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Ornamental ponds as Nature-based Solutions to implement in cities

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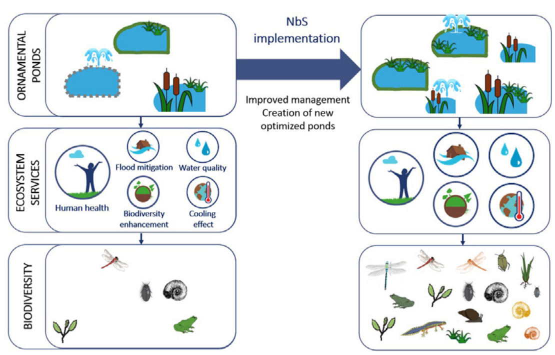
HIGHLIGHTS

- Ornamental ponds are often designed for a single objective, aesthetic enjoyment, and lack multifunctionality.
- However, ornamental ponds present a potential for delivering more ecosystem services, especially biodiversity.
- Low-cost management measures can easily increase their multifunctionality and promote the biodiversity.
- Ornamental ponds and their networks represent Nature-based Solutions for addressing societal challenges in cities.

GRAPHICAL ABSTRACT



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ABSTRACT

Small waterbodies such as ponds are widely represented in cities, contributing to the blue-green infrastructure, improving human well-being. Ornamental ponds are particularly abundant in the densest urbanized areas, especially in parks, in private grounds such as gardens and also imbedded in the green infrastructure. However, their multifunctionality remains infrequent, as generally aesthetic enjoyment is the main ecosystem service targeted. The promotion of native biodiversity is rarely a priority, as are other ecosystem services (e.g. flood mitigation or water purification). It is nevertheless questionable if such mono-functional ponds could also be able to provide other services. Indeed, an innovative approach would be to increase the multifunctionality of ornamental ponds, especially for biodiversity. This was investigated in 41 ornamental ponds designed for providing aesthetic enjoyment in the city of Geneva (Switzerland). The biodiversity was assessed, as well as selected ecosystem services (water retention, phytopurification, cooling effect, carbon sequestration). A survey among the population was also conducted. This survey underlined a recognized contribution of ornamental ponds to well-being. However, the assessment of the ecosystem services evidenced a lack of multifunctionality for most of these ponds. They presented a low biodiversity, compared to more natural ponds and to unimpaired ponds. Furthermore, they performed poorly for most other ecosystem services investigated. There were nevertheless exceptions, with selected ponds displaying a multifunctionality, even for ecosystem services for which they were not designed. It was also shown that ornamental ponds could easily be optimized for biodiversity by simple low-cost management measures. Additional ecosystem services could also be promoted. The performance of small ornamental ponds is best when ponds are considered collectively, as pondscapes, with their cumulative benefits. New ornamental pond implementation is therefore encouraged, as their multifunctionality turns them into Nature-based Solutions able to contribute to solving several societal challenges and to improve human well-being.

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1. Introduction

The rate of urbanization is currently increasing sharply, leading to a degradation of the environment and the quality of life in cities (Buhaug and Urdal, 2013; Grimm et al., 2008; Seto et al., 2012). This situation is exacerbated by the concomitant pressure of climate change (IPCC, 2023). In this context, many new societal challenges have to be urgently addressed in cities, in particular those linked to natural and climatic hazards, climate resilience, water management, air quality, health and well-being, place regeneration, green space management and biodiversity enhancement. Innovative approaches are therefore expected for preserving and improving the quality of life in the cities. The implementation of Nature-based Solutions (NbS) represents a particularly well adapted approach, as it provides several benefits supporting sustainable urbanization (Kabisch et al., 2016). “Nature-based Solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits” (IUCN, 2020). The implementation of NbS in cities constitutes therefore a pillar of international, national and local policies for addressing major societal challenges and improving the well-being of inhabitants, as well as promoting biodiversity in the urban matrix.

The promotion of NbS, through its multifunctional framework, allows reorienting and redesigning the management and planning of urban infrastructure that would otherwise be too unidirectional. Indeed, the perspective of a single benefit, as in the case of stormwater management has frequently led the implementation of blue-green infrastructure, for example in the United States (Newell et al., 2013) and also in Asia (Jiang et al., 2018). There is therefore a need to develop integrated planning models that assess synergies and trade-offs between ecosystem services provided by the greening programs (Meerow and Newell, 2017).

Many NbS implemented in European cities are related to the creation or management of parks and (semi)natural green areas, blue areas, urban green spaces connected to green infrastructure, allotments and community gardens, external building greens, green areas for water management and derelict areas (Xie and Bulkeley, 2020). In this list, blue areas are represented mainly by running waters, fens, marshes, wetlands, lakes and ponds. Ponds (waterbodies with a surface between 1 m^2 and 5 ha) and their networks (i.e. pondscapes) offer a large potential as NbS. Indeed, this has already been evidenced in less urbanized areas, like sub-urban or rural areas, where they are recognized for offering crucial habitats for biodiversity and for delivering multiple ES, such as climate mitigation and adaptation to climate change, water purification, flood mitigation and cultural benefits (e.g. recreational possibilities) (Biggs et al., 2017; Cuenca-Cambronero et al., 2023).

In the context of biodiversity decline, the most important ecosystem service provided by ponds and pondscapes nowadays is probably the provision of habitats for biodiversity. Indeed, a wide body of international evidence now shows that ponds are exceptionally important waterbodies for biodiversity at catchment and landscape levels, where they support more freshwater species than rivers or lakes (Biggs et al., 2017). However, the creation of ponds is usually linked to other services. In many agricultural landscapes, these waterbodies have long been associated with small-scale water storage for food production, directly (e.g. fish, watercress) or indirectly (livestock watering), erosion control, water purification, local irrigation or even domestic uses (EPCN, 2008). This is still the case today in places where agriculture is extensive, as in several parts of Asia, Africa and South-America (e.g. Bichsel et al., 2016; Gao et al., 2015; Simaika et al., 2016). A unexpected service of pondscapes in the agricultural landscape, is also pollination, as the abundance of insect-pollinators is higher with the presence of ponds (Stewart et al., 2017). Some other pond types are implemented specifically for flood mitigation or water purification, and are therefore widespread in periurban or suburban areas: they are known as Stormwater ponds, Sustainable Drainage Systems (SuDS) (Woods Ballard et al., 2015), or constructed wetlands (Vymazal, 2011). Urban areas are mainly impervious, and rainfalls lead to a large volume of runoff. Ponds have potentially a high hydraulic efficiency for buffering this water flow, and best management practices are available for planning the implementation of such constructed waterbodies (Urbonas and Stahre, 1993). Pond water quality is often impaired in cities by pollution linked to surface runoff that potentially brings suspended solids, nutrients, heavy metals, pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, endocrine-disrupting chemicals, salts, bacteria, and many other pollutants. Highly vegetated ponds can therefore be effective for reducing such pollution, through the cumulative effect of various processes: chemical precipitation, sedimentation and burial, filtration, volatilization, adsorption and microbial degradation, and plant and microbial uptake (Manzo et al., 2020; Vergeles et al., 2015). The cooling potential of waterbodies is also today a motivation for the creation of blue areas, especially in cities. Indeed, large water volumes can reduce air temperature, especially if integrated in a blue or green landscaping (Coutts et al., 2012; Gunawardena et al., 2017; Kuşçu Şimşek and Ödül, 2018; Sun et al., 2012; Yao et al., 2023). However, the real impact of ponds of small sizes is insufficiently documented with respect to this ES (Gunawardena et al., 2017). In urban areas, cultural ecosystem services take a particular importance, and connection to nature, interaction with wildlife and aesthetic appreciation are often highly expected by citizens. In urban parks, ponds are often valued by people for enhancing their green space experience, as evidenced in London (Ngiam et al., 2017) or Sweden (Pedersen et al., 2019). Another additional potential service offered by ponds, rarely considered in urban areas, is the sequestration of carbon. Ponds are now recognized as collectively constituting a large carbon sink (Downing et al., 2008; Taylor et al., 2019). They are nevertheless also a large methane source (Holgerson and Raymond, 2016). Knowledge remains still scarce on this topic, especially in urban areas.

Within the highest urbanized areas of cities, small ponds are numerous, but they are mostly represented by ornamental ponds. Their implementation and management often have the objective of delivering cultural ecosystem services (ES) linked to their aesthetic value, such as recreation (maintaining mental and physical health) or aesthetic appreciation. As biodiversity is rarely a target, these ornamental ponds cannot be considered NbS as such. These ornamental ponds generally contribute only moderately to native biodiversity conservation, and furthermore, they host many alien and even invasive species (Oertli et al., 2018; Teurlincx et al., 2019). Most public parks host such ponds created for purposes linked to their aesthetic value, to leisure and to well-being. In residential areas, garden ponds are particularly numerous (Davies et al., 2009) and are mostly also ornamental ponds, as they are created for aesthetic enjoyment. Garden ornamental ponds frequently host many alien species such as goldfish and colored waterlilies. The biodiversity in garden ponds is often low, both locally and regionally, when compared to more natural ponds (Hill and Wood, 2014; Hill et al., 2021). Nevertheless, their potential for a contribution to biodiversity conservation is not to discard, as they can host threatened species (Copp et al., 2008). Ornamental ponds lack multifunctionality, as also they are not expected to deliver regulating ES, as for example those linked to regulation of water quantity, regulation of water quality, or regulation of local air quality.

In ornamental ponds where the target is to promote only cultural ES, a selection of regulating or supporting ES could probably easily be promoted for contributing to a well-being in cities. For example, biodiversity can easily be promoted in urban ponds, as a cost-effective management can create habitats favoring a higher diversity (Oertli and Parris, 2019). Also, regulating services, as those linked to water quality or water retention, could undoubtedly be promoted. The multifunctionality of these ornamental ponds could therefore turn their implementation into efficient NbS.

This study investigates in a representative European city, ornamental ponds that are designed for aesthetic enjoyment or leisure. We selected 41 ornamental ponds in the most urbanized area of a medium-sized city, Geneva (Switzerland), to assess their multifunctionality. The biodiversity was measured, focusing on five taxonomic groups: aquatic plants, freshwater snails and beetles, dragonflies, and amphibians. Additional information was collected for four regulating ES: water retention, phytopurification, cooling effect and carbon burial. A social survey was also conducted to assess the acceptance of ornamental ponds in the city, and their contribution to well-being.

Our main hypothesis is that these 41 urban ornamental ponds will provide only weak benefits for biodiversity and other ecosystem services. Nevertheless, we expect that the 41 ornamental ponds will show a gradient in supplying ES, allowing identifying the conditions under which some benefits are provided for one or several ES. Furthermore, we will try to identify the main driving variables for biodiversity. The final objective is to provide a science-based framework to propose a strategy for increasing the multifunctionality of ornamental ponds, especially for providing habitats for biodiversity.

2. Methods

2.1. Study site

The investigations were conducted in Geneva (Switzerland), a medium-sized European city covering 16 km^2 and hosting 204′000 citizens. Geneva and the surrounding urbanized area together form the "Grand Genève" with 2000 km^2 and 1 million inhabitants. A total of 41 ornamental ponds were identified in the most densely built-up urban area of Geneva, i.e. the area with an impervious surface coverage higher than 40 % (calculated from the local GIS layers). Their geographic location is presented in Fig. 1, and six representative examples of ornamental ponds are illustrated in Fig. 2. Due to the high density of constructions in this area, the space for nature is quite restricted, and therefore the ponds are almost all small, with a median size of 90 m^2 (min: 2; max: 3752) (see Appendix A for detailed values). These 41 ornamental ponds were located in various contexts: 17 in public parks, 13 in private gardens, 7 in schools, 4 diverse (retirement home, international organization, urban farm, industry).

2.2. Contribution of ornamental ponds to the well-being of the citizen

A social survey was conducted among 380 citizens in five public parks in the urban area of Geneva (Fig. 1): Parc des Franchises, Parc Brot (Fig. 2e), Jardin de la Paix (Fig. 2b), Parc Bertrand, Parc La Grange, each of them hosting one ornamental ponds. All five ponds have a primary objective to provide aesthetic enjoyment. The answers were collected face-to-face in situ, with a first set of 92 answers in the summer of 2018 (Meilland, 2018) and a second set of 288 answers in the summer of 2022 (Vasco et al., 2023). The two sets were combined, as there were no statistical differences between them (inter-parks or inter-years). The enquiries were composed from a large set of questions (see details in Meilland, 2018; Vasco et al., 2023). Nevertheless, only the most relevant question for the present study is presented here. This question was closed-ended (five-point scale) and assessed the contribution of a pond to people's quality of life.

2.3. Biodiversity and environmental variables

The biodiversity inventory targeted five taxonomic groups representative of ornamental pond biodiversity: aquatic plants, aquatic macroinvertebrates (snails- Gastropoda - and beetles-Coleoptera), adult dragonflies (Odonata) and amphibians. These groups were chosen because they include flagship species for urban ponds (e.g. aquatic plants, frogs, dragonflies). Furthermore, these groups are ecologically complementary with

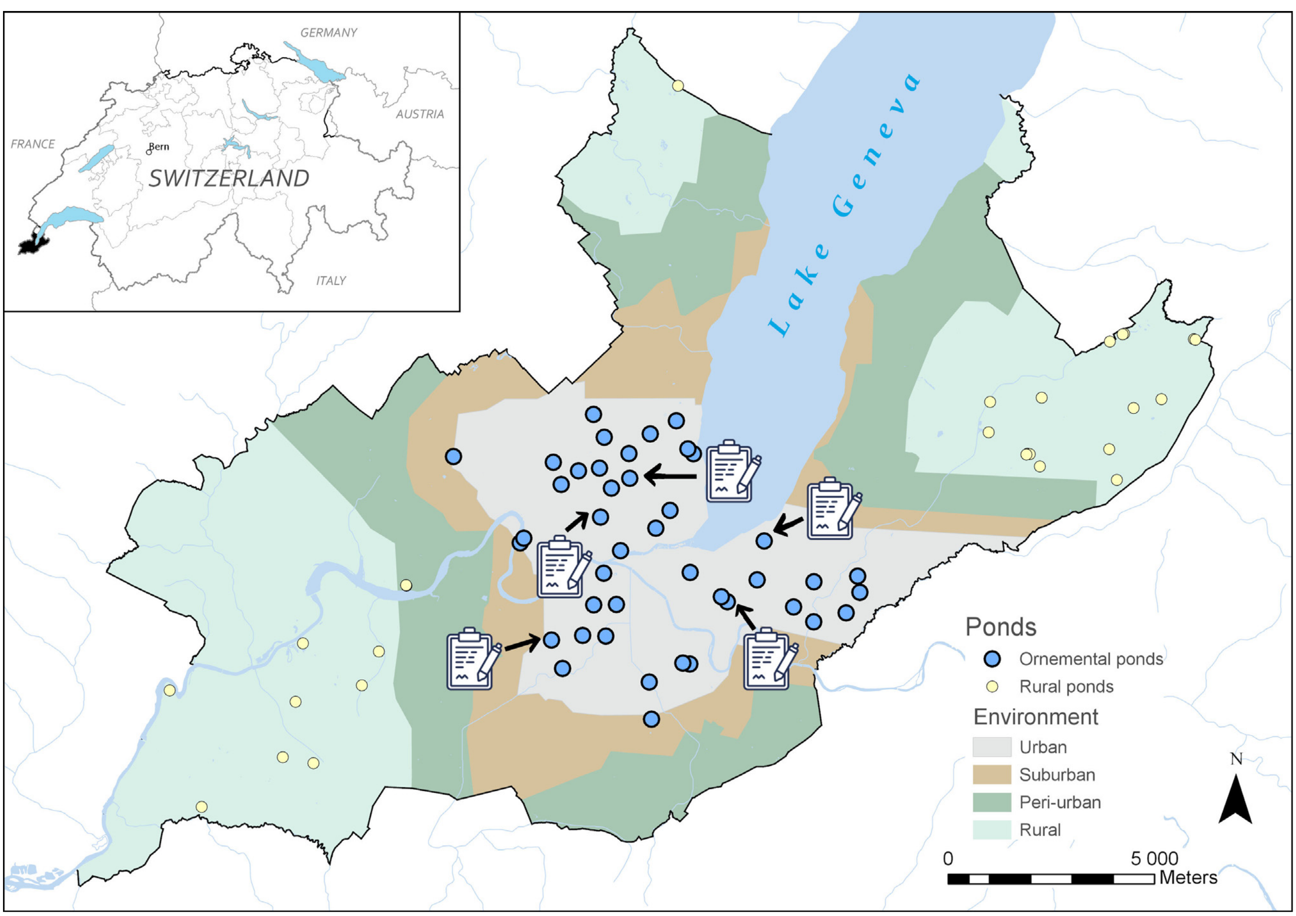

Fig. 1. Geneva and surrounding region (Canton of Geneva, Switzerland) and location of the 41 ornamental ponds (blue dots) investigated in the most urbanized area ("urban" area with >40 % of impervious surface). The five public parks where social surveys have been conducted are also indicated. The rural ponds investigated for the biodiversity section are highlighted by yellow dots. The upper left insert represents Switzerland, with the Canton of Geneva in black.

Fig. 2. Illustration of six ponds, representative of the 41 ornamental ponds investigated in the city of Geneva (Switzerland). These six ponds are presently used for their aesthetic value. Ponds a, b, e, f are located in public parks, and ponds c and d in private areas (an industry and an international organization).

respect to their life cycle, their position in the food web, their habitat preferences and their ways of dispersal. Plants are primary producers, snails are primary consumers, and beetles are secondary consumers (predominantly predators). Adult dragonflies can be considered as indicators of habitat quality in aquatic/terrestrial ecotones, especially regarding the structure of the shoreline vegetation. Amphibians are highly dependent on terrestrial habitats and landscape structure in the pond environment, furthermore, they are especially endangered in Switzerland, as also in other parts of the world. These five indicator groups also show marked differences in their dispersal strategies: passive (vegetation and snails), active terrestrial (amphibians), and active aerial (dragonflies and beetles).

Pond inventories were carried out in 2012 for 22 ponds, 2013 for 16 ponds and 2021 for 3 newly created ponds. The standardized sampling followed the IBEM method ("*Index de Biodiversité des Etangs et Mares*", Indermuehle et al., 2010), based on an assessment method developed by Oertli et al. (2005). A biodiversity index is calculated and represents the proportion of the biodiversity presented by a given ornamental pond compared to the biodiversity of a virtual similar "natural" pond in unimpaired conditions. The maximal value of this index is therefore 1 and represents 100 %, which indicates that the potential of the pond is fully achieved in this case. A lower value indicates that the biodiversity is not fully developed. This standardized index is calculated using the number of species for amphibians and the number of genera for the other groups (plants, snails, beetles, dragonflies). This IBEM biodiversity index was carried out on the 41 ornamental ponds. In addition, it was also calculated for 27 rural ponds (same year and methods) located in the rural area from the region of Geneva (Fig. 1), in order to provide comparative values representative for areas with a lower pressure from urbanization.

A large set of environmental variables were measured in 2012 and 2013 to describe each pond, in relation to water quality (conductivity, transparency, turbidity, Chlorophyll a, cyanophycean, pH, temperature), pond morphometry (surface area, maximal depth, mean depth, shoreline linearity index, drawdown height) and other features (age, type of pond substrate, shade by trees, presence of fishes, presence of ducks), pond vegetation (proportion of the shoreline occupied by emergent vegetation, proportions of the pond area covered by submersed vegetation, by vegetation with floating leaves, and by emergent vegetation), connectivity with other urban ponds in a 1000 m width belt (number of ponds; number of ponds weighted according to distance and pond area; number of ponds hosting amphibians; number of ponds hosting dragonflies), land use (% covered by buildings, cultivated land, forests, urban vegetation and waterbodies) in the buffer area (50 m width belt) and in the environment (500 m width belt).

Some of these variables would require a long-term monitoring for a good characterization, and they were therefore excluded from the outset for further analyses (e.g. temperature, pH). A preliminary analysis was then conducted with the remaining variables (Pearson correlation matrix), and a subset of the most relevant and non-redundant variables was selected to conduct the analysis of the relation between biodiversity and the variables. The 13 variables selected were: the pond age (or age since last restoration/cleaning), the pond area, the mean depth, the water quality as expressed by Chlorophyll a, the proportion of the buffer area occupied by buildings or urbanized surfaces, the proportion of the environment occupied by buildings or urbanized surfaces, the nature of the pond bottom substrate (from artificial to natural), the proportion of the pond shaded by trees, the proportion of the shoreline occupied by emergent vegetation, the proportion of the pond area covered by submersed vegetation, by vegetation with floating leaves, and by emergent vegetation, and the connectivity (number of other ponds in a 1000 m width belt). These variables are presented in the Table 1 (means, medians, minimal and maximal values), with also selected elements of the method. The detailed values for each pond are presented in Appendix A, also for 6 additional variables.

For more information on the methods for assessing the biodiversity and the environmental variables, see in Oertli et al. (2005) or Indermuehle et al. (2010), and the user-friendly layout on the related website (IBEM, 2008).

To identify the main driving variables of biodiversity, we used a modelling approach through stepwise linear regression (forward selection, with alpha-to-enter value = 0.25), produced with the Minitab® Statistical Software (Minitab, 2021). This statistical tool identifies the most significant variables to produce the regression.

2.4. Other ecosystem services

As ornamental ponds can potentially provide other ecosystem services than aesthetic enjoyment and biodiversity, a rapid assessment was conducted for a selection of regulating ecosystem services, through the collection of some basic information.

Table 1
The 13 variables investigated for their relation with aquatic biodiversity, with a short description of the methodology, and the itemized information collected on the 41 ponds.

Parameter	Units	Methods	Mean	Median	Min	Max
Age	years	Survey of managers	31	26	0.7	150
Area (m^2)	m^2	Based on aerial photographs	292	90	2	3754
Mean depth	m	Average of about twenty measurements distributed in transects	0.5	0.44	0.1	2
Proportion of urbanization in a 50 m radius	%	Proportion occupied by buildings or urbanized surfaces, measured from local cartography of land cover (calculated by GIS)	37 %	31 %	0 %	94 %
Proportion of urbanization in a 500 m radius	%	Proportion occupied by buildings or urbanized surfaces, measured from local cartography of land cover (calculated by GIS)	54 %	58 %	17 %	87 %
Chlorophyll a	μg/l	Maximal value from measurements carried out in situ with AlgaeTorch (bbe Moldaenke), on several dates in summer (3 to 4 measures). Values above 100 μg/l indicate hypertrophic conditions, and indicate an impairment of the pond.	95	27	3.4	600
Substrate type	Class (0, 1, 2)	Three classes: natural (0), artificial but covered by a natural substrate (1), artificial (2)	1.1	1	0	2
Proportion of pond shaded by trees	Class (1 to 5)	Estimated from aerial photographs, followed by in situ checking. Five classes: 1 (0–5 %), 2 (5–25 %), 3 (25–50 %), 4 (50–75 %), 5 (75–100 %)	2.1	1	1	5
% of shoreline with vegetation	%	In situ measurement of the proportion of the shoreline covered by emergent aquatic vegetation (e.g. reeds, cattails, rushes, irises)	26 %	5 %	0 %	100 %
% of pond area with floating vegetation	%	Visual in situ assessment of the proportion of the pond area covered by vegetation with floating leaves (%; e.g. water lilies)	15 %	6 %	0 %	100 %
% of pond area with submersed vegetation	%	Visual in situ assessment of the proportion of the pond area covered by submersed vegetation (%; e.g. water milfoil, pond weed)	4 %	0 %	0 %	29 %
% of pond area with emergent vegetation	%	Visual in situ assessment of the proportion of the pond area covered by emergent aquatic vegetation (e.g. reeds, cattails, rushes, irises)	20 %	9 %	0 %	100 %
Connectivity	Number of ponds	All ponds were counted in a 1000 m radius. Their location was mapped in previous studies (e.g. Oertli et al., 2018).	6.8	5	0	20

2.4.1. Phytopurification

The water purification potential (filtration of nutrients and pollutants) was assessed on the 41 ponds on the basis of their potential for phytopurification. Indeed, the vegetation is largely responsible for the purification performance of a pond (Vymazal, 2011). The plants uptake directly nutrients, but moreover, the roots and the biofilms favor microbiological degradation. Furthermore, the presence of dense plant beds promotes the mechanisms of sedimentation, precipitation, and filtration. Therefore, phytopurification will be more performant in ponds with higher aquatic vegetation cover. The coverage of each pond by the aquatic vegetation (emergent, floating, or submerged) was expressed in m^2 and was measured in summer.

2.4.2. Water retention

The water quantity regulation potential was assessed by measuring the storage capacity of the waterbody (= its maximum water volume). This metric is often selected for monitoring effects of waterbodies and wetlands on flood resilience (e.g. in the EU project MERLIN https://project-merlin.eu/). In urban areas, it is a proxy of the real regulation performance of a pond, as often a pond is not empty when there is a sudden water inflow, for example during a storm event. In a second step, the potential of buffering of a storm event was also assessed, by converting the volume of the pond into the number of hectares of impervious surface receiving the same volume of rainfall. A storm event was defined as a 25 mm rainfall, which corresponds to a volume of 250 m^3 for one hectare of impervious surface. The runoff coefficient was set to 100 %, a very overestimated value, as real runoff coefficient is often between 40 % and 80 %.

2.4.3. Cooling effect

The cooling effect is particularly important in urban areas in the context of global warming, in particular for its potential impact on local air quality (e.g. temperature, humidity) and for the mitigation of the urban heat island. This regulating service has a direct impact to the cultural ES, as people recreation and mental and physical health. The investigation aimed here to assess if the presence of an ornamental pond is perceived as "cooling" by the visitor. This assessment of the potential of an ornamental pond for bringing a cooling feeling to the citizen was conducted on the 41 ponds. Based on expert knowledge (from the Laboratory for Environment, Climate, Energy and Architecture from HEPIA-HESSO), eight parameters were considered for assessing the cooling effect (Table 2). A score from 1 (low) to 5 (high) was given to each of the eight parameters characterizing climate/comfort of each pond. The total of the 8 scores provided the final assessment of each pond, comprised therefore between 8 (minimal value) and 40 (maximal value). The detailed values characterizing each pond are presented in Appendix B.

2.4.4. Climate regulation: carbon burial

Because the measurement of carbon burial is time and resource costly, it was only assessed on a subset of 15 ponds. Carbon sedimentation was estimated through two methods: sediment coring (in 2020) and sediment traps (in 2020 and 2022). The method of sediment coring was used when the age of the pond or the last date of dredging was known. Five sediment cores were taken per pond, at different locations. Their content was dried at 105 °C and then burned at 550 °C for 4.5 h to calculate the organic carbon content through loss on ignition (LOI). Following Downing et al. (2008), organic carbon content was expressed as 0.47 ∗ LOI. The yearly carbon burial rate was then estimated for the entire pond and converted in CO_2e (1 ton of carbon = 3.67 tons of CO_2e). For other ponds, we used a method based on sediment traps. These traps were deployed for three months, between April and July, at three locations between the shore and the center of the pond. Upon retrieval, their content was dried, weighed, and burned, following the same procedure as for the sediment cores. The yearly carbon burial rate was calculated based on the assumption that sediment accumulates for 6 months of the year. From the 16 investigated ponds, five ponds were equipped with sediment traps, five were cored, and six were assessed with both methods.

Note that this assessment only includes the burial of carbon, and do not consider GHG emissions. Furthermore, the future of this sequestered carbon is not considered: indeed, in most cases it will be exported by the managers, at various frequencies (often between 1 and 2 decades, but sometime yearly).

2.5. Assessing the performance of an ornamental pond in providing habitats for biodiversity and additional ES

To translate/summarize the pond performance in providing habitats for biodiversity and also additional ES (water retention, phytopurification, cooling effect), a standardized score was assigned to these four ES delivered for each of the 41 pond. Carbon burial was not considered, because it was measured only on 15 ponds.

To standardize the scores, the measurements made for the four ES (see previous sections) were all transformed into a scale from 0 to 5. The mark

Table 2
The eight parameters considered for assessing the cooling effect of the 41 ornamental ponds, and the scale used for attributing a score (from 1 to 5).

Parameter measuring the cooling effect	Comment	Scale used for attributing a score
(i) Water surface area	The larger it is, the greater the cooling effects	• <200 m²: insufficient (1) • 500 m²: average (3) • >2000 m²: very good (5)
(ii) Bank design	A first parameter favoring evaporation	• mineral substrate and steep slope: bad (1) • natural substrate colonized with vegetation and low slope: very good (5)
(iii) Open water with access to breezes and wind	A second parameter favoring evaporation	• closed situation (e.g. by buildings, dense vegetation or other obstacles): bad (1) • very open situation: very good (5).
(iv) Water droplet production	A third parameter favoring evaporation	• water jet, waterfall, fountain, situated near the banks: very good (5). • no such features: bad (1)
(v) Sunny or shaded situation	Solar radiation is the main heat input to the water body	• exposed and clear: bad (1) • average (3) • shaded without prejudice to the sky view or breezes: very good (5).
(vi) Possibility for people of a direct contact with the water	Physical contact with water provides high cooling potential to users	• stepping stones; accessible, gently sloping banks; adequate water quality; easy access to water at several points (5) • no such features: bad (1)
(vii) View of the sky (sky view factor SVF)	Clear sky provides cold radiation (~0 °C); visible sky, including reflection, provides radiative cooling	• clearance, size, possibility to place oneself above the water mirror (footbridge, island, stepping stones) • small, inaccessible: bad (1) • large, clear, with access to the water mirror: very good (5)
(viii) Layout of the surroundings	Thermal comfort provided by surroundings is as important as the water body itself	• mineral surfaces, without shade: bad (1) • ventilated shaded rest areas, vegetation: very good (5)

"5" represented the maximal value obtained by the ES (e.g. maximal value on the boxplot from Figs. 4 and 5). The measured values were therefore all divided by the maximal value and multiplied by 5.

This analysis of the performance of each pond for delivering the four ES will emphasize the ponds with high scores for several ES (e.g. scores >2.5) and that are therefore multifunctional.

Furthermore, a Principal Component Analysis (PCA) was used to visualize the position of the ponds in function of the scores, and to evidence the relationships between the ES. The PCA was computed with the "ade4" package (Dray and Dufour, 2007) in RStudio Version 2022.07.2 + 576 (R Core Team, 2020).

3. Results

3.1. Contribution of ornamental ponds to the well-being of the citizen

A vast majority of the 355 citizens questioned in the five public parks expressed a positive contribution of the ornamental pond to their quality of life. This contribution was qualified as high or very high for 75 % of respondents (Fig. 3). The ponds from these five parks were all created with the objective of delivering aesthetic enjoyment, and therefore the provision of this targeted cultural ES was fully fulfilled.

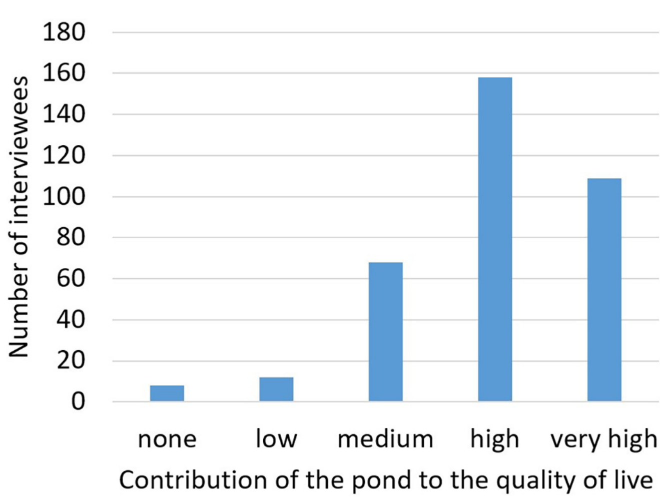

Fig. 3. Contribution of an ornamental pond to the quality of life, as expressed by 355 citizens questioned in five public parks from the urban area of Geneva.

3.2. Biodiversity in the studied ponds

3.2.1. The sampled biodiversity

In the 41 ornamental ponds, 163 different taxa were sampled. Most taxa were identified at the species level: 93 species of aquatic plants (including 10 considered non-native species; i.e. Oertli et al., 2018), 9 species of snails, 12 species of beetles, 21 species of dragonflies and 6 species of amphibians. The full list of taxa is presented in Appendix C, along with their frequency of occurrence. The most frequent taxa were a dragonfly species (the damselfly *Coenagrion puella*), an amphibian (the newt *Ichthyosaura alpestris*) and an emergent aquatic plant (the iris *Iris pseudacorus*), all present in half of the investigated ponds. The most frequent non-native taxon was the water lily *Nymphaea* spp. (horticultural varieties traded in shops as ornamental plants), present in 40 % of the ponds. A threatened species in Switzerland, the amphibian *Bufo bufo* (red list status "Vulnerable"), was present in 40 % of the ponds.

The richness per ornamental pond, expressed by the mean number of genera, was highest for aquatic plants (7.2 genera), followed by dragonflies (2.1 genera), and amphibians (1.7 genera). It was particularly low for snails and beetles (0.6 genus for each) (Table 3). These five mean richnesses were markedly lower than those measured on 27 more natural ponds (rural ponds) of the same region.

3.2.2. The index of biodiversity

The index of biodiversity (aquatic plants, snails, beetles, dragonflies, amphibians; all pooled) calculated for the 41 ornamental ponds was generally low: the observed biodiversity reached on average 26 % of the expected biodiversity for reference condition (Fig. 4). This mean value is for example much lower than the proportion attained by more natural ponds in the rural area from the same region of Geneva (49 %). The taxonomic groups taken separately presented very contrasted patterns in the ornamental ponds. On the one hand, dragonfly richness was relatively good (mean index of 50 %), but on the other hand, aquatic beetles and snails presented very low values (mean index of respectively 3 % and 12 %). Aquatic plants (mean index of 37 %) and amphibians (mean index of 24 %) were between both situations.

The five ponds that performed best (with an index between 47 % and 54 %) were three in public parks (e.g. pond in Fig. 2a) and two in private areas (in a garden an in an urban farm).

A single pond often makes only a moderate contribution to regional biodiversity, and it is collectively that ponds, then considered as a pondscape, host a very large species diversity (Biggs et al., 2017; Oertli et al., 2002). In our studied set of ornamental ponds, when considering only amphibians, beetles and snails, the richness of a single pond (alpha richness) represented

Table 3
Richness in genera (mean, median, min, max) of the 41 urban ornamental ponds, for aquatic plants (excluding non-native taxa), snails (Gastropoda), beetles (Coleoptera), dragonflies (Odonata) and amphibians. The richness of 27 rural ponds is also indicated, for comparison purposes.

	Aquatic plants		Gastropoda		Coleoptera		Odonata		Amphibians	
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Mean	7.2	11.4	0.6	1.6	0.6	9.2	2.1	7.6	1.7	4.7
Median	6	10	0	1	0	7	1	8	1	5
Min	0	0	0	0	0	0	0	0	0	1
Max	24	29	4	6	6	28	11	19	4	9

on average only 3 % of regional richness (gamma richness), whereas the cumulated richness of the whole set represented on average 56 % (from data in Zamora-Marín et al., 2020).

3.2.3. Relation between biodiversity and pond/environmental parameters

To identify the main driving variables of biodiversity, we investigated the relations between the biodiversity measured in the ornamental ponds and the environmental parameters. The produced models underlined the importance of 11 parameters (Table 4). Pond depth is a parameter from the design that is of central importance, as this metric was selected in four different models: all taxa, plants, dragonflies and amphibians (all with $p < 0.05$). The presence of vegetation also turns out to be particularly important. The proportion of the shoreline has to be highly covered by aquatic emergent vegetation, as well as the coverage of the pond area by submersed or with floating leaves vegetation (for beetles), and by emergent vegetation (for snails). A good connectivity, indicated by the presence of other ponds in the environment, is also associated with a high biodiversity, here for snails, beetles and amphibians. The biodiversity showed a negative relation with some parameters. An artificial pond bottom (concrete, liner) turns out to be particularly negative for biodiversity, and contributed negatively in the models of all taxa, beetles, dragonflies and amphibians. A largely built environment is also negative and turned out to be negatively related to the index of biodiversity of all taxa and of snails. The shade linked to trees is also negative (all taxa, dragonflies, amphibia; $p < 0.05$), except for snails.

3.3. Additional ecosystem services provided by the 41 ponds (water retention, phytopurification, cooling effect, carbon burial)

3.3.1. Water retention (and flood control)

Most of the 41 ornamental ponds presented a small water volume (median: 46 m^3; mean: 135 m^3) (Fig. 5a), and therefore had a too low storage capacity for regulating rain runoffs. Nevertheless, the two highest values attained 700 and 800 m^3, making these ornamental ponds potentially relevant for efficient runoff regulation. Indeed, during a storm event, they are potentially able to buffer the runoff linked to 3 ha from the impervious drainage area. These two best-scored ponds were located in a public park and in a private area (i.e. pond in Fig. 2d). This evidences that flood control, a non-target ES for ornamental ponds, can potentially also be promoted.

The cumulative value of the 41 ornamental ponds attains 5500 m^3, indicating that collectively their storage capacity can buffer the runoff linked to 22 ha of impervious surface. This stresses the importance to consider ponds also collectively, as a pondscape.

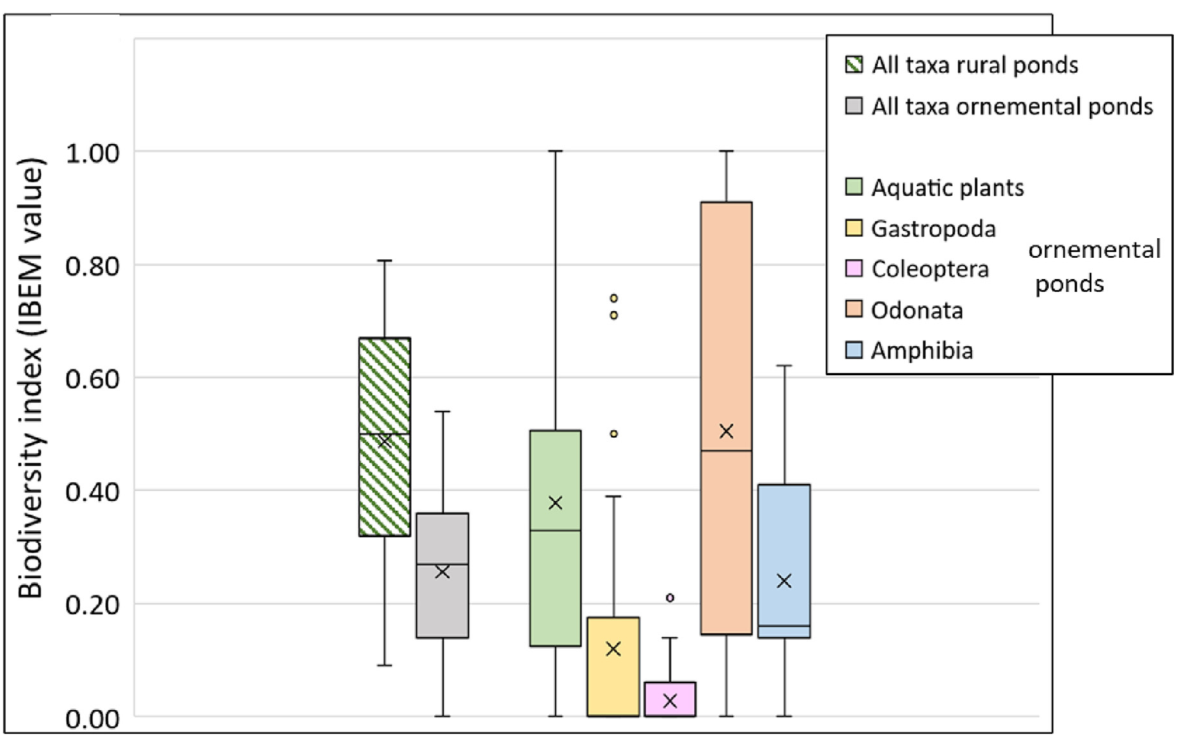

Fig. 4. Biodiversity observed in the 41 ornamental ponds: aquatic plants, aquatic snails (Gastropoda), aquatic beetles (Coleoptera), dragonflies (Odonata), amphibians, and all taxa (the five groups pooled). The IBEM biodiversity index represents the ratio between observed taxa richness and reference taxa richness (see Method section). The maximal value is therefore 1 and represents 100 %, indicating that the potential of the pond is fully attained. The values reached by 27 more natural ponds in the nearby rural landscape (localization in Fig. 1) are also presented for all taxa pooled (green dashed pattern).
The cross indicates the mean values, and the black horizontal line the medians.

Table 4
The six models of the relationships obtained by stepwise linear regression between the pond/environmental predictors and the biodiversity index of aquatic plants, snails (Gastropoda), beetles (Coleoptera), dragonflies (Odonata) and amphibians. The values represent the coefficients integrated for each predictor in the regression equation (alpha = 0.25). The positive relations are highlighted in green and the negative ones in red. The most important predictors are indicated by asterisks (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$).

	All taxa	Aquatic plants	Gastropoda	Coleoptera	Odonata	Amphibia
R^2	48%	18%	48%	41%	31%	56%
Predictors						
constant	*0.364*	*0.282*	*0.057*	*0.0318*	*0.767*	*0.430*
Mean depth	0.186 **	0.279 *			0.404 *	0.144 *
Water quality		-0.0005				
Built buffer area			−0.002			
Built environment	−0.171		−0.224			
Artificial substrate	−0.042			−0.029 **	−0.129	−0.097 **
Shade	−0.039 *		0.042 *		−0.125 **	−0.080 ***
Vegetated shoreline	0.154 *					
Pond coverage by submersed vegetation				0.118		
Pond coverage by vegetation with floating leaves				0.058		
Pond coverage by emergent vegetation			0.291 **			
Connectivity			0.014 *	0.003		0.008

3.3.2. Phytopurification

Due to the small size of most ponds, the surface covered by aquatic vegetation was also unsurprisingly low (median: 21 m^2; mean: 52 m^2) (Fig. 5b). Furthermore, few ponds presented well-developed macrophyte beds. Therefore, the phytopurification potential related to the studied ponds remained low. Nevertheless, it is worth noting that three ponds presented values exceeding 200 m^2, markedly higher than all other 38 ponds. One was located in a private area and two in public parks (i.e. pond in Fig. 2f). This evidences that phytopurification, a non-target ES for ornamental ponds, can potentially also be promoted.

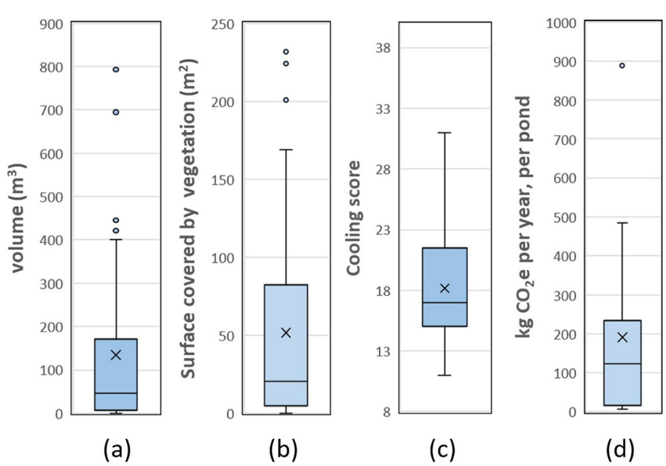

Fig. 5. Measurement of four regulating ES delivered by the investigated ornamental ponds.
(a) Potential for phytopurification (surface covered by aquatic vegetation; in m^2). (n = 41 ponds).
(b) Water retention: pond storage capacity (water volume; left scale, in m^3). (n = 41 ponds).
(c) Cooling effect, represented by a cooling score (maximum potential value: 40). (n = 41 ponds).
(d) Yearly carbon burial, expressed by whole pond. (n = 15 ponds).

3.3.3. Cooling effect

Most of the 41 ornamental ponds presented a relatively low cooling score (Fig. 5c), indicating a low cooling effect potentially felt by people. Indeed, the mean value was 18 and the median 17, situated in the lower part of the scale of potential values of the index (8 to 40). The low score was mainly related to the small sizes of the ornamental ponds, which are also often linked to a closed situation (e.g. by buildings or other obstacles). However, the low cooling potential was also linked to a lack of some features needed to bring a cooling effect (see Table 2). This particularly relates to: (i) the possibility for people to have a direct contact with the water (open banks, footbridge, island, stepping stones), and also (ii) features that promote the production of droplets (water jet, waterfall, fountain, located near the banks).

There were nevertheless several values above mean (score of 20) and one particularly high value (31). This high value indicates an excellent cooling effect. The pond is a large waterbody (3750 m^2; Fig. 2d). The high cooling effect is linked to the large surface, but also to several features (see Table 2) enhancing the cooling effect: presence of trees and shade, accessibility of people to the water, water droplet production (water jet), and open water in a location that lets the wind through.

3.3.4. Regulation of climate: carbon burial

We observed a high discrepancy of values for carbon burial rates among the 15 ornamental ponds investigated (6 to 889 kg CO_2e a^{-1}). The mean burial rate was about 191 kg CO_2e a-1 per pond (i.e. 0.33 kg CO_2e m^{-2} a^{-1}) (Fig. 5.d), a high value compared with some other urban terrestrial ecosystems. For instance, the burial rate of urban trees is estimated to be 0.29 kg CO_2e m^{-2} a^{-1} (Nowak and Crane, 2002), whereas turfgrasses only trap between 1.25E-10 and 5.14E-10 kg CO_2e m^{-2} a^{-1} (Qian and Follett, 2012). The highest burial rate was observed in three ponds from public parks. It would now be necessary to also measure gas emissions (e.g. methane) to build a carbon budget for each pond.

3.4. Multifunctionality of the 41 ornamental ponds

All 41 ornamental ponds were designed for providing cultural ES linked to their aesthetic value (e.g. aesthetic enjoyment, recreation, mental and physical health). The performance of these ponds for providing ES that are not targeted was assessed here for biodiversity and also for three regulating ES: cooling effect, water retention, and phytopurification. A performance score obtained by each pond (scale from 0 to 5) was measured for these four ES, and the mean value was also calculated (see detailed values in Appendix D). The mean values were very low for most ponds (median of 1.4), and this evidenced the low ability of the ponds to provide these ES. There were nevertheless 5 ponds with high scores (scores: 2.6 to 3.1), which therefore exhibit a degree of multifunctionality: four park ponds (e.g. ponds in Fig, 2a, 2e, 2f) and one garden pond.

The potential of each of the 41 ponds for providing an additional ES to the cultural ES was also assessed (Fig. 6). For providing a first additional ES, this potential is on average good (mean performance score: 3.0/5). Nevertheless, for providing a second additional ES this potential is on average low (mean score: 2.0/5). The potential to provide additionally a 3rd and a 4th ES are then dropping sharply and are very low (respective mean scores: 0.9/5 and 0.3/5).

This underlines that the multifunctionality of these 41 ornamental ponds is low. The maximal values presented by some ponds (Fig. 6) confirm nevertheless their multifunctionality. This indicates also that there is a large potential to optimize most of the ponds.

The first additional ES was biodiversity for 51 % of the ponds and cooling for 32 % of them. The second additional ES was cooling for 54 % of the ponds and biodiversity for 29 % of them. The last additional ES was water retention for 80 % of the ponds. These results underline that biodiversity seems an additional ES that is relatively easy to achieve, contrarily to water retention.

3.5. Relationships between the ES

Based on the performances (scores) evidenced for providing the ES, a principal component analysis was used to ordinate the ponds according to their ES and to illustrate the relationships between the ES (Fig. 7). Biodiversity and water retention showed trends in opposite directions, while cooling and phytopurification were closely linked. The position of the ponds demonstrated the multifunctionality of a selection of them. For example, GE9945 (pond "*Préjins*") performed particularly well for biodiversity, but also for other ES. This is indeed a park pond, that has benefited from measures in order to promote biodiversity, with a diversification of habitats, including the implementation of large vegetated areas. GE9955 (pond from the botanical garden), GE9978 (a private garden pond) and GE9952 (park pond "Franchises") also showed a good multifunctionality.

4. Discussion

4.1. Contribution of ornamental ponds to human well-being

The 41 ornamental ponds investigated in Geneva were implemented in the urban area with a single objective targeting aesthetic enjoyment, to promote the well-being of the inhabitants. Therefore, these ponds were expected to deliver cultural ES such as aesthetic appreciation or recreation (for maintaining mental and physical health). This social objective is motivated by the presence of a large density of population living in the surrounding area. The high urbanization of the area can also explain the small size of most existing ponds, linked to the low offer of space available for nature. Therefore, the multifunctionality of these ornamental ponds was not a priority, and the promotion of biodiversity was clearly not an objective. Furthermore, several other regulating ES potentially useful in cities were not considered, for instance regulation of water quality, flood control and cooling effect. When the visitors of the public parks were asked about the contribution of an ornamental pond to their well-being, the answer was clearly positive, with even 75 % of the interviewees considering such a contribution to be high or very high. Indeed, it is already recognized that urban waterbodies establish an important contact between people and nature, contributing to the quality of life of those who visit them (Garrett et al., 2019; Pedersen et al., 2019; Vaeztavakoli et al., 2018). This acceptance of ponds by people is an opportunity for implementing this type of blue nature dots in the urban matrix. As we will develop it thereafter, ponds created for the well-being of citizens can deliver several other services (such as regulating ecosystem services).

4.2. Biodiversity in ornamental ponds

The biodiversity of the 41 investigated ornamental ponds turned out to be low: it averaged half of the biodiversity of ponds from the nearby rural area or one fourth of reference condition ponds. Low biodiversity in urban areas is not a surprise, and this was already often reported for

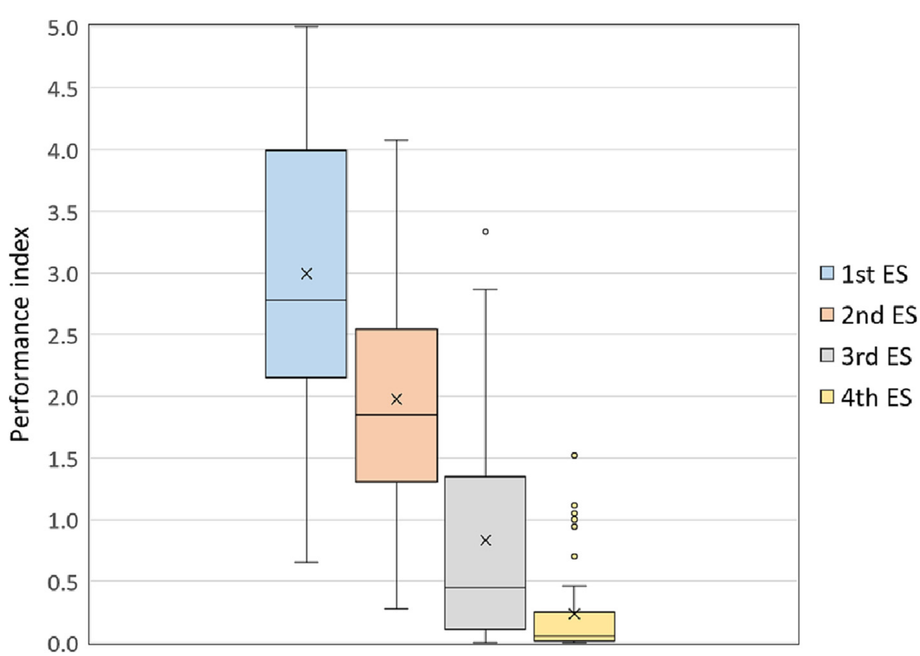

Fig. 6. Potential of the 41 ornamental ponds for delivering additional ES, as traduced by the performance of the ES (scores, from 0 to 5). The four additional ES considered were biodiversity, cooling effect, water retention, phytopurification. The 1st ES is the ES best performed by the pond, and can be one of the four ES. The 2nd to 4th are the following best performing ES, in order. The cross represents the mean values.

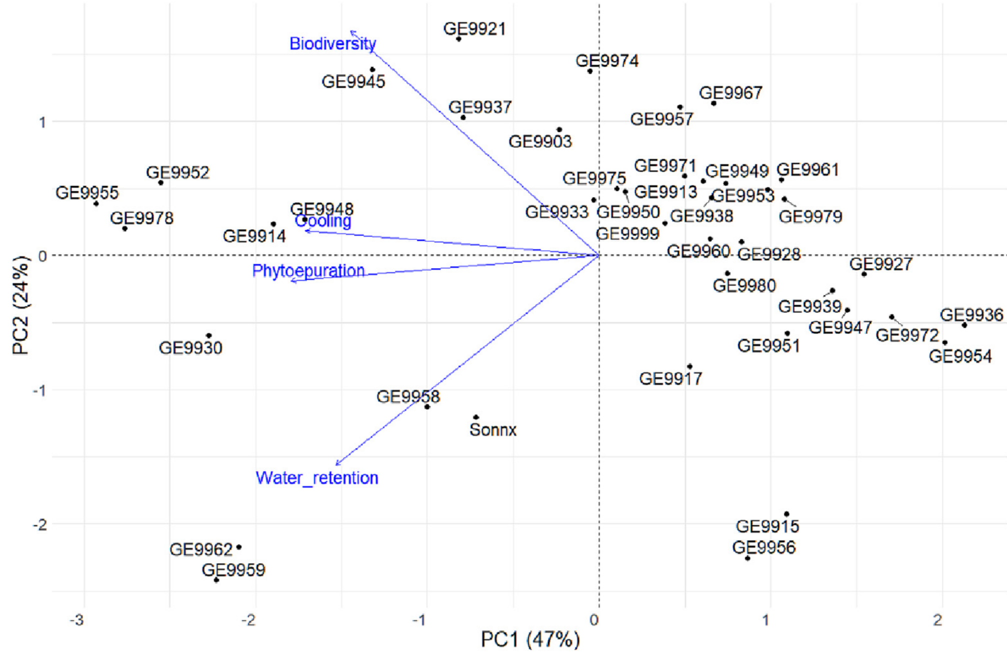

Fig. 7. Principal component analysis (PCA) of the 41 ponds according to their ES and relationships between the four ES (biodiversity, phytopurification, water retention, cooling effect). The pond codes and the associated scores for each ES are detailed in Appendix D.

ponds, including for aquatic plants, invertebrates and amphibians (e.g. Hamer and Parris, 2011; Magee et al., 1999; Noble and Hassall, 2015). Ornamental ponds also host many alien species, and sometimes invasive species, especially aquatic plants introduced for aesthetic reasons (Hussner, 2012; Oertli et al., 2018). The low diversity is in large part linked to a lack of habitats (such as natural substrates and plant beds) and to mismanagement (Goertzen and Suhling, 2013; Hassall, 2014; Oertli and Parris, 2019). Ornamental ponds are often intensively managed to increase the aesthetic value of parks or gardens, with regular cleaning or removal of plants and accumulated sediment, a practice that refrains the development of the biodiversity. In our study, an artificial bottom (liner, concrete) was negatively related with biodiversity, as was a lack of vegetation (on the shoreline or the pond open area).

Nonetheless, some of the investigated ponds performed relatively well and presented a well-developed biodiversity. These included public park ponds and garden ponds, and this confirms that ponds that are not implemented for promoting biodiversity are also able to deliver this additional service. Indeed, the review of Oertli and Parris (2019) evidenced that it is quite easy and inexpensive to implement simple measures that promote biodiversity in urban ponds. The main feature that is often underrepresented is the presence of large aquatic plant beds (emergent and submerged) (Goertzen and Suhling, 2013; Hassall, 2014). From our results, also supported by the literature review, a well-designed pond for biodiversity would have a sufficient depth (>0.6 m) and a natural substrate, and would be well vegetated (shoreline and pond area) with the different types of vegetation (emergent, submersed, with floating leaves). The trees in the buffer area should not be predominant, in order to keep the shading of the pond below 50 %. The urban matrix should be as less constructed as possible and should host several other ponds to promote the connectivity. The features to avoid would be a too shallow depth (<0.4 m), an artificial substrate (liner or concrete), and a lack of vegetation.

Ponds are small ecosystems and therefore host a limited number of species. In dense urbanized areas, ornamental ponds are often small because of the low availability of land for implementing them. There are nevertheless exceptions, and public parks of large cities can host large waterbodies (e.g. Hyde Park in London, Central Park in New York, Huangxing Park in Shanghai, Rodrigo de Freitas in Rio). When of small size, the ponds have to be considered in networks for assessing their benefit. Indeed, pond biodiversity is characterized by high beta diversity (Biggs et al., 2017; Céréghino et al., 2008; Oertli et al., 2002), and therefore the more numerous ponds are, the greater their regional biodiversity will be. This is what is also shown here: this network of 41 ornamental ponds represented 56 % of the regional biodiversity, while a single ornamental pond only contributed on average 3 %. Urbanization is often associated with an increase in biotic homogenization (Knop, 2016; McKinney, 2006), that would be reflected here in homogeneous species composition between the ponds (low beta diversity). This was not the case in this study.

4.3. Other ecosystem services potentially offered by ornamental ponds

4.3.1. Retention of water (and flood mitigation)

The delivery of this regulating ES is not an objective for ornamental ponds. With no surprise, the potential for regulating water quantity turned out to be low for most ponds. Indeed, they all had small water storage capacity (median volume: 46 m^3). This is for example 750 times lower than a typical stormwater pond located in the nearby suburban area (i.e. the "*lac des Vernes*"; with 35′000 m^3 of water retention). There were nevertheless some ornamental ponds which presented higher values (i.e. 700 and 800 m^3). Therefore, retention of water is a non-target ES, that can be provided by ornamental ponds. The performance of the ornamental ponds for this ES is also largely increased if they are considered collectively. Even if one single pond may not matter, a hundred ponds do. Furthermore, their small size makes their implementation much easier than a larger waterbody. Here for example, the implementation of 50 ponds with a retention of 800 m^3 each would allow a retention potential of 40′000 m^3, a volume larger than the one of the existing stormwater pond "*lac des Vernes*". In conclusion, an individual small ornamental pond makes a low contribution, but collectively, a network of ornamental ponds (a pondscape) represents an effective buffer for rainfall.

4.3.2. Regulation of water quality

This regulating ES was assessed through the potential of phytopurification of each pond, as the vegetation is in large part responsible for the water purification performance of a pond (Vymazal, 2011). This potential, measured by the area covered by aquatic macrophyte beds (e.g. reeds, cattails, submerged species), turned out to be low in most of the investigated ornamental ponds, and this was not really a surprise as this ES was not an objective for the managers of all 41 investigated ponds. This result is also linked to the small size of most ponds, that limits macrophyte cover area, and additionally to the low macrophyte coverage rate of most ponds (even the larger ones). Indeed, in urban areas, it is quite infrequent to have large macrophyte surfaces, and often management (or mismanagement) measures aim to reduce them. Our investigation has nevertheless evidenced some better cases, and three ponds presented a good phytopurification potential (two in public parks and one in a private area). These specific cases evidence that water purification can also be promoted in ornamental ponds, as an additional ES. Indeed, management measures are quite simple in order to promote this service.

The optimization for water purification in ornamental ponds can be achieved by capitalizing on management practices effective in constructed wetlands (e.g. Manzo et al., 2020; Paing et al., 2015; Vergeles et al., 2015). Indeed, some measures can partly be adapted or directly applied in ornamental ponds. For example, the presence of large macrophyte beds is recognized to be effective for pollution reduction (Al-Isawi et al., 2017; Gholipour et al., 2022). Reed belts (*Phragmites australis* or *Typha latifolia*) are often planted in constructed wetlands (Gholipour et al., 2022) and can be planted in a preliminary pond. Furthermore, another simple measure is to increase the water residence time (e.g. up to 15 days). The residence time is recognized as an additional factor that facilitates the removal of pollutants (Collins et al., 2016; Jia et al., 2019; Vergeles et al., 2015). A pond volume should also be higher than 250 m^3 for a catchment of 1 ha, to provide an optimized retention of nutrients and organic matter (Sønderup et al., 2016).

As ornamental ponds are numerous in the urban matrix, their cumulative role also has to be taken into consideration. The multiplication of these small blue dots can provide as much benefit as one single water treatment plant. They also have the potential to depurate urban runoff waters that often concentrate a large part of the pollution produced by cities.

4.3.3. Cooling effect

The cooling effect is a regulating ES promoting the well-being of people, and is particularly important for healing and relaxation. This ES is therefore expected for ornamental ponds that receive many visitors (as in public parks). But small ponds have a water volume too low to significantly impact microclimate (e.g. the air temperature). Nevertheless, they have a beneficial impact on people through the cooling feeling that partly remains psychological (view of the water, listening to water). Our index of cooling effect, measured on the 41 ornamental ponds, evidenced an effect mostly low. This was partly related to their small size, as a small surface area and reduced open water (without access to wind) refrain the cooling effect. As the cooling effect was an ES infrequently targeted in the implemented ponds, the lack of efficiency for cooling was also linked to a lack of simple features (e.g. open banks, footbridge, fountain), that would, even for a small waterbody, enhance the cooling effect. One of the 41 investigated ornamental ponds, presented nevertheless a very good cooling potential, linked to the presence of most of the requisite features that promote cooling. This stresses that even if this ES is not targeted, it can be easily promoted in ornamental ponds with simple management measures (e.g. selected features from Table 2).

Another aspect of cooling, not addressed here, is the impact on microclimate, with the reduction of temperature, that directly addresses the challenge of the heat island effect. A coupled green-blue infrastructure has proven to be particularly powerful for improving microclimate (Coutts et al., 2012; Gunawardena et al., 2017) and the well-being of citizens during summer heats. This objective could therefore be supported by the multiplication of the ponds and by framing them into the green-blue matrix.

4.3.4. Regulation of climate: Carbon burial

The measurements on a selection of 15 ornamental ponds evidence a potentially high rate of carbon trapping. This is consistent with other investigations (e.g. Taylor et al., 2019) and stresses that ponds represent very efficient ecosystems for sequestering carbon. This regulating ES is not targeted when creating ponds and managing them. Indeed, there is still a gap in the knowledge on carbon fluxes in ponds, and especially on factors that could influence them. Ponds are also now recognized as emitters of large quantities of methane (e.g. Holgerson and Raymond, 2016). It is therefore necessary to know under which conditions a pond carbon budget is directed towards sequestration rather than emission. A case study evidenced a balance directed largely towards emission in an urban pond (van Bergen et al., 2019). Nevertheless, our data indicated that there is a very large discrepancy between ornamental ponds. It is therefore important to conduct additional investigation in urban areas, and above all to identify the driving factors for emission and sequestration. Nutrient loading could be one of the incriminated factors, with high concentrations favoring methane production (Peacock et al., 2019). To measure properly this ES, it is also necessary to consider the whole life cycle of carbon. Indeed, in urban ponds, contrarily to natural ponds that are slowly landing, the sediments are generally removed by the managers, and this is a very common practice in ornamental ponds. The pathway of these sediments is therefore to be investigated and to be considered in the carbon budget.

4.4. Multifunctionality of ornamental ponds

The multifunctionality of the 41 investigated ornamental ponds was low on average, with a low biodiversity and a low performance for delivering regulating ES. This result was not surprising, as these ponds were all designed for cultural ES, as aesthetic enjoyment and psychological or physical activities.

Nevertheless, a small number of ponds diverged from the main trend and demonstrated their multifunctionality with performances above average for all measured ES. Additionally, for each of the considered ES, some ponds that were not designed for this purpose performed well. These two results evidence that an ornamental pond can potentially deliver efficiently several services and can be multifunctional. The promotion of biodiversity is for example an ES that can be quite simply achieved (see developments in Oertli and Parris, 2019), and that can be added to most existing (or new planned) ornamental ponds. Also, effective stormwater treatment can be achieved while maintaining the aesthetic requirements of an urban waterbody (Persson et al., 1999). In the previous section we presented also several examples of measures promoting the other considered ES. A framework for increasing the multifunctionality of ornamental ponds, especially for providing habitats for biodiversity, is illustrated in Fig. 8.

As a pond has by definition a relatively small size, the performance of a single pond for delivering ES remains limited. Therefore, it is the quantity of ponds that matters, and their network (a pondscape). The small size of a pond is nevertheless an advantage when considering its implementation in the urban matrix, as it will require little space as well as few resources. The multiplication of the blue dots in an urban matrix will collectively provide several ES, with a cumulative performance for each ES. Such a pondscape can be much more efficient than a single large waterbody. Furthermore, their coupling and incorporation in a larger blue-green infrastructure reinforces the potential benefits (Fenner, 2017).

The multifunctionality can nevertheless also present some limits with ponds. This is the case when ES performances are not correlated or when there is a dichotomy between positive and negative effects of ES (see also Bullock et al., 2011; Meyer et al., 2018). Management to maximize the production of one ecosystem service often results in substantial declines in the provision of other ecosystem services (Bennett et al., 2009). For example, the planting of trees along the shoreline is a simple management measure that produces contrasting effects on different ES. Indeed, the shade of the trees offers a beneficial cooling to people. However, the leaf litter input in the pond can negatively impact the water quality and in turn will decrease habitat conditions for biodiversity. In this type of situation, the planning at the pondscape scale is the good solution, as the focus on ES can be different among ponds. This can still be realized while promoting multifunctionality, as non-conflicting ES can be promoted. This multifunctionality will be here the prerogative of the pondscape, and not of a single pond.

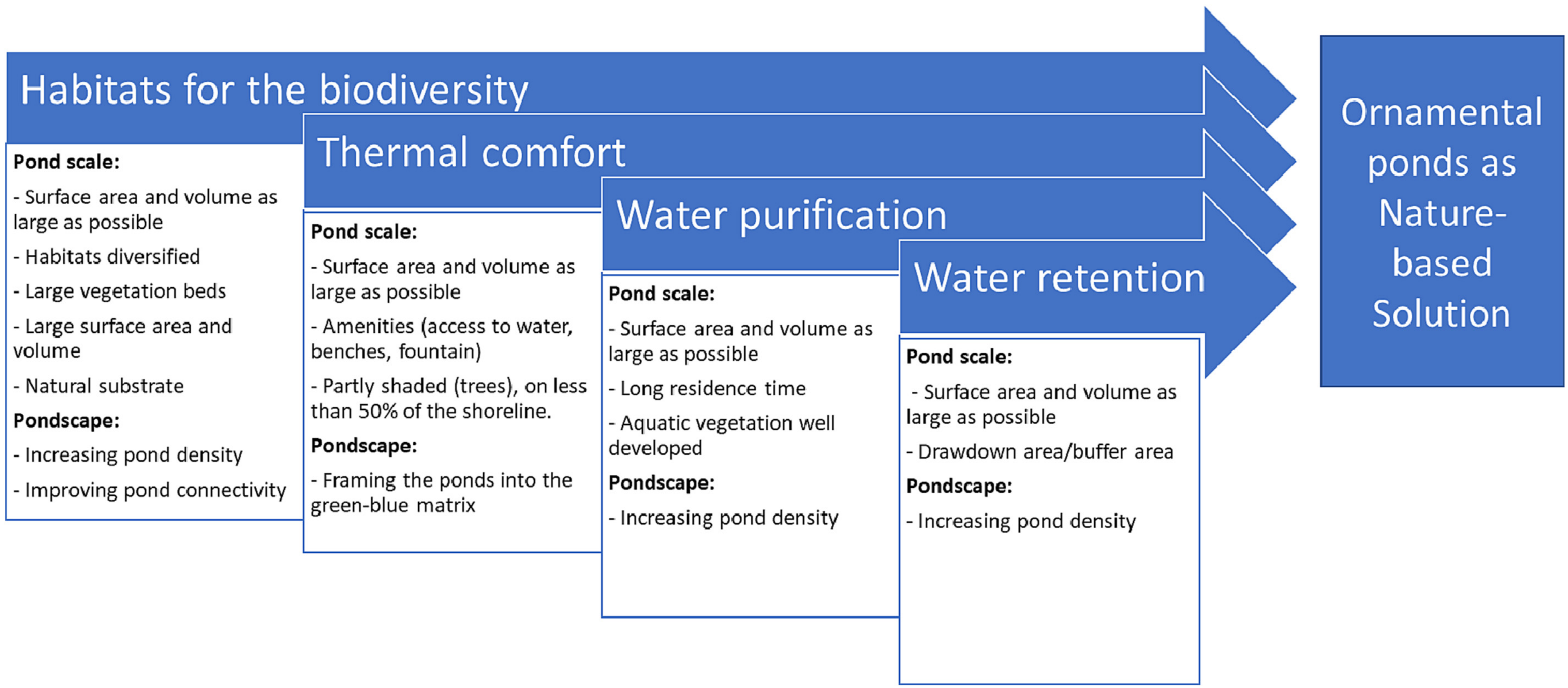

Fig. 8. A selection of key management measures for optimizing the benefits of four ecosystem services (habitats for biodiversity, thermal comfort, water purification, water retention), and for turning ornamental ponds into efficient Nature-based solutions at the local (pond) and larger area (pondscape) scale.

4.5. Conclusion

The investigation of the ES provided by 41 ornamental ponds implemented in the most densely urbanized area of Geneva evidenced that most ponds are not multifunctional, as they are generally designed to deliver a single cultural service. Their performance to provide additional ES remains weak. The conservation of native biodiversity is rarely a priority, and ornamental ponds present a low species richness. Nevertheless, for each regulating ES investigated, some outlier ponds were identified and performed well for an ES that they were not designed for. Furthermore, a minority of ponds still proved to be multifunctional, performing well in the delivery of several ES. This evidenced that a large potential exists in cities for improving the design of existing ornamental ponds and for implementing new ponds with a multifunctional design. The management measures to potentially put in action for improving the design are known, and easy to implement at a low cost (Fig. 8). It includes for example the promotion of vegetated areas (beneficial for biodiversity and water purification), the increase of the retention time of water (beneficial for water purification), the addition of features favoring people's contact with water (beneficial for cooling effect) and the increase of surface area and water volume (beneficial for all ES). Biodiversity is particularly easy to promote, by using a natural substrate (on top of or instead of concrete and liner), by ensuring a sufficient depth and by promoting the aquatic vegetation on the shoreline and on open areas of the pond.

Finally, a regional approach is to be considered in landscape and urban planning when implementing ornamental ponds. It is a high number of ponds (i.e. a pondscape) that will efficiently deliver multiple ES, through the sum of the contributions provided by each single pond. The urban pondscape will offer a large regional biodiversity, buffer flood events, purify the urban water runoff, provide a cooling feeling to many citizens, and give the opportunity to people to have a close contact with nature. The implementation of an urban pondscape will therefore provide an efficient Nature-based Solution that will help to address several societal challenges, including those linked to climate change and urbanization.

CRediT authorship contribution statement

Beat Oertli: Writing - original draft, Conceptualization, Methodology, Investigation, Data curation, Validation, Formal analysis, Funding acquisition, Project administration. **Marine Decrey**: Investigation, Data curation, Resources, Project administration. **Eliane Demierre**: Methodology, Investigation., Writing - Review & Editing. **Julie Fahy**: Selected aspects in relation with « carbon burial », Investigation, Writing - Review & Editing. **Christiane Ilg:** Investigation, Data curation, Resources, Project administration. **Peter Gallinelli**: All aspects in relation with « Cooling effect », Writing - Review & Editing. **Fernanda Vasco**: Most aspects in relation with « Social survey ». Writing - Review & Editing.

Data availability

Data will be made available on request.

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.

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Appendix A. Supplementary data

These data include description of the 41 ponds investigated in this study (Appendix A), the results of the measurement of the ES (Appendix B), the biodiversity (list of the sampled taxa; Appendix C) and the performance scores for the measured ecosystems services (Appendix D). Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2023.164300.

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