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Opinion Paper

Challenges and opportunities in the use of ponds and pondscapes as Nature-based Solutions

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Abstract Ponds and "pondscapes" (networks of ponds) are crucial habitats for biodiversity and for delivering multiple benefits to humans, so-called "Nature's Contribution to People", such as climate mitigation and adaptation to climate change, creation, and maintenance of habitat for biodiversity, water purification, flood mitigation and cultural benefits (e.g., recreational possibilities). However, ponds are not often considered as Nature-based Solutions to provide all these benefits. In addition, there is insufficient knowledge on how to manage and restore ponds to maximise their role to increase the resilience of ecosystems and society to climate change. To facilitate improved implementation of ponds as Nature-based Solutions for the delivery of a wide range of Nature Contributions to People, it is important to generate and integrate biodiversity, ecosystems, societal, economic and policy knowledge. Hence, there is a need for evidence-based guidance to support the broader use of ponds. Here, we review the role of ponds and pondscapes in delivering Nature's Contributions to People and provide an overview of the challenges and opportunities for their broader implementation as Nature-based Solutions. Finally,

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we propose a conceptual framework that can help the implementation of pond Nature-based Solutions, and that outlines future research needs.

Keywords Ponds and pondscapes · Nature-based Solutions · Nature contributions to people · Freshwater biodiversity · Climate change · Societal challenges

Introduction

In recent years, numerous reports have shown humanity's failure to tackle two of the major global crises: climate change and biodiversity loss (IPBES, 2019; WWF, 2020; IPCC, 2021). As evidence on the deterioration of natural ecosystems is growing, large-scale approaches with strong national and international collaboration are needed to face these global challenges. One such approach that has been increasingly promoted recently is the use of Nature-based Solutions (NbS) (Mendes et al., 2020; Davies et al., 2021). NbS are defined by the International Union for the Conservation of Nature (IUCN) as: "Actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges, such as climate change, effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN, 2020). The Biodiversity Strategy for 2030 in Europe highlights the value and importance of NbS in fighting biodiversity loss, climate change and other critical challenges. As such, the use of NbS can both facilitate the delivery of numerous Nature's Contributions to People (NCP), i.e. different contributions of nature to people's quality of life (Díaz et al., 2018; Brondizio et al., 2019), such as flood risk management, pollination or pollutant control (Burdon et al., 2013; Hankin et al., 2021; Walton et al., 2021), and help to change human perceptions of the value of different habitats, which in turn can support the effective protection and management of ecosystems. A NCP framework emphasises that culture is central in relation to all links between nature and people. It recognizes that, while nature provides many important goods and services such as tangible products or regulating functions, it also has rich cultural, social, spiritual and religious importance which needs to be acknowledged in decision-making (Kadykalo et al., 2019). A good example is food coming from nature that provides people with calories for survival, but at the same time is important for food security, food sovereignty, cultural identities, and human enjoyment.

Recently, there has been a growing interest from researchers, governments and policymakers in NbS implementation to address societal challenges (Faivre et al., 2017; Nika et al., 2020), in parallel with a significant increase in the use of freshwaters as NbS in human-dominated landscapes (Keesstra et al., 2018; Maiolo et al., 2020). Freshwater ecosystems host some of the most diverse communities worldwide but are also among the most exposed to human-driven environmental change (WWF, 2020). At a landscape

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scale, ponds, defined as small water bodies (1 m^2 to 2–5 ha.) that can be permanent or seasonal, man-made or natural (see glossary) (Richardson et al., 2022), are habitats of many endemic, threatened or rare species (Davies et al., 2008). In Europe alone, ponds support up to 70% of the regional freshwater species pool (Oertli et al., 2005). However, due to their small size and often the underappreciation of the benefits they provide, ponds are particularly vulnerable to anthropogenic stressors, including climate change, pollution, or habitat degradation (Hill et al., 2021a; Epele et al., 2022).

Ponds are crucial environments to deliver multiple vital NCPs that contribute to human well-being (Díaz et al., 2018; Hill et al., 2021a). These include regulation of water quantity and quality, the creation and maintenance of habitats for biodiversity, food provision, carbon storage and climate regulation, flood control, groundwater recharge, natural pest control, pollution amelioration, pollination, nutrient flux to adjacent ecosystems, as well as non-material benefits such as opportunities for recreation and tourism or inspiration (EPCN, 2007; Cardinale, 2011; Landuyt et al., 2014; Pascual et al., 2017; Walton et al., 2020). Because of their key contribution to biodiversity conservation, their potential role in climate change mitigation and adaptation, and their provision of a wide range of NCPs, ponds are particularly well-suited to be used as NbS (Table 1). As ponds are often poorly managed, the provision of the different NCPs can be jeopardised, and ponds may host lower biodiversity than natural or well managed water bodies (Perrone et al., 2022) and even act as sources of exotic species (Sinclair et al., 2020), as well as net carbon sources (Peacock et al., 2021).

Ponds play a key role in increasing connectivity between freshwater habitats by providing stepping-stone habitats that enable the dispersal of a wide range of species in the landscape (Juračka et al., 2019; Hyseni et al., 2021). Pondscapes, defined as a network of ponds and their surrounding matrix (Boothby, 1997), are critical for supporting the diversity and functioning of pond metacommunities (Heino et al., 2021). A set of individual ponds typically covers a large gradient of local environmental conditions (Borthagaray et al., 2015; Rodríguez-Tricot & Arim, 2020; Cunillera-Montcusí et al., 2021). These environmental gradients and the effect of stochasticity in local community assemblies promote regional diversity by enhancing spatial turnover in local community composition between ponds within a pondscape. Heterogeneity between ponds can also provide predator-free environments, such as temporary or small ponds without fish predators (Wellborn et al., 1996; Søndergaard et al., 2005; Scheffer et al., 2006; Chase et al., 2010), but also a refuge from diseases and a buffer from the impact of invasive species (Deacon et al., 2018). As both the biodiversity and other NCPs delivered by individual ponds may differ from the NCP's delivered at the pondscape level, and also as ponds may provide multiple solutions to different challenges at a pondscape scale, there is a need to explicitly consider multiple spatial scales in assessments of NCP delivery (Thorslund et al., 2017).

Despite their great importance, ponds and pondscapes are largely neglected in water- and nature-related national and international policies, due to an assumption that small water bodies are not as important in the provision of NCPs as larger ones (Linnerooth-Bayer et al., 2014; Hill et al., 2018). Many policies define a minimum threshold of ecosystem area for which the policies should apply, often excluding small water bodies (Biggs et al., 2017). For instance, the EU Water Framework Directive (WFD) aims to protect all water in Europe and has made progress in that direction, yet it excludes water bodies with a surface area below 50 ha (WFD, Annex II 2000/60/EC). This limit hinders the protection and restoration of many small lakes and all ponds and likely negatively affects freshwater biodiversity as a whole (van Rees et al., 2021). The only exceptions in terms of European conservation protection policies are the Mediterranean temporary ponds and turloughs (Boix & Batzer, 2016; Reynolds, 2016) that are important to the designation of Special Areas of Conservation in Annex 1 of the European Habitat Directive (Council of the European Communities, 1992) due to the high number of threatened species that they host. The application of conservation measures to larger freshwater environments only is ecologically insufficient for the protection of biodiversity hotspots such as ponds and pondscapes (Hill et al., 2018). Furthermore, the scale at which pond conservation is usually performed (i.e. individual site designation) is not the scale at which ponds contribute most to biodiversity and other NCPs (i.e., pondscape scale) (Hill et al., 2016; Cunillera-Montcusí et al., 2021).

In this paper, we place ponds and pondscapes in the spotlight to showcase their importance as NbS,

Table 1 Selected studies of evidence showing the Nature Contributions to People that ponds and pondscapes Nature-based Solutions provided

NbS	Implemen-tation	NCPs	NbS's benefits	Ref
Creation of wetlands	Belgium	Habitat creation	Increase of macroinvertebrates diversity	Boets et al. (2011)
Creation of flood paths	England	Regulation of water quantity	Improve flood control and water storage	Hankin et al. (2021)
Restoration and management of ponds	England	Pollination	Increase of pollinator interactions	Walton et al. (2021)
Management of agricultural ponds	England	Habitat maintenance	Increase of macrophytes biodiversity and establishment of historical communities	Sayer et al. (2012)
Management of ponds and riverine areas	England	Regulation of water quantity	Reduction in magnitude and timing of flood peaks. Reduction in surface runoff	Short et al. (2019)
Creation of agricultural ponds	France	Regulation of water quantity	Increase of functional richness and dispersion of macrophytes at lower phosphorous concentration	Arthaud et al. (2012)
Creation of ponds	France	Habitat creation and maintenance. Provision of inspiration	Increase in biodiversity Increasing water quality and quantity. Increase in visual amenity	Céréghino et al. (2007)
Creation of wetlands	Italy	Regulation of water quantity. Provision of physical and physiological experiences	Flood protection and increase of water quality. Maintenance of biodiversity. Increase spaces for recreation, relaxation of physical activities	Liquete et al. (2016)
Creation of ponds	Netherland	Habitat creation	Increase in biodiversity. Maintenance of existing ecosystems services	Leeuwen et al. (2021)
Creation and restoration of wetlands	Spain	Habitat creation and maintenance. Regulation of water quality	Recovery of ecological functioning of the wetlands. Increase in species and habitat biodiversity	Quintana et al. (2018)
Creation of wetlands	Spain	Habitat creation and maintenance. Regulation of water quality	Restoration of historic habitats. Increase macrophytes and zooplankton diversity	Rodrigo et al. (2018)
Creation and restoration of temporary ponds	Spain	Habitat creation	Increase and recovery of zooplankton diversity and richness	Badosa et al. (2010)
Creation of ponds	Spain	Habitat creation	Increase in amphibian diversity	Ruhí et al. (2012)
Creation and restoration of permanent and temporary ponds	Switzerland	Creation and maintenance of habitats	Increase in Odonata biodiversity	Indermuehle & Oertli (2006)
Creation of ponds	France, Spain, and Switzerland	Creation of habitats	Increase of diversity (amphibians, beetles, and snails)	Zamora-Marín et al. (2021)

Table 1 (continued)

NbS	Implemen-tation	NCPs	NbS's benefits	Ref
Creation of agricultural ponds	Argentina	Regulation of water quantity	Decrease of amphibian's richness and abundance (compared with natural habitats)	Perrone et al. (2022)
Creation of ponds	Florida	Creation of habitats	Increase in plants diversity (including invasive species)	Sinclair et al. (2020)

provide an overview of challenges and opportunities in this respect, as well as highlight the issues that need to be considered in the implementation of ponds as NbS. We also outline the knowledge gaps in research on ponds and pondscapes, particularly concerning global changes and biodiversity. Finally, we present a conceptual framework to develop and test the implementation of ponds and pondscapes as NbS (Fig. 1).

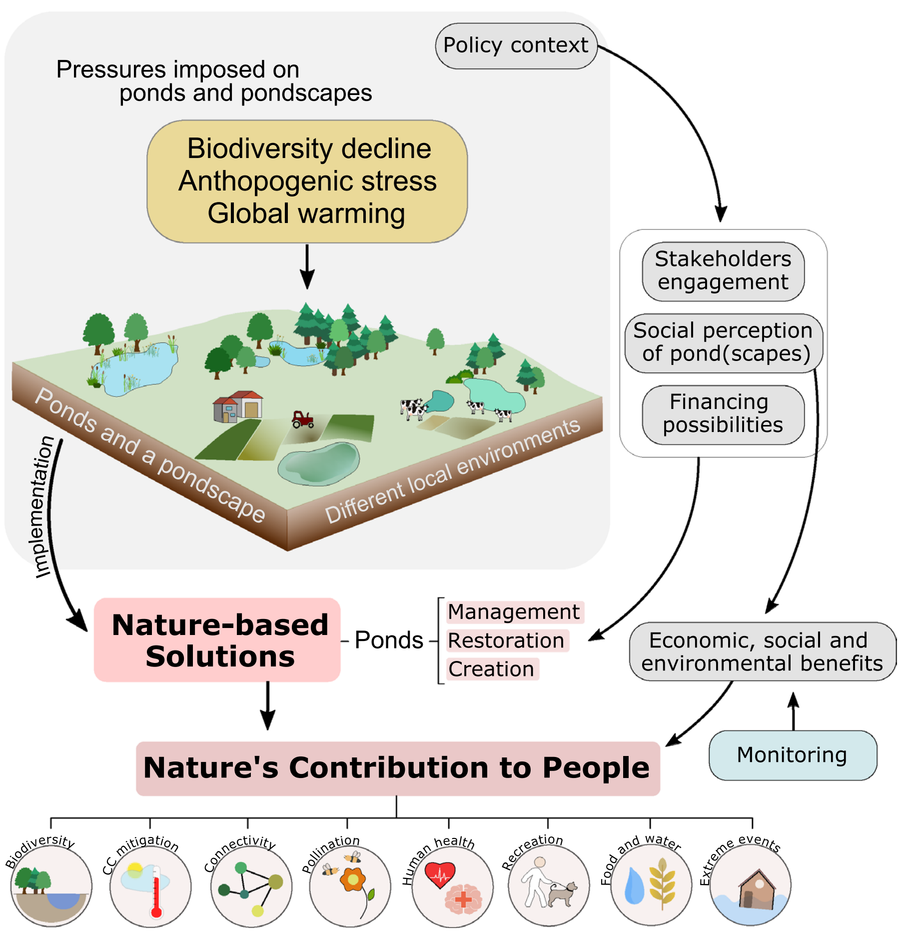

Fig. 1 Symbolic representation of ponds and a pondscapes, pressures imposed on them, their role as Nature-based Solutions and examples of some of the Nature Contributions to People they provide (circles at the bottom of the Figure). The five components of the proposed conceptual framework are shown in the right-hand panel (grey boxes)

Glossary:

Nature-based Solutions (NbS) are the actions inspired, copied, or supported by nature that provide benefits to biodiversity, ecosystems, and human well-being, including social, cultural, and economic. Following this definition, ponds can be divided into three types of NbS (for a more detailed definition and specific examples, see supp. Table 1):

- Pond creation—creating a new pond site where there was formerly no water body
- Pond restoration—restoring an existing pond or resurrecting a pond formerly present, but currently in-filled (Alderton et al., 2017; Sayer et al., 2022)
- Pond management—on-site actions ensuring improved functioning of a pond or pondscape (Sayer et al., 2012; Eggermont et al., 2015)

Ecosystem services (ES) are the direct and indirect contributions of ecosystems to human well-being. These can be divided into provisioning (e.g., food and water), regulating (e.g., carbon storage, water purification), cultural (e.g., recreation, health benefits) and supporting services (e.g., biomass production, nutrient cycling)

Nature Contributions to People (NCP) are all the positive and negative contributions of living nature to the quality of life for people, divided into three main categories: regulating (e.g., habitat creation, pollination, regulation of air quality or regulation of climate), material (e.g., energy, food and water or medical and genetic resources), and non-material (e.g., physical, and psychological experience and identity support) NCPs. The NCP concept builds on and expands the ES concept and includes the local knowledge of communities and the temporal and spatial context of it

Ecosystem functions (EF) are biological, physical, and geochemical processes that take place within ecosystems including productivity, decomposition, nutrient recycling, and energy flow-related functions. These EFs are important prerequisites for the delivery of the NCPs that ecosystems provide to humans

Pond: Small standing water with a surface area from 1 m^2 to 2–5 ha that may be permanent or seasonal, man-made or naturally created. While there are different definitions of ponds, in this paper we follow the definition of (Richardson et al., 2022)

Pondscape: Network of ponds spatially distributed in a terrestrial matrix and their connectedness (Boothby, 1997)

Importance of ponds and pondscapes

Over the past 20 years, our understanding of biodiversity's effects on ecosystem functions and stability has greatly improved (Loreau et al., 2001; Cardinale et al., 2012; Duffy et al., 2017). There is now a large body of empirical and theoretical work that demonstrates the positive effects of biodiversity on various ecosystem properties and processes. For instance, biodiversity promotes biomass production and pollination success (van der Plas, 2019), increases the resistance of ecosystem productivity to climate extremes (Isbell et al., 2015), ensures a stable supply of different NCPs (Hooper et al., 2005), and may even help decrease pathogen and herbivore damage (van der Plas, 2019). While the disproportionate contribution of ponds to local and regional biodiversity is increasingly acknowledged, there seems to be little action when it comes to pond biodiversity conservation. In the last century alone, losses of ponds have increased dramatically, with reductions of over 50% in many European countries, and even reaching 90% in some European regions (e.g. Netherlands, Switzerland and some parts of GermanyOertli et al., 2005; EPCN, 2007). The loss of natural ponds, and the associated decline of landscape connectivity, have profound negative consequences for pond biodiversity (Horváth et al., 2019) and NCPs delivery (Gozlan et al., 2019) and may result in considerable socio-economic losses (Rogers et al., 2022). As shown in Table 1, we summarise existing knowledge on the different NCPs that ponds and pondscapes provide. However, we recognise that there is currently insufficient knowledge on how the ongoing environmental changes impact the ability of ponds to deliver important functions to society.

Given their abundance and connectivity with other freshwater ecosystems, ponds have the potential to influence the carbon cycle by acting as both carbon sinks and sources (Holgerson & Raymond, 2016). Burial rates of carbon in ponds' sediments are estimated to be 20–30 times higher than in other ecosystems such as peatlands, grasslands or woodlands (Downing et al., 2008; Taylor et al., 2019; Gilbert et al., 2021). Other studies have shown that ponds store higher concentrations of greenhouse gases such as CO_2 and CH_4 per unit of surface than larger lakes and oceans (Downing et al., 2008; Downing, 2010). However, ponds also account for carbon emissions, estimated at 15.1% of CO_2 emissions and 40.6% of diffusive CH_4 emissions (Holgerson & Raymond, 2016; Yvon-Durocher et al., 2017; Peacock et al., 2019). The balance between carbon burial and emission can be influenced by many factors, including temperature, hydroperiod, eutrophication or the presence of vegetation (DelSontro et al., 2016; Davidson et al., 2018; DelVecchia et al., 2021). For example, changes in land use and eutrophication can affect oxygen availability, the amount and quality of organic matter, and pond microbial community composition and their activity, affecting carbon exchange with the atmosphere (Obrador et al., 2018). Yet, accurate estimation of carbon exchange from ponds is challenging, due to high temporal variability in emissions. A recent meta-analysis of existing data found that over 50% of CH_4 emissions from freshwaters come from habitat types with highly variable emissions over the year, such as temporary ponds (Rosentreter et al., 2021). This important albeit poorly quantified role in the C cycle contrasts with the fact that, due to their small size (sometimes < 0.1 ha) and the difficulty of mapping them, ponds have, thus far, been most often excluded from global estimations of greenhouse gas emissions from inland waters, especially in climate policies (Saunois et al., 2020; IPCC 2019).

Ponds are also important for water quantity and quality regulation. For instance, the natural connection between ponds and riparian ecosystems can provide flood protection at the watershed level (Tang et al., 2020) in areas at a high risk of flooding (Liquete et al., 2016; Short et al., 2019). Rural ponds also constitute precious water sources for cattle watering, irrigation, and firefighting, all especially important in summer or in semi-arid places, when water availability can be limited (Céréghino et al., 2007) or climate variability is high. All of these pond-related uses are especially important in the context of climate change, with rapid increases in the occurrence of extreme hydrological events, such as floods, heat waves, and droughts (Schlaepfer et al., 2017)IPCC et al., 2021). In addition, ponds can be constructed for water quality management, e.g. by removing phosphorus and other pollutants from runoff and stormwater (Comings et al., 2000; Wadzuk et al., 2010; Williams et al., 2020), although it is recognised that this use may compromise pond ecological quality (Williams et al., 2020).

Ponds and pondscapes also provide numerous non-material NCPs that are important to consider in relation to how the current loss of biodiversity may affect human societies. Nature provides different experiences to people, which are perceived by different groups in a non-quantifiable manner. While it is difficult to measure or assess these contributions, they are also important to human well-being (Hill et al., 2021b). Ponds and pondscapes can provide stress relief, support for human health and quality of life, spaces for recreational activities, including walking, jogging, cycling and gardening, or social interaction (Kabisch et al., 2017), aesthetic experiences and support of educational and spiritual activities (Bennett et al., 2015; Ghermandi & Fichtman, 2015; Raymond et al., 2017).

Challenges and opportunities for implementing ponds as NbS

The implementation of ponds and pondscapes as NbS can provide the necessary tools to simultaneously promote the protection of ponds and their biodiversity and support the delivery of crucial NCPs. For instance, the creation of ponds and pondscapes that support landscape connectivity, as well as strategic conservation and restoration measures linked to ponds and pondscapes, can enhance biodiversity (Sayer & Greaves, 2020; Hyseni et al., 2021). At the same time, enhanced biodiversity increases the overall stability and functioning of ecosystems, which in turn may lead to a more stable and long-term delivery of important benefits for humans (Balvanera et al., 2006) and nature. As shown in Table 1, several studies have investigated the potential of ponds and pondscapes as NbS in providing different NCPs including the improvement of the ecological status of ecosystems and consequently biodiversity (Table 1). However, there are still numerous barriers and challenges that hinder the establishment, development, and appropriate management of ponds and pondscapes, linked to existing knowledge gaps on the ecological status and functioning of ponds and pondscapes, to the economic, policy and social context they operate in (Hill et al., 2018, 2021a), and to the costs and benefits of using ponds and pondscapes as NbS (Short et al., 2019).

The combination of the different anthropogenic factors involved in ponds and pondscapes (e.g. social, political, economic and financial factors) can affect the ecological status of ponds and pondscapes by driving either their protection and conservation or their deterioration and destruction (Stafford et al., 2021; Toxopeus & Polzin, 2021). The implementation and management of ponds and pondscapes as NbS not only relies on ecological knowledge, but requires explicit consideration of the social, political, and economic context (Balian et al., 2014). In particular, there is a need for engaging stakeholders from relevant sectors operating at multiple spatial and different governance scales, in current and future decisions concerning ponds and pondscapes. In this context, stakeholders interested in the issue of pondscape management could be, for example, environmental NGOs, public authorities at different levels, business representatives (e.g. farmers, tourism operator companies), land owners and land owner associations (Calhoun et al., 2014; Ureta et al., 2021). In addition, it is crucial to consider the possibilities for financing pond preservation, construction, restoration, or adequate management, as well as the policy context that either enables or limits the use of ponds and pondscapes as NbS. These different aspects are discussed in the next section, where we present a conceptual framework for a broader uptake of ponds and pondscapes as NbS.

A conceptual framework for the implementation of ponds and pondscapes as NbS

Because ponds, and their role in societies, have been largely neglected in both ecological research and policies, as well as action on the ground (Biggs et al., 2017), there is an urgent need to promote broader uptake of ponds as NbS. Ponds and pondscapes as NbS can help to address several ongoing environmental changes, such as climate change, water quality deterioration, and biodiversity decline, and support the delivery of numerous important NCPs (Rey-Valette et al., 2017). What is currently missing is the empirical knowledge on the variability of benefits provided by pondscapes (i.e., economic, social, and environmental benefits), as well as how some NbS benefits may compromise others (Arthaud et al., 2012). In addition, relatively little is known about the political and social context of the ponds and pondscapes NbS, as well as factors enabling their successful implementation, such as NbS financing.

Based on available information on ponds and pondscape roles in addressing biodiversity decline and climate change challenges, as well as the numerous NCPs they deliver, we introduce a *conceptual framework* for the implementation of ponds and pondscapes as NbS. Figure 1 provides a symbolic representation of a pondscape with different pressures imposed on individual and collective ponds and shows that the implementation of ponds as NbS can support or enhance the delivery of numerous NCPs. The figure also includes the five main components of the proposed framework that reflect the focus areas that need to be considered when planning the implementation of ponds or pondscapes as NbS: (1) policy context; (2) the economic, social, and environmental benefits; (3) stakeholder engagement; (4) social perception of ponds and pondscapes; (5) actual possibilities of financing.

Understanding the *policy context* of ponds and pondscapes NbS is important for its implementation. Considering ponds and pondscapes in relevant policies, as well as the development of clearly defined local and international policy targets are fundamental to motivating effective pond NbS action and enabling policymakers and stakeholders to evaluate the effectiveness of potential management decisions (Nika et al., 2020). Such policy targets need to integrate concerns of different sectors as pondscapes impact on and are impacted by the policies, regulations and strategies of different sectors and policy areas (Castro & Rifai, 2021). These are, for example, the agricultural, urban development, spatial planning, biodiversity conservation, or tourism sectors. In ponds located on private land, trade-offs between development, private interests and conservation have to be considered, and policies must ensure compatibility between existing and future human uses (and the local economic benefits) and the protection of ponds due to their intrinsic value for nature. Institutional fragmentation, or even opposite mandates, may also impede the efficient implementation of ponds and pondscapes as NbS, as a lack of coordination across concerned sectors may lead to suboptimal outcomes, i.e. potential benefits of ponds and pondscapes are not integrated or maximised (Blicharska & Johansson, 2016; Kati & Jari, 2016; Oertli, 2018). To incorporate specific concerns about pondscapes, there is a need to use appropriate policy instruments and approaches, as well as to explore the discourses that respective policies initiate. A policy inventory and policy analysis can reveal existing factors, including different instruments, that can either facilitate or hinder the creation and adequate management of pondscapes.

In addition, as there is relatively little information about the potential benefits of ponds and pondscapes as NbS, there is a need for more research in this area. Specifically, there is a need to *comprehensively assess the economic, societal, and environmental benefits* of ponds and pondscapes as NbS. Long-term and systematic monitoring of pond-derived NbS can provide information on NCPs it provides and whether it has addressed the challenges for which it was implemented. However, such monitoring requires both resources and commitment, which are not always easily available. To assess the success of pond NbS it is also necessary to develop a set of clear indicators to measure their performance and impact.

When it comes to implementing ponds on the ground, *stakeholder engagement* is crucial to identify the different interests that are at play in the area where the ponds and pondscapes NbS may be created, restored, or managed. This can be linked to land ownership or land use, as it is common that pond conservation takes place on privately owned land (Hambäck et al., 2022). For example, different stakeholders may have different priorities regarding the ponds they use or manage; local communities may prioritise NCP such as recreation, artistic or mental health resources or food production, while landowners, non-governmental organisations (NGOs) or risk management authorities may prioritise others, such as agricultural uses or flood risk management, climate regulations or habitat creation and maintenance to promote biodiversity. This prioritisation conceals issues of power relationships, accessibility to public funding and management practices (Cornea et al., 2016).

Stakeholder knowledge is also important in assessing, valuing, and prioritising the contribution of pond and pondscape NbS to biodiversity and different NCPs (Watkin et al., 2019). Such knowledge can be used to arrive at the most complete and accurate assessment possible of the different benefits (Mathé & Rey-Valette, 2015), including potential trade-offs and co-benefits of NbS implementation (Hambäck et al., 2022). Moreover, stakeholder engagement supports the development of a trusting relationship between stakeholders and researchers which in turn contributes to the legitimacy, and effectiveness of action (Hill et al., 2021a). For example, in the UK, the restoration of on-farm ponds was advanced through a multiannual programme involving civil society initiatives, researchers, local authorities and farmers that resulted in strong local commitment and continues to yield positive results (Sayer & Greaves, 2020).

Alongside engaging stakeholders and learning about their priorities and needs, it is also important to assess the *social perception of ponds and pondscapes.* In general, there is often a lack of information regarding the history of ponds in a region, the perspectives of the general public and inhabitants on ponds and pondscapes, and which benefits from NbS are most important to them. However, information about how the different stakeholders and the general public perceives ponds and their role can help further refine the key reasons underlying the need to promote ponds and pondscapes as NbS, and also can help make potential conflicts explicit. It also helps to ensure better effectiveness of the implementation of ponds in NbS work and supports the selection of the right management practices, as it aids in consideration of the diversity of viewpoints from different actors (Rey-Valette et al., 2017).

Finally, the presence of NbS *financing* is key for the implementation of ponds and pondscapes; however, securing financing for this is a major challenge (Davies et al., 2021). For example, the initial cost of pond creation includes the planning, digging, or buying of the terrain followed by the costs associated with the maintenance, management, and monitoring of NbS. Additionally, the interest of private financers in ponds and pondscapes NbS depends on the potential benefits of NbS, particularly in monetary terms. Financers very often seek a return on their investment and need to be made aware of the value created by the NbS, and how this will be created and delivered. Integral attributes of NbS pose two major challenges for creating convincing business cases, and for accessing financing: (1) NbS deliver multiple benefits to a number of different beneficiaries, over different timescales. This ‘scattering’ of benefits between different stakeholders means that, often, multiple beneficiaries have to collaborate on NbS, as only together do their individual benefits outweigh the costs of implementing and maintaining NbS (Toxopeus & Polzin, 2021); (2) many of the benefits generated by NbS are not adequately valued or rewarded by the market. This includes biodiversity conservation and carbon sequestration, which are public goods, or regulation of water pollution or flooding, which are undervalued externalities arising from other actions (Xepapadeas, 2011). This is especially relevant to ponds due to their small size and general lack of knowledge on the benefits they provide, commonly leaving such NbS at the discretion of available public budgets (Faivre et al., 2017) and the subject of often contrasting sectoral pressures.

Conclusions

Despite their strong ties with human societies, their importance for biodiversity, their potential for climate change mitigation and for the delivery of other important NCPs, ponds are underrepresented in research and conservation policies. Conservation and management efforts have been focused preferentially on larger lakes and rivers-catchment systems, with detrimental consequences for the conservation of small ecosystems such as ponds. Nevertheless, the loss and degradation of ponds is known to have profound and negative effects on the delivery of NCPs, such as the creation of habitat for biodiversity and potential for climate change mitigation and adaptation, regulation of water quality and quantity and numerous intangible benefits. Because of the different benefits ponds and pondscapes provide, they can be used as NbS that can help to address local and global environmental challenges. However, to achieve that, there is an urgent need to increase the awareness of policymakers, other stakeholders, and general society of the crucial role of ponds and pondscapes, and to promote an enabling social and policy context that would allow for broader use of these small but important ecosystems as NbS.

The conceptual framework developed in this paper provides an overview of key aspects that need to be addressed in relation to that. This framework can be used in two ways. First, it can guide future research focus in relation to ponds and pondscapes. With regard to pond benefits, there is a particular need for studies on the biodiversity value of these ecosystems at local, regional, and international scales, studies on pond ecology and particularly on GHG fluxes, both when ponds are flooded and dry, as well as studies on the other NCPs that can be delivered by pondscapes. When it comes to the social and policy context of ponds, studies on pond perceptions, and the common barriers and opportunities in the implementation of ponds and pondscapes NbS, particularly with regard to the needs and priorities of different stakeholders, as well as financing options, are also necessary. Second, the framework can serve as a guide for local managers and other stakeholders that may want to implement ponds and pondscapes as NbS. It includes the different aspects that such actors need to consider when planning the creation, restoration, or management of these ecosystems. Particularly, it highlights the often neglected issues such as policy context in which ponds are embedded, social perception, and thus, the potential for the acceptance of the potential NbS action.

While this work progresses and new knowledge and data accumulate, we make a plea for a concerted effort to develop a database of existing ponds and pondscapes NbS that includes best practice examples and success stories to enable learning for improved future implementation of ponds and pondscapes as NbS.

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Declarations

Conflict of interest All the authors of the manuscript are part of PONDERFUL project and declare no conflict of interest.

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