the separate Generalized Linear Models (Table 3) show that season had a significant reduction in deviance (between 25-30%) for taxon richness and a lower (16-25%) but still significant reduction in deviance for total density. Season did not link to the water quality score i.e. there was no relation found between macroinvertebrate species indicating either good or bad water quality to the period they were sampled.

Table 3 also shows that pond depth, submerged vegetation and water quality class had an additional significant effect on taxon richness. Interestingly, the contribution of season became insignificant after including depth as the second explanatory variable. Depth reduced deviance more than season and the additional reduction in deviance by submerged vegetation was roughly one quarter of the total

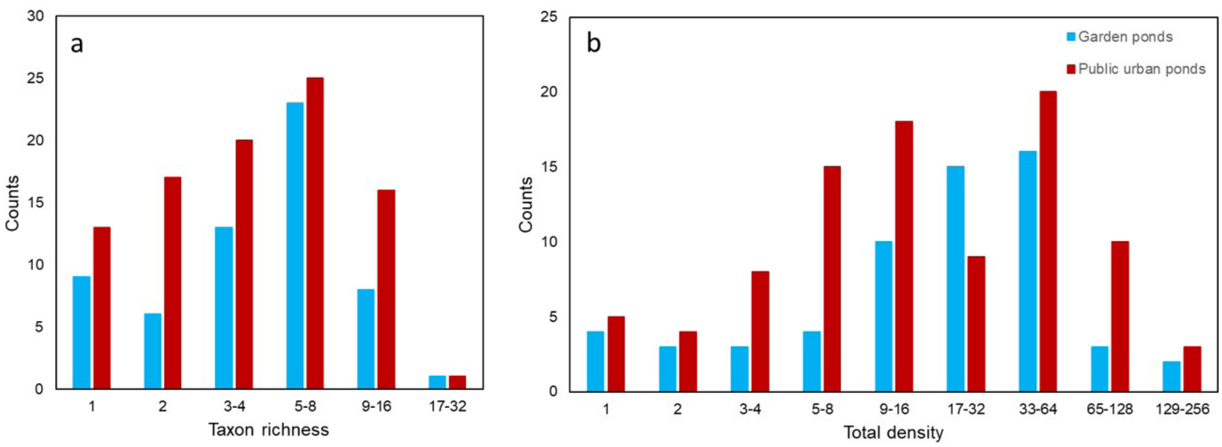

Figure 2. Frequency distribution of taxon richness (a) and total density (b) of macroinvertebrates in garden (blue bars) and public urban (red bars) ponds in the Netherlands in 2021.

Table 3. Results of separate Generalized Linear Models (GLMs) applied to the response variables showing deviance reduction (D_{red} in %) and the Wald Chi square (X^2) together with the p-values (p) from the Test of model effects. GLM with normal distribution and identity as link for water quality score and quasi-Poisson distribution and log link for taxon richness and total density.

Response variable	Variables	n	Chi-Square		
			Deviance reduction (%)	X^2	p
Taxon richness	Intercept			90.335	0.000
	Season		25.6	50.638	<0.001
	Type	152	0.2	0.355	0.551
	Intercept			226.273	0.000
	Season		5.8	5.368	0.068
	Depth pond	64	34.1	6.679	0.035
	Intercept			437.173	0.000
	Season		28.9	26.585	<0.001
	Fish	65	5.1	4.370	0.224
	Intercept			392.927	0.000
	Season		27.8	21.811	<0.001
	Submerged vegetation	54	9.4	6.563	0.038
	Intercept			356.666	0.000
	Season		26.3	15.966	<0.001
	Floating vegetation	53	0.5	0.311	0.856
	Intercept			491.216	0.000
	Season		30.6	29.257	<0.001
	Width pond	64	0.4	3.639	0.308
	Intercept			70.654	0.000
	Season		24.6	48.284	<0.001
	Water quality score	152	9.6	17.621	0.001
Total density	Intercept			72.918	0.000
	Season		23.2	33.106	<0.001
	Type	152	0.0	0.064	0.800
	Intercept			421.544	0.000
	Season		16.6	5.561	0.062
	Depth pond	64	8.5	4.951	0.084
	Intercept			448.461	0.000
	Season		18.2	9.231	0.010
	Fish	65	3.2	1.714	0.634
	Intercept			482.365	0.000
	Season		16.2	7.043	0.030
	Submerged vegetation	54	1.2	0.476	0.788
	Intercept			307.205	0.000
	Season		16.2	6.144	0.046
	Floating vegetation	53	0.3	1.214	0.545
	Intercept			459.231	0.000
	Season		16.7	7.612	0.022
	Width pond	64	1.5	0.754	0.860
	Intercept			66.571	<0.001
	Season		23.2	34.670	<0.001
	Water quality score	152	7.3	9.129	0.058
Water Quality Score	Intercept			1.787.880	0.000
	Type	152	2.2	3.467	0.063
	Intercept			697.227	0.000
	Depth pond	64	5.3	3.587	0.166
	Intercept			751.561	0.000
	Fish	65	1.3	0.904	0.824
	Intercept			5.503.351	0.000
	Submerged vegetation	54	0.3	0.164	0.921
	Intercept			560.419	0.000
	Floating vegetation	53	6.4	3.626	0.163
	Intercept			628.049	0.000
	Width pond	64	1.7	1.138	0.768

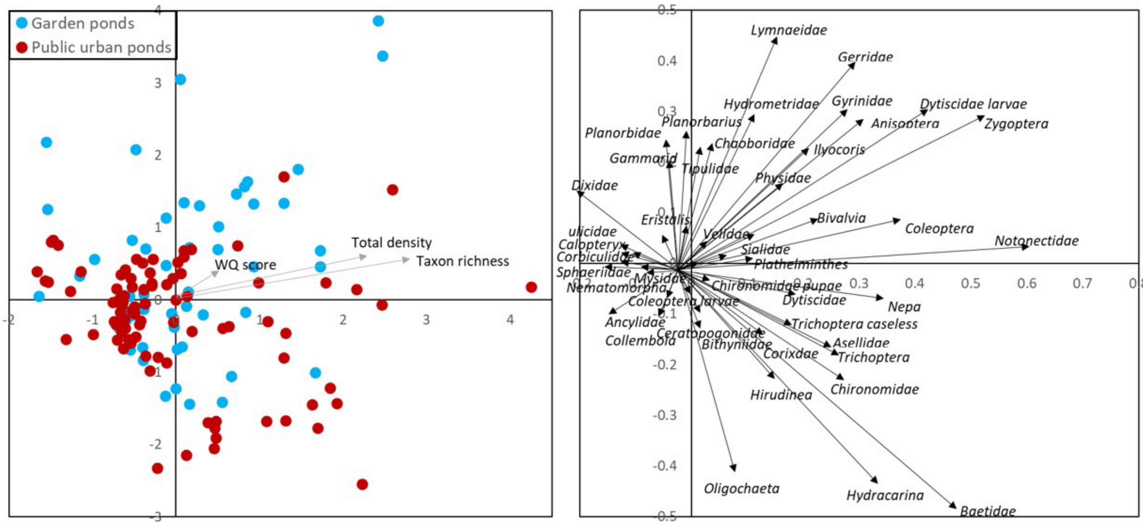

Figure 3. Graphical representation of the results of a principal components analysis applied to macroinvertebrate counts in garden and public urban ponds in the Netherlands in 2021 in which the variable 'season' was used a covariate and the variables 'Taxon richness', 'Total density, and 'Water Quality score' were treated as supplemental variables. The horizontal axis corresponds with the first principal components axis (Eigenvalue 0.120), the vertical axis with the second axis (Eigenvalue 0.082). Left panel shows the position of the samples from garden (blue dots) and public urban (red dots) ponds and the direction of increase (arrow head) and strength (arrow length) of the supplemental variables. Right panel shows the species represented by arrows indicating their direction of increasing abundance.

reduction. Fig. 4 shows that the relationship between taxon richness and depth was not linear with the highest richness observed in the middle depth class and lowest in the deeper ponds. Little submerged vegetation, including no vegetation, had a significantly lower taxon richness than moderate and abundant submerged vegetation.

For total density, none of the factors had a significant additional effect on deviance reduction although for depth and water quality score the additional effect showed a trend (p<0.10). For the water quality score, no significant relationships were established with depth, size, fish, submerged and floating vegetation. Pond type showed only a weak trend.

Discussion

This study compared macroinvertebrate communities from garden ponds with those from public urban ponds and evaluated the effects of depth, presence of fish, presence of submerged and floating vegetation on community composition, taxon richness, total density and water quality score. To study these relationships, data collected by volunteers in garden ponds (n=60) and public urban ponds (n=92) was analysed and evaluated. As with other studies based on data collected by volunteers, the quality of the data can be questioned (Hunter et al. 2013, Balázs et al. 2021). Identification of animals up to species or genus level can be an important source of faults and mistakes. Although identifying animals to higher taxonomic units, as is done in the Waterdiertjes.nl initiative, will lower the risk on errors, minor mistakes in identification will always be inevitable both for volunteers and professionals. Difficult to distinguish

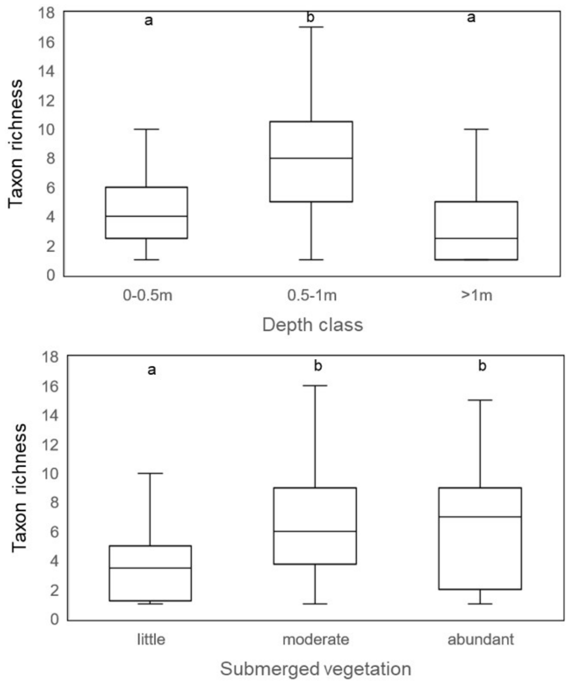

Figure 4. Relationship between taxon richness and depth class (upper panel) and coverage of submerged vegetation (lower panel). Categories that are not significantly different from each other share letters as obtained from the GLMs.

taxa, like swimming mayfly larva and a young damselfly larva, received a comparable water quality indicator value in the assessment tool and a possible mistake will therefore have a small effect on the calculated water quality score. In a few cases, we merged recordings made on the same day in the same pond to one observation. These recordings were made by secondary school students working together and it is very unlikely that this merging led to a very different sample size. To characterize the environment, volunteers had to make an estimate for a number of variables that had broad classes. Using class variables on the one hand is not very precise but reduces possible errors on the other hand. For most volunteers, estimating the presence of fish and the vegetation layers will be more difficult than estimating the dimensions of the water system. Although training of volunteers may increase the accuracy and precision of citizen science data (Hunter et al. 2013), compulsory training may result in a lower participation by volunteers. Data on dimensions, presence/absence of water vegetation and fish was only available for approximately 40% of the ponds. This had a limiting effect on possible data analyses tools. For example, the multivariate Redundancy Analysis requires complete series of biotic and abiotic data (Ter Braak and Smilauer 2012) and applying such a technique to the present dataset would disregard more than half of the data. Availability of more observations on the requested additional information would, therefore, have been very beneficial. Paying more attention to this aspect during the campaign could have helped and is a valuable learning point for future campaigns of Waterdiertjes.nl. Waterdiertjes.nl does not have strict guidelines for participating. While the lack of protocols and guidelines may lead to a higher degree of participation and possibly to more awareness of water quality issues, this will also generate bias in the sampling procedure, handling of samples and data. Such a lack of standardised sampling protocols and insufficient sample size is, however, not unique to data generated by volunteers but also occurs in regular science (Baker and Penny 2016). Furthermore, the larger number of observations that can be generated by volunteers (Kelling et al. 2015) may minimize the impact of this bias. Although differences may exist between inventories made by volunteers and professionals (e.g. Peeters et al. 2022), results of volunteers and experts generally matched (Pinto et al. 2020).

Season

Macroinvertebrate community structure and composition may change seasonally (Álvarez-Cabria et al. 2010, Wang et al. 2022) among others due to differences in life-cycles leading to temporal replacement of species (Butler 1984). The multivariate analysis applied in the present study supports this with 6.5% of the total variation being explained by season. The results of the GLMs also showed that season contributed significantly to explain differences in taxon richness and total density. Interestingly, there was no significant seasonal effect on the water quality assessment. Tools to evaluate biological water quality should respond to changes in the quality and preferably not to other environmental factors (Stark and Phillips 2009) and should be consistent over time if quality remains comparable (Karr et al. 1987). Since observations over time have been done in different urban ponds, the lack of a seasonal pattern is no proof for the temporal consistency of the assessment tool. Monitoring a number of ponds multiple times during a year may shed light on this issue.

Water depth

Water depth was hypothesized to have a positive effect on macroinvertebrates. This study revealed that water depth showed no clear pattern in the macroinvertebrate community composition but had a strong and significant effect on taxon richness even overruling the seasonal effect. Adding water depth as an explanatory variable together with season showed a trend in total density. The importance of depth has been shown in other studies (Hill et al. 2021) and deeper waters are likely to offer more heterogeneous environmental conditions (Heino 2000). Furthermore, deeper waters are also less likely to dry during warm summers (Heino et al. 2017). Interestingly, in those studies diversity increased with depth while in the present study richness was lowest in the deeper garden ponds (>1m). Richness seems to show an optimum in the intermediate depth class (0.5-1.0 m) with the shallowest urban ponds (<0.5 m deep) also being poorer in richness. Multiple reasons could possibly underly this: (1) these very shallow waters are frequently limited in size and thus offer a less heterogeneous environment (Heino 2000), (2) are much more vulnerable for warming due to their limited volume, resulting in unfavourable (too high) water temperature conditions in summer, and (3) the small surface area of the aquatic environments may possibly hamper the colonization by macroinvertebrates especially if surface waters are scarce in the urban environment. Deeper urban ponds were also relatively poor in richness. Possible reasons for this low diversity could be: (1) volunteers may have difficulty in sampling all available habitats, and (2) sometimes these ponds are stocked with benthivorous feeding fish that negatively affect the macroinvertebrates (Bonneau and Scarnecchia 2015).

Macrophytes

Submerged macrophytes were expected to stimulate macroinvertebrate diversity because in natural water systems they perform some key functions like contributing to keeping the system in a clear state, providing oxygen during photosynthesis, offering food and shelter for zooplankton and macroinvertebrates, and competing with algae for nutrients (Scheffer 1998, Moss et al. 2003). The majority of urban ponds had moderate to abundant submerged macrophyte cover. No clear pattern was found between submerged vegetation and macroinvertebrate community composition but the GLM showed that submerged macrophytes had a significant effect on taxon richness. Shallow lakes are known to have different alternative stable states with one state characterized by crystal clear water and the presence of submerged water plants and another state dominated by algae resulting in a turbid state (Janssen et al. 2014, Hilt et al. 2017). Phosphorus loading and competition for nutrients between the macrophytes and algae are the crucial drivers behind these states (Scheffer 1998). A similar competition for nutrients resulting in alternative stable states can be seen in small, wind sheltered ponds and ditches (Netten et al. 2011, Peeters et al. 2013). In those sheltered systems, one state is dominated by free-floating macrophytes (usually duckweed) completely covering the water surface blocking all sunlight and leading to anaerobic conditions. The other is characterized by a rich submerged vegetation and clear water (Scheffer et al. 2003). In both cases, excessive nutrients entering the systems are responsible for the shift from clear water to the undesired turbid state. Most garden ponds will likely not receive a high nutrient load because use of fertilizers is very limited. Furthermore, many garden ponds are fed with precipitation and in dry summers with tap or groundwater, and these sources are known to be poor in nutrients (McGoff et al. 2017). This results thus in a limited nutrient range and therefore a shift towards a turbid state is not likely. Interestingly, only a very limited number of urban ponds had high coverage of floating vegetation in the present study and therefore the expected negative effect on macroinvertebrates is probably not visible. The multivariate analysis showed the separate position of a group of public urban ponds that are characterized by larger width (>15m). These ponds had little floating vegetation probably due to the lack of protection against wind by which floating vegetation can be easily blown away (Peeters et al. 2013).

Fish

Unexpectedly, this study did not find a clear relationship between the presence of fish and macroinvertebrates. Estimating fish presence is possibly different between garden and public urban ponds. Owners of garden ponds usually know quite well what fish is present in their ponds even without sighting them during the sampling of macroinvertebrates. Information on the presence of fish in public urban ponds on the other hand comes mostly from sightings during the sampling and the recorded absence of fish in public urban ponds thus indicates that no fish has been observed but this is not a guarantee that fish is absent. This difference may lead to bias in the fish recordings possibly blurring relationships. In natural freshwater ecosystems, fish play a key role in their functioning and generates several ecosystem services beneficial for humans (Holmlund and Hammer 1999). In very small freshwater systems, opportunities for larger fish to survive are severely limited (Scheffer et al. 2006). Especially bottom feeding fish like bream and carp may exert strong effects on macroinvertebrate diversity (Bonneau and Scarnecchia 2015). Also invasive fish species may have a strong negative effect on macroinvertebrate like pumpkinseed fish (Van Kleef et al. 2008). Several garden ponds have been specifically constructed for fish (Hill et al. 2021) and these, usually deeper ponds were stocked with larger fish in this study. It is very likely that these ponds were gardened with care by their owners to maintain healthy fish. Fish densities in those ponds can be much higher than in comparable natural pools, having a negative effect on the presence of macroinvertebrates. This effect may overrule the tendency of deeper, natural ponds to have a richer species than composition than shallower ponds. Furthermore, intensive maintenance is frequently needed to maintain fish in garden ponds. Due to the too low productivity of garden ponds, additional food is frequently supplied. Permanent filters are installed to reduce algal growth, fountains are placed to ensure sufficient oxygen in the water and macrophytes are removed multiple times a year. All these measures may negatively affect macroinvertebrate richness and water quality.

Garden ponds and public urban ponds

Since garden ponds were anticipated to be exposed to less environmental stressors than public urban ponds, it was expected that they had a better water quality. Despite a trend in the water quality scores, no significant difference was observed in water quality classes between garden and public urban ponds. The multivariate community analyses showed a large overlap between garden and public urban ponds. However, there was a distinct group of larger urban ponds with a moderate depth and little floating vegetation. This group was characterized by taxa like Baetidae, Hydracarina, Oligochaeta and to a lesser extend Hirudinea, Corixidae and Chironomidae. Also a group of garden ponds could be distinguished which had larger amounts of snails (Lymnaeidae, Planorbarius, Planorbidae) and animals that live on the surface of the pond (Gerridae, Gyrinidae) but without clear correlations with other environmental variables. The overlapping samples all had relatively few taxa and individuals. Although Waterdiertjes.nl suggests to sample at least 50 individuals for obtaining a reliable water quality score, roughly 75% of the public urban and 85% of the garden ponds examined did not meet this criterion. It seems, therefore, that collecting 50 animals is a challenging task for volunteers. Another possible reason for the large overlap between garden and public urban ponds might be the use of the name trail for identification of the macroinvertebrates. This name trail lists only a limited number of taxa and as a result possible differences that exist on the species or genus level may disappear when comparing on family or higher taxonomic level. Therefore, it could be that this study underestimates the differences between garden and public urban ponds. Small habitat size and isolation may promote species richness in natural ponds (Scheffer et al. 2006), but many garden ponds may even be much smaller than those natural ponds. This study clearly showed that garden ponds, indeed, were significantly smaller than the public urban ponds. The number of macroinvertebrates that can inhabit those very small ponds will be very low. Even carefully sampling all animals will then not generate the desired number of individuals. Another possible cause is related to pond ownership and the sampling procedure. One owner of a garden pond clarified that sampling your own garden pond is performed much more carefully than sampling public water systems in order to avoid damaging the pond itself. Another reason for the low macroinvertebrate richness and density could be the frequently occurring unnatural conditions in these urban ponds. Garden ponds as well as public urban ponds are mostly man-made water systems. Many public urban ponds suffer, for example, from unnatural, steep banks that strongly reduce habitat heterogeneity and associated macroinvertebrate richness (Heino 2000). Garden ponds on the other hand are sometimes so shallow that under natural conditions they would dry up in a hot summer. To preserve the pond, they are refilled with tap water but in a hot summer the high temperature will reduce the availability of oxygen in the water making the conditions harsh for the macroinvertebrates. In addition, garden ponds are sometimes stocked with fish that in natural situations wouldn't reach such a high density or wouldn't have any fish present at all. Most public urban ponds and nearly all garden ponds are man-made water systems. Garden ponds have been constructed for various reasons such as for their aesthetic value or to support biodiversity or ornamental fish (Hill et al. 2021). The differences in underlying reasons for constructing urban ponds as well as their heavily maintenance may result in ecosystems that are under strong pressure leading to species poor communities since only a limited number of species is able to cope with multiple stressors (Vinebrooke et al. 2004).A comparison between garden and non-urban ponds in the UK showed a lower species richness for garden ponds (Hill et al. 2021). Despite this lower diversity, the blue spaces in gardens may fulfil an important role in the urban environment since these ponds receive much less pollution in comparison to other urban water systems. Those comparatively unpolluted urban waters are scarce (McGoff et al. 2017) and offer opportunities for species requiring good water quality that otherwise would not survive and may, therefore, function as stepping stones in urban environments.

Water quality and citizen science

Regional water authorities in the Netherlands have a long tradition in monitoring abiotic conditions and biotic lifeforms (algae, zooplankton, macrophytes, macroinvertebrates, fish) in various freshwater ecosystems. Interestingly, they have no clue about water quality in garden ponds since those blue spaces in the urban environment are not monitored by them (Peeters et al. 2022). According to the WFD, garden ponds are too small water systems to be of interest for the water professionals and furthermore these professionals usually have no access to these ponds. The last decades there is also a tendency in scientific research to cut budgets on monitoring and as a consequence it becomes more and more difficult for scientists to perform comparative field studies, like studying garden ponds. Citizen science initiatives on the other hand can ask volunteers to monitor their own environment as shown in this study. Other examples are the British study on mammals in gardens (Toms and Newson 2006), the study on pollinating bees and garden plants in the UK (Anderson et al. 2020) or the garden bird count in the Netherlands (https://www.vogelbescherming.nl/tuinvogeltelling). Frequently, citizen science projects gather data on temporal and spatial scales that are different from professional investigations. The present study investigated macroinvertebrates and related water quality in urban ponds and generated data and information leading to new insights like the non-linear effect of depth and the absence of a clear effect of fish in these ponds. The added value of citizen science has also been recognized by the European Water Framework Directive that encourages the involvement of interested parties (EC 2003, Van der Heijden and Ten Heuvelhof 2012) as well as by the United Nations for monitoring the progress of a number of Sustainable Development Goals (UN 2015, Bishop et al. 2020).

Conclusions

Analysis of data collected by volunteers in urban ponds in the Netherlands in 2021 showed that garden ponds are usually smaller and have a higher coverage of floating vegetation than public urban ponds. Despite these differences in conditions, there were no clear differences in water quality based on macroinvertebrates between garden ponds and public urban ponds. The time of year the sampling was performed (season) had an expected impact on the macroinvertebrate community structure, taxon richness and total density, but not on the assessed water quality class.

Taxon richness and to a lesser extent total density were correlated with the depth of the pond. Taxon richness did not show a linear relationship with depth but had an optimum at the middle depth class (0.5 – 1 m). Submerged vegetation was only significantly related to taxon richness with the lowest cover class having fewer macroinvertebrate taxa than the other two depth classes. Floating vegetation had no effect at all and unexpectedly, the presence of fish had also not a significant effect on the macroinvertebrates and water quality score.

Urban ponds may differ in macroinvertebrate community composition and water quality. Since garden ponds have comparatively unpolluted water, they may serve as essential habitats and stepping stones for species requiring good water quality in urban environments.

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Author Contributions

ETHMP: conceptualizing, data analyses, writing, editing & reviewing
MW: conceptualizing, editing
AAMG: conceptualizing, editing
LMSS: conceptualizing, editing

Data Accessibility

All data analysed in this study are available in supplementary Appendix S1.

Supplemental Material

The following materials are available as part of the online article at https://escholarship.org/uc/fb

Figure S1. Graphical representation of the positions of the samples on the first (horizontal) and second (vertical) axis of a principal components analysis with logarithmically transformed counts of macroinvertebrates and the variable season as covariable.

Appendix S1. Macroinvertebrate data from the inventory in garden ponds and public urban ponds launched by Waterdiertjes.nl in the Netherlands in 2021 together with the water quality indicator value per taxon.

Appendix S2. Calculated water quality score and class based on macroinvertebrates and additional information on dimensions, and presence of vegetation and fish in garden ponds and public urban ponds in the Netherlands in 2021.

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