Chapter 8

The ecology and management of urban pondscapes

Christopher Hassall, Matthew Hill, David Gledhill and Jeremy Biggs

Introduction

Urban wetlands are an often neglected habitat, despite being very common (Davies *et al*. 2009). Lakes have been described as sinks for the consequences of human activity (Moss 1998). If so, then urban ponds may bear the brunt, being poorly buffered against perturbation and situated in areas of peak human activity. This neglect means that the evidence base for the management of urban ponds is limited, especially in the context of biodiversity enhancement. Much is still unknown about the exact number and distribution of urban ponds in cities around the world and questions remain unanswered about their contribution to biodiversity. While larger ponds and those in public areas are relatively easy to map, the numbers and character of garden ponds is much harder to pin down. The difficulty in accessing private gardens makes the large-scale assessment of garden pond ecology challenging. One estimate places the number of garden ponds in the UK between 2.5 and 3.5 million (Davies *et al*. 2009). It is unclear what quality of habitat these ponds provide and how they contribute to urban biodiversity.

While the precise definition of a pond varies geographically and between researchers, a pond is typically described by its area. In this context a pond can be defined most commonly as an area of lentic water <2 ha (Biggs *et al*. 2005). They can be largely permanent or temporary habitats and can be either natural or artificial in origin. Urbanisation can be major cause of pond loss (Wood *et al*. 2003). Conversely, many aquatic habitats have been created by human activity. These include industrial lagoons (to supply water or store waste materials), sustainable urban drainage systems (SUDS), amenity ponds in parks and garden ponds (Figure 8.1).

Applying theories of pond ecology established for rural locations may be problematic. It is possible that urban ponds represent a unique habitat and not merely an analogue for rural ponds. The potential homogenising effect of urbanisation on ponds is little explored. Are ponds in the city of Birmingham more similar to ponds in Glasgow, Liverpool or London than to their rural neighbours? Research on urban rivers suggests they represent

(*continued*)

(*continued*)

Figure 8.1 Urban ponds comprise a range of diverse habitats including garden ponds (top left), industrial mill ponds (top right), nature reserves (bottom left), and stormwater management facilities (bottom right). Photo credits clockwise from top left: MH, Matthew Hartley (CC-BY 2.0, https://flic.kr/p/gQcB8u), Futurilla (CC-BY 2.0, https://flic.kr/p/fpuBRS), and CH.

novel ecosystems with unique combinations of species (Francis 2014). In common with many small scale features of the landscape ponds have often been considered of relatively little biodiversity value. It is in fact their small size that makes ponds so significant for regional biodiversity (Hassall 2014). A single pond may hold fewer species than, for example, a river. However, even within a small area ponds can differ greatly in their prevailing biotic and abiotic conditions. Therefore a network of small ponds can hold far greater numbers of species than a single body of water with the equivalent area (Oertli *et al.* 2002). This coupled with the dynamic nature of individual ponds increases the need for pondscape scale conservation. In addition ponds can provide refuges and stepping stones for species in highly modified landscapes.

In the UK alone over half of all ponds have been lost in the last 150 years (Williams *et al.* 2010). Ponds across Europe have declined by 55 per cent in Sweden (1914–1970) and there has been as much as a 90 per cent decline in the Netherlands (1990–1989) (Hassall 2014). Even within the UK there is considerable variation in estimates of pond loss ranging from 6 per cent in Edinburgh (up to 1990) and 90 per cent within London (1870–1984). This decline is not restricted to urban areas with much more rural counties like Cheshire showing a 60 per cent drop in the number of ponds between 1870 and 1993 (Wood *et al.* 2003). There is evidence the trend is reversing with an estimated 12.5 per cent increase in pond numbers in UK between 1998 and 2007 (Williams *et al.* 2010). Less easy to determine, but equally important are changes in the ecological quality of the pondscape. The spatial arrangement of ponds can be as important as their number and can have a major impact on their biodiversity (Gledhill *et al.* 2008).

While research into urban ponds is limited, practitioners spend time, effort and funds in pond creation and management. Many management strategies are based on anecdotal evidence rather than reliable scientific data. This review highlights key aspects of urban pond landscape ecology and uses the available evidence to provide novel insights into their ecology, management and policy. Accompanying discussions of ecosystem services and the socio-ecology of urban pond landscapes can be found in Blicharska and Johansson (Chapter 10, this volume).

Ecology

Biodiversity

Urban ecosystems of any kind raise a number of (arguably) unique and interacting anthropogenic stressors that must be taken into account in order to understand the ecology of habitats and species living in urban areas. The general patterns of biodiversity decline across cities suggest a generally negative (though complicated) relationship between the intensity of urban land use – from rural to suburban to urban core – and biodiversity in a wide range of groups (McKinney 2008). Previous studies of urban ponds have shown, however, that ponds within urban areas can provide considerable biodiversity habitat even compared to rural ponds (Hassall and Anderson 2015), while other ponds have a very low ecological quality even though they may be dedicated to biodiversity (Noble and Hassall 2015). This heterogeneity of habitats, both in terms of their physicochemical attributes and the diversity of the biological communities they may support, means that simple rules for conserving and enhancing pond resources are not available. A second consequence of urban pond heterogeneity is that different stakeholders may have different experiences of urban ponds. Managers may perceive a generally poor-quality set of habitats that are dominated by eutrophic and otherwise polluted ponds lacking in biodiversity. Researchers, on the other hand, have tended to emphasise the potential benefits to biodiversity for a wide range of species (Hassall 2014).

While there is a general understanding that urban ponds can (though do not always) constitute an important habitat for biodiversity in built-up areas, there is a lack of clarity concerning the particular factors that drive biodiversity patterns in urban ponds. To a certain extent this is true of ponds in general (Hassall *et al.* 2011), and it is notable that there are differences in key biodiversity drivers even between substantial datasets of pond biodiversity; the National Pond Survey in the UK (ca. 200 minimally impacted ponds) indicated no effect of shading (Biggs *et al.* 2005) while a larger study (425 ponds) showed a significant, though non-linear, effect of shading (Hassall *et al.* 2011). Urban ponds have been studied in a range of contexts, and a number of central predictors emerge:

- *Surrounding land cover* – urban ponds are surrounded by a terrestrial matrix that is not only inhospitable to purely aquatic species but that also produces problems for the aquatic environment itself through run-off. Evidence for the importance of local land use comes from Australian amphibian communities (Hamer and Parris 2010) and Canadian macroinvertebrates (Hassall and Anderson 2015).
- *Connectivity* – the degree of hydrological connectivity is a 'double-edged sword' for ponds. Their small size and isolation reduces the effects of pollution events and other stressors, but also reduces the rate of colonisation of flora and fauna. Studying connectivity is hampered by poor definitions of what constitutes 'connectivity' (Lindenmayer and Fischer 2007), the taxon-specific nature of barriers, the poor performance of current models of connectivity (Winfree *et al.* 2005), and the potential for connectivity to distract from more important concepts such as habitat area and quality (Hodgson *et al.* 2009). Despite this, connectivity (pond density) has been shown to correlate with diversity in urban ponds (Parris 2006; Gledhill *et al.* 2008; McCarthy and Lathrop 2011).
- *Vegetation* – a final factor in the determination of urban pond biodiversity appears to be the nature and management of riparian and

emergent vegetation. Studies have shown a strong association between the presence of vegetation and the diversity of urban odonates (Goertzen and Suhling 2013), while chemical (Ackley and Meylan 2010) or mechanical (Fontanarrosa *et al.* 2013) removal of vegetation resulted in a decline in biodiversity.

The landscape scale

While there is a growing support for the view that ponds in cities can provide substantial refuges for biodiversity, there is still a lack of joined-up thinking in the ways in which these habitats are integrated into the wider landscape (Chester and Robson 2013). We suggest that this breakdown occurs at two spatial scales. The first scale is at the city-level, where particular types of urban water bodies tend to fall under the remit of different local authority groups. Stormwater management ponds may be managed by engineers, park lakes may be managed by countryside rangers, industrial ponds may be managed by private businesses, and garden ponds are managed by local residents. Without reasonably complete inventories of urban aquatic resources, it is difficult to see how small water bodies such as ponds can be optimised for biodiversity. The 'pondscape' approach (Boothby 1997) takes local connectivity into account when attempting to delineate a region over which a network of ponds can act. Inherent within that concept is the intervening matrix, but there have been few quantifications of connectivity in urban terrestrial or aquatic systems. Recent studies have suggested that the matrix may be less important than previously thought when looking at metapopulation processes (Prugh *et al.* 2008; Watling *et al.* 2011). It has previously been noted that amphibians experience an urban landscape that has 10 per cent of the permeability of a rural landscape (Hitchings and Beebee 1997), but connectivity is species specific (Tischendorf and Fahrig 2000). Urban areas form a key part of the matrix and need to be managed and understood if protected area networks are to be successful (e.g. Bruinderink *et al.* 2003).

The second scale at which there has been a lack of integrated thinking on urban ponds is in the comparisons between different cities. There have been studies performed on urban pond biodiversity on all continents, and yet, while the data are potentially comparable, the focus of those studies has been region-specific (Hassall 2014). There exists a considerable opportunity for collaborative urban pond ecology across cities, countries, and academic disciplines, which will greatly enhance our holistic understanding of the nature of these habitats. Similar studies have been conducted for pollinator (Carvalheiro *et al.* 2014) and tundra systems (Elmendorf *et al.* 2012) and have yielded considerable insights that allow the researchers to control for regional variations to extract general trends. These approaches, coupled with the opportunities presented by citizen science (see below), could produce substantial progress in our understanding of the functioning of urban ecosystems but require considerable long term funding.

Climate

Among the most significant factors influencing, and being influenced by, urban water bodies is climate. Lakes, ponds and rivers in urban areas act to buffer against the urban heat island (UHI) effect, remove heat through evaporation, or carry heat away (in the case of rivers), reducing the temperature of urban environments (Kleerekoper *et al.* 2012). The UHI produces a set of urban water bodies that may exist at a considerably higher temperature than ponds in surrounding non-urban landscapes, although this has not been formally studied. Runoff entering urban ponds from impermeable surfaces causes surges of hot water into urban ponds (Hester and Bauman 2013), and the outflow from those ponds has been shown to produce temperature spikes in local rivers (Lieb and Carline 2000). While many urban stressors have been studied, the coupling of chronic temperature elevation caused by the situation of urban ponds within warmer urban environments and the acute temperature elevation caused by runoff from impermeable surfaces has received little attention. A variety of thermal thresholds have been described for vector competence in insect disease vectors (Cornel *et al.* 1993) and increasing temperatures are thought to be driving the expansion of cyanobacterial blooms (Paerl and Paul 2012). Temperature also appears to be a primary determinant of aquatic biodiversity (Rosset *et al.* 2010), but the capacity for warmer water bodies to reach their theoretical diversity limits will be limited by the capacity of the regional species pool to colonise urban areas.

In combination with variation in temperature, variations in the quantity and frequency of precipitation also influence urban pond ecology. In drought-stressed landscapes urban ponds can be a refuge for species that require freshwaters (Parris 2006). However, urban run-off tends to contain a greater concentration of pollutants at higher rates of precipitation (e.g. Taebi and Droste 2004) which may lead to acute exposure to pollutants above the tolerance limits of aquatic species (Sanzo and Hecnar 2006). Pollutants enter urban waters both from surface wash-off but also atmospheric scrubbing, which both contribute to urban stormwater runoff quality in complex ways (Tsihrintzis and Hamid 1997). Urban ponds tend to have relatively low residence times due to high runoff from the surrounding impervious urban area (Persson 2000), but precipitation and temperature can interact when runoff is heated by urban impervious surfaces (Hester and Bauman 2013). The ecological consequences caused by these climate processes, in terms of biodiversity and ecological function, are poorly understood.

Management

Conservation evidence

Whilst it is widely recognised that, at the landscape (pondscape) scale ponds may support greater biodiversity and can have a higher conservation value than other wetland habitats (Williams *et al.* 2004), the wider value of urban ponds has been poorly quantified historically. Evidence appears equivocal, with some evidence indicating that macroinvertebrate biodiversity of the 'best' urban and garden ponds may be comparable to those in rural locations (Hassall and Anderson 2015), but that some garden ponds may support very limited communities comprising less than ten taxa (Hill and Wood 2014). The limited examination of urban wetland habitats reflects a variety of issues regarding public and scientific perceptions and more fundamental issues such as:

I the diversity of urban pond types and functions – ranging from ornamental features, sediment and surface drainage detention ponds through to wildlife features within school grounds (Hassall 2014);

II the accessibility and visibility of urban drainage features on private enclosed land and urban domestic garden ponds largely hidden from view has meant that most are unseen by anyone except the owner (Hill and Wood 2014); and

III the absence of statutory routine monitoring except where taxa with specific conservation designations are known to occur (Wood *et al.* 2003).

Given the wide variety of ponds that occur in both rural and urban locations and the different functions they perform, it is probably not surprising that a number of myths and misconceptions regarding the management of ponds in both rural and urban areas persist (Biggs *et al.* 1994). Examples of management strategies that potentially lack a clear conservation or scientific basis but have been widely advanced include: (i) ponds should be at least two metres deep; (ii) the bigger the pond the better; (iii) ponds should not be shaded by trees; (iv) all pond zones should be maintained and they should be dredged to prevent them from becoming choked with vegetation; and (v) water level fluctuation should be minimised and drying is disastrous for pond communities (Biggs *et al.* 2005). Although these statements and management strategies may be appropriate in some instances, they would result in the homogenisation of pond micro-habitats and significant loss of adjacent habitat diversity at the landscape scale if applied to all ponds; and the elimination of ephemeral ponds (Nicolet *et al.* 2004).

There is a clear need to recognise that most urban ponds have been anthropogenically created and that the management of individual ponds should reflect the objectives and requirements they were designed to perform or more specifically 'society's' or the owner's vision for the pond. In addition, management interventions within small water bodies should be sensitive and appropriate in relation to their size and location in relation to other water bodies and ponds – their connectivity. The large scale removal of all vegetation or complete dredging of a pond could be detrimental to the communities it supports, eliminate any existing conservation value or even re-set the successional trajectories. There is a long tradition of providing guidance to pond owners regarding their management dating from the late nineteenth- through to the early twentieth-century naturalist's view of ponds being the outdoor extensions of aquariums (Furneaux 1911). Today there are numerous practical guides regarding the management of ponds as ornamental features (Robinson 2009) or to support specific faunal groups, most notably amphibians with a high dependence on pond habitats and specific conservation designations (e.g. Smith and Sutherland 2014). However, it is also important to ensure that other floral and faunal groups are specifically considered within management and conservation objectives, and that a more holistic approach is adopted. At the pondscape scale this is imperative because conservation and management centred on specific groups (e.g. amphibians) or species (e.g. Great Crested Newt – *Triturus cristatus*) cannot necessarily be generalised to other taxa. There is therefore a need for a variety of strategies that can be applied to different urban water bodies so that within a given area a variety of floral and faunal groups and species are conserved and to support 'wildlife' in general (Bardsley 2012).

From globe to garden

In some areas of the globe the management of small urban waterbodies is driven by public health concerns and the need to control the vectors in disease such as malaria or West Nile virus (Matthys *et al.* 2006; Lambin *et al.* 2010). It is easy to forget that garden ponds are largely unknown in many regions. It has been estimated that there could be as many as 3.5 million garden ponds in the UK covering up to 349 hectares (Davies *et al.* 2009). This means there are literally millions of autonomous managers and habitat engineers of gardens ponds. In some instances the creation of ponds and water features has been encouraged by high profile 'celebrity gardeners' and there has been a wave of interest in home and garden improvements (e.g. Titchmarsh 2013).This current interest is not new and there is a long tradition of providing guidance to the garden pond owners (e.g. Hodge 1933; Sterry 1982). However, this is not without problems, since the advice given for the creation and management of a pond stocked with ornamental fish (Papworth 1984) is highly likely to be different, and in some instances apparently contradictory, to that for wetland and aquatic plants (Hessayon 1993) or for wildlife more widely (Williams *et al.* 1999). In some instances this has resulted in taxa commonly associated with ponds being identified as potential 'nuisances' or 'pests' including larger diving beetle adults and larvae (Dytiscidae), dragonfly larvae (Odonata) and the water-scorpion (Nepa cinerea) as a threat to small fish (Hodge 1933) or caddisfly larvae (Trichoptera), non-biting midge larvae (Chironomidae) and the China mark moth caterpillar (Pyralidae) as potential pests in ponds with floating leaved ornamental plants (Titchmarsh 2013). Potentially the greatest threat to the long term management and conservation of small water bodies and organisms that they support is the stocking of ornamental ponds with non-native fish or plants and the unseen invertebrates and algae that may be associated with them. In the absence of appropriate management, effective bio-control measures or failures of the supplier to correctly identify non-native plant/fish species correctly, some have the potential to become invasive species leading to the displacement/exclusion of native taxa and disruption of 'normal' ecosystem processes. Garden ponds have been the potential source of introductions of a range of organisms including algae, macrophytes, fish, terrapins, molluscs and crustaceans (Hassall 2014).

There is a need for a systematic review of urban pond conservation and management interventions to increase awareness of the biodiversity and wider values of urban ponds. This is required to ensure that all of those with a vested interest in ponds are aware of existing diversity and values of ponds, ranging from local government organisations who own large numbers of ornamental and operational ponds, non-government organisations and charities who frequently undertake management and conservation activities on both rural and urban ponds, garden pond owners and the general public (see Chapter 10). Most modern practical guides on pond creation and management have clearly recognised that there are variety pond types and as a result a range of targets (including purely aesthetics and for the management of a range of different flora, fauna or communities) that require flexible management and conservation objectives (Hessayon 1993; Bardsley 2012). The potential role and wider value of urban gardens in supporting and even enhancing biodiversity and as habitats for wildlife has been increasingly recognised (Goddard *et al.* 2010). Some organisations, such as a the Royal Society for the Protection of Birds (RSPB) and the Freshwater Habitats Trust, have identified the crucial role that the general public and 'Citizen Science' has to play in this process through the collection and recording of a variety of data and support this alongside primary research and conservation activities (Goddard *et al.* 2013). These activities can be extended to ponds in public areas, including municipal parks, school ponds and golf courses through local wildlife groups or pond warden schemes (e.g. The Footprint Trust 2014).

Policy

Background

Ponds are not currently well-served by policy intended to protect freshwater habitats and the biodiversity supported by those habitats. The main reason for this is that it is only quite recently that the importance of ponds as freshwater habitats has been realised, with key data sources only becoming available in the last 10 to 15 years. For example, the study of Williams *et al.* (2004), showing how the contribution to biodiversity made by ponds at landscape scale was similar to that made by rivers, was only published ten years ago and the insightful views of Downing (2010) about the tendency to underestimate the importance of small waters are even more recent. In Europe and the UK, the most important practical implication of this late recognition of the importance of ponds is seen in the implementation of the European Union Water Framework Directive (EC 2000). Although the WFD specifically states that it is concerned with the protection of *all* freshwaters, the agencies responsible for its implementation had virtually no information about the importance of small waters, either still or flowing, when developing the detailed rules guiding its application in the Member States. Consequently, ponds and small lakes were largely excluded from the practical implementation of the WFD, and even small running waters were considered only in as much as they might influence the more 'significant' downstream waters into which they flowed. Given what is now known about the importance of small waters, both for freshwater biodiversity and other ecosystem processes, this omission has had profound implications for the protection of the water environment throughout Europe. In contrast to the WFD, ponds are slightly better recognised in European nature conservation legislation. Thus, the Habitats Directive (EC 1992) refers to a small number of specific pond types (e.g. Mediterranean temporary ponds, natural dystrophic lakes and ponds) and also provides specific protection for a small number of pond associated species, mainly amphibians (e.g. Great Crested Newt, *Triturus cristatus*). However, as with the WFD, because much of the detailed knowledge of the importance of ponds only became available some time after the original development of the Habitats Directive, there remain many gaps in the protection it provides for the ponds and their associated species.

The policy framework

Legislation protecting freshwater habitats broadly falls into two categories: (i) pollution and water resources orientated legislation which is intended to maintain the general condition of freshwaters and (ii) nature conservation legislation which aims to protect specially endangered examples of the habitat or species dependent on it. At the European level this division is broadly enshrined in the objectives of the Water Framework Directive and the Habitats Directive, respectively, and echoed in national legislation. However, although the European directives are important, it is international biodiversity conventions (particularly the Convention on Biological Diversity) that have led to the development of what are currently the most practically influential policies protecting ponds in the UK: the development of the concept of Priority Habitats and Priority Species, formalised in the Natural Environment and Rural Communities Act of 2006 for England and Wales (HMSO 2006) and in other mechanisms in Northern Ireland and Scotland (JNCC and Defra 2012). These legislative developments post-dated the late-1990s and early 2000s surge of knowledge about ponds and have begun to provide a practical framework for UK pond conservation and management.

A second set of policies is more concerned with the use of ponds in protecting other parts of the water environment, rather than with the ponds themselves. In these approaches, such as using ponds as part of a Sustainable Urban Drainage System (SUDS) or creating balancing ponds to hold back rapid surface water runoff from urbanised areas, ponds are made mainly to provide protection for other parts of the water environment, although the construction of new water bodies does provide some biodiversity benefits. Rules encouraging the use of ponds to deliver ecosystem services stem mainly from flood and pollution control legislation influenced mainly by implementation of the Water Framework Directive and the Floods Directive (EC 2007). Modern legislation on SUDS is outlined in the Flood and Water Management Act 2010 (HMSO 2010), although key schedules have not yet been implemented. These activities continue the long tradition of using man-made ponds to provide a service (e.g. fish for food, industrial water supply, drinking water) which may additionally bring benefits for freshwater biodiversity.

Water environment policy and ponds

The main freshwater policy driver, the Water Framework Directive, currently has little influence on ponds. With a size cut-off at 50 ha for the recognition of standing water bodies, a very large proportion (in excess of 95 per cent) of ponds and smaller lakes are excluded from the interventions of the Directive. Although it is sometimes suggested that the broad catchment-scale water pollution control policies applied under the directive, particularly those concerned with reducing polluting runoff from the land, should benefit smaller waters, there is little evidence that this is occurring so far (Williams *et al.* 2010). For example, in recent work undertaken on catchment freshwater biodiversity patterns, Biggs *et al.* (2014) found that freshwater wetland plant biodiversity continued to decline in all freshwaters, including ponds, in a landscape where there was a typical level of application of agri-environment measures which, reflecting standard policy priorities, were largely focused on protecting running freshwater ecosystems. Although the majority of ponds are currently outside the purview of the Water Framework Directive, in the UK, around a dozen sites with ponds, which are identified as Special Areas of Conservation (SAC), are considered under the protected areas rules of the Water Framework Directive (Environment Agency 2011).

Conservation policy and ponds

Nature conservation legislation has more influence on ponds. Practically, conservation legislation relating to ponds falls into two categories: that protecting the habitat and that protecting the species that use the ponds. Nature conservation organisations have been quicker to recognise the significance of ponds than those concerned with water management and, as a result of this, the most important policy tool for protecting ponds and their biodiversity derives from conservation legislation, specifically from the implementation of the Convention of Biological Diversity in the UK. This has led to the identification of ponds of high ecological quality as priority habitats under the UK Biodiversity Action Plan (and its subsequent forms in different component countries of the United Kingdom) and the identification of priority species. It is estimated that about 20 per cent of all ponds are likely to be priority habitats (BRIG 2011) and 10 per cent of *all* priority species – terrestrial and aquatic – can be found in ponds (list available from Freshwater Habitats Trust 2015).

Ponds of high ecological quality were first identified as part of the UK Biodiversity Action Plan in 2007 following the revision of the priority species and habitats lists first developed in 1995 (BRIG 2007). The importance of small waters was further confirmed in the Natural Environment White Paper of 2011 (Defra 2011). Although implemented by different mechanisms in the four countries of the UK they have remained priority habitats. Priority ponds are identified according to their biological characteristics and are those ponds that (i) are habitats of high conservation importance (i.e. including Habitats Directive community types), (ii) support species of high conservation importance, (iii) support exceptional numbers or populations of key species, (iv) are of high ecological quality (assessed using the Predictive SYstem for Multimetrics, PSYM, a rapid assessment protocol for the ecological quality of ponds), or have some other important characteristics (for example, pingos – mounds of earth-covered ice that create ponds when the ice melts – are priority ponds, irrespective of their other biological features) (JNCC and Defra 2012). A Pond Habitat Action Plan was prepared in 2008 giving overall targets for UK (Environment Agency and Pond Conservation 2008). In England, Natural England has set a target for 90 per cent of priority habitats being in Good condition by 2020. Different arrangements have been made in the other UK member countries (JNCC 2013).

Over 100 priority species are known to be associated with ponds with the number slowly growing as knowledge of the habitat preferences of freshwater species grows. Initial analyses indicated that ponds supported more priority species than lakes, and similar numbers to rivers (Webb *et al.* 2010). However subsequent unpublished analyses for the UK-based Million Ponds Project (Freshwater Habitats Trust 2014) shows that number of priority freshwater species associated with ponds was at least 25 per cent greater than originally estimated by Webb *et al.* (2010).

Where next for pond policy?

The policy context relating to ponds has developed quickly as more information about the habitat has become available. Work on ponds, and the development of policy, has had to overcome some deeply held assumptions about freshwaters: that small waters are less important than large ones; that man-made water bodies are less important than those naturally created; that individual water bodies, rather than networks of water bodies, are the unit that should be protected; that fairly clean water is acceptable for protecting freshwater biodiversity rather than aiming for the highest water quality standards which it is increasingly clear are needed to protect freshwater biodiversity (C. Mainstone, Natural England, personal communication).

Consequently, although much good progress has been made in underpinning practical natural conservation action for ponds with the necessary policy, three important areas of policy development require further work:

1 Effective practical inclusion of small waters in the Water Framework Directive. A pan-European network of specialists is beginning to work on this issue (EEB and FHT 2013)
2 Effective identification of the networks of freshwater habitats that support freshwater biodiversity: this process is beginning with work to identify Important Freshwater Areas encompassing all types of freshwaters, coordinated by the Freshwater Habitats Trust.
3 Establishing effective mechanisms for incorporating the protection of freshwater biodiversity into the Water Framework Directive River Basin Management Plans, and integrating this work with nature conservation policies intended to protect freshwaters.

Conclusion

Urban pond ecosystems have a great deal to offer in terms of biodiversity and ecosystem services, but we currently lack a comprehensive management framework that takes into account the spatially distributed and variable nature of these habitats. Over the past 20 years, considerable progress has been made in understanding both the value of, and threats to, ponds, and this has led to a series of advances in how we think about conservation across multiple sites. A clear challenge within urban environments is the intensive exploitation of green and blue space for ecosystem services, and the ensuing conflict that arises between management for biodiversity and other priorities, particularly urban drainage and aesthetics. However, there is growing evidence that a small number of alterations to management, such as the promotion of riparian vegetation and the exclusion of particularly destructive ornamental plants and animals, could result in substantial biodiversity gains without necessarily suppressing ecosystem services. Gaining support for and implementing such measures will need to involve not only ecologists but also politicians, local residents, engineers, and designers in order to produce a transdisciplinary solution to this multifaceted problem. Yet another dimension is the international perspective: this review has focused on the UK with some reference to Europe and beyond, but there is a great need to evaluate patterns in urban ecology across different social, cultural, economic, political and geographical landscapes to establish whether common patterns and problems are present, and if they can be treated with common remedies.

References

Ackley JW and Meylan PA (2010) Watersnake Eden: use of stormwater retention ponds by mangrove salt marsh snakes (*Nerodia clarkii compressicauda*) in urban Florida. *Herpetological Conservation and Biology* 5: 17–22.

Bardsley L (2012) *The Wildlife Pond Handbook,* London, New Holland Publishers Ltd.

Biggs J, Corfield A, Walker D, Whitfield M and Williams P (1994) New approaches to the management of ponds. *British Wildlife* 5: 273–287.

Biggs J, Stoate S, Williams P *et al.* (2014) *Water Friendly Farming: Results and practical implications of the first 3 years of the programme,* Fordingbridge, Freshwater Habitats Trust, Oxford, and Game and Wildlife Conservation Trust.

Biggs J, Williams P, Whitfield M, Nicolet P and Weatherby A (2005) 15 years of pond assessment in Britain: results and lessons learned from the work of pond conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems* 15: 693–714.

Boothby J (1997) Pond conservation: towards a delineation of pondscape. *Aquatic Conservation: Marine and Freshwater Ecosystems* 7: 127–132.

BRIG (2007) *Report on the Species and Habitat Review. Report by the Biodiversity Reporting and Information Group (BRIG) to the UK Standing Committee June 2007,* Accessed December 2014, Available at: http://jncc.defra.gov.uk/PDF/UKBAP_Species-HabitatsReview-2007.pdf.

BRIG (2011) *UK Biodiversity Action Plan Priority Habitat Descriptions* Peterborough, JNCC.

Bruinderink GG, Van Der Sluis T, Lammertsma D, Opdam P and Pouwels R (2003) Designing a coherent ecological network for large mammals in northwestern Europe. *Conservation Biology* 17: 549–557.

Carvalheiro LG, Biesmeijer JC, Benadi G *et al.* (2014) The potential for indirect effects between co-flowering plants via shared pollinators depends on resource abundance, accessibility and relatedness. *Ecology Letters* 17: 1389–1399.

Chester ET and Robson BJ (2013) Anthropogenic refuges for freshwater biodiversity: Their ecological characteristics and management. *Biological Conservation* 166: 64–75.

Cornel AJ, Jupp PG and Blackburn NK (1993) Environmental temperature on the vector competence of *Culex univittatus* (Diptera: Culicidae) for West Nile Virus. *Journal of Medical Entomology* 30: 449–456.

Davies ZG, Fuller RA, Loram A, Irvine KN, Sims V and Gaston KJ (2009) A national scale inventory of resource provision for biodiversity within domestic gardens. *Biological Conservation* 142: 761–771.

Defra (2011) *The Natural Choice: Securing the Value of Nature,* London, The Stationery Office.

Downing JA (2010) Emerging global role of small lakes and ponds: little things mean a lot. *Limnetica* 29: 9–24.

EC (1992) Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora, 22/07/1992. *Official Journal* L 206: 7–50.

EC (2000) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy, 22/12/2000. *Official Journal* 327/1: 1–73.

EC (2007) Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks, 06/11/2007. *Official Journal* 288: 27–34.

EEB and FHT (2013) *Report of the Workshop on the Protection and Management of Small Water Bodies,* Brussels and Oxford, European Environmental Bureau and Freshwater Habitats Trust.

Elmendorf SC, Henry GHR, Hollister RD *et al.* (2012) Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time. *Ecology Letters* 15: 164–175.

Environment Agency (2011) *Protected areas register,* Accessed December 2014, Availableat:http://webarchive.nationalarchives.gov.uk/20140328084622/http://www.environment-agency.gov.uk/static/documents/Research/RBMP_protected_areas_register_v3_1_082011.xls.

Environment Agency and Pond Conservation (2008) *Habitat Action Plan for Ponds. Draft 12. 01/07/2008*, Available from Freshwater Habitats Trust.

Fontanarrosa MS, Collantes MB and Bachmann AO (2013) Aquatic insect assemblages of man-made permanent ponds, Buenos Aires City, Argentina. *Neotropical Entomology* 42: 22–31.

Francis RA (2014) Urban rivers: novel ecosystems, new challenges. *WIREs Water* 1: 19–29.

Freshwater Habitats Trust (2014) *Creating ponds for priority species under the UK's Biodiversity Action Plan,* Accessed 10/12/2014, http://www.freshwaterhabitats.org.uk/projects/million-ponds/bap-species/.

Freshwater Habitats Trust (2015) *BAP Species,* Accessed: 13/07/2015, http://www.freshwaterhabitats.org.uk/projects/million-ponds/bap-species/.

Furneaux WS (1911) *Life in Ponds and Streams,* London, Longmans, Green, and Co.

Gledhill DG, James P and Davies DH (2008) Pond density as a determinant of aquatic species richness in an urban landscape. *Landscape Ecology* 23: 1219–1230.

Goddard MA, Dougill AJ and Benton TG (2010) Scaling up from gardens: biodiversity conservation in urban environments. *Trends in Ecology and Evolution* 25: 90–98.

Goddard MA, Dougill AJ and Benton TG (2013) Why garden for wildlife? Social and ecological drivers, motivations and barriers for biodiversity management in residential landscapes. *Ecological Economics* 86: 258–273.

Goertzen D and Suhling F (2013) Promoting dragonfly diversity in cities: major determinants and implications for urban pond design. *Journal of Insect Conservation* 17: 399–409.

Hamer AJ and Parris KM (2010) Local and landscape determinants of amphibian communities in urban ponds. *Ecological Applications* 21: 378–390.

Hassall C (2014) The ecology and biodiversity of urban ponds. *WIREs Water* 1: 187–206.

Hassall C and Anderson S (2015) Stormwater ponds can contain comparable biodiversity to unmanaged wetlands in urban areas. *Hydrobiologia* 745: 137–149.

Hassall C, Hollinshead J and Hull A (2011) Environmental correlates of plant and invertebrate species richness in ponds. *Biodiversity and Conservation* 20: 3189–3222.

Hessayon DG (1993) *The Rock & Water Garden Expert*. London: Transworld Publishers.

Hester ET and Bauman KS (2013) Stream and retention pond thermal response to heated summer runoff from urban impervious surfaces 1. *Journal of the American Water Resources Association* 49: 328–342.

Hill MJ and Wood PJ (2014) The macroinvertebrate biodiversity and conservation value of garden and field ponds along a rural-urban gradient. *Fundamental and Applied Limnology* 185: 107–119.

Hitchings SP and Beebee TJC (1997) Genetic substructuring as a result of barriers to gene flow in urban *Rana temporaria* (common frog) populations: implications for biodiversity conservation. *Heredity* 79: 117–127.

HMSO (2006) *Natural Environment and Rural Communities Act (c.16)*, London, The Stationery Office.

HMSO (2010) *Flood and Water Management Act. (c.29)*, London, The Stationery Office.

Hodge AE (1933) *Garden Ponds and Pools: Their Construction, Stocking, and Maintenance*. London: HF and G Witherby Ltd.

Hodgson JA, Thomas CD, Wintle BA and Moilanen A (2009) Climate change, connectivity and conservation decision making: back to basics. *Journal of Applied Ecology* 46: 964–969.

JNCC (2013) *UK Post-2010 Biodiversity Framework: Implementation Plan*, Peterborough, JNCC.

JNCC and Defra (2012) *UK Post-2010 Biodiversity Framework*, Peterborough, JNCC.

Kleerekoper L, van Esch M and Salcedo TB (2012) How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling* 64: 30–38.

Lambin EF, Tran A, Vanwambeke SO, Linard C and Soti V (2010) Pathogenic landscapes: Interactions between land, people, disease vectors, and their animal hosts. *International Journal of Health Geographics* 9: 54.

Lieb D and Carline R (2000) Effects of urban runoff from a detention pond on water quality, temperature and caged Gammarus minus (Say) (Amphipoda) in a headwater stream. *Hydrobiologia* 441: 107–116.

Lindenmayer DB and Fischer J (2007) Tackling the habitat fragmentation panchreston. *Trends in Ecology and Evolution* 22: 127–132.

Matthys B, Vounatsou P, Raso G *et al.* (2006) Urban farming and malaria risk factors in a medium-sized town in Cote D'Ivoire. *The American Journal of Tropical Medicine and Hygiene* 75: 1223–1231.

McCarthy K and Lathrop R (2011) Stormwater basins of the New Jersey coastal plain: Subsidies or sinks for frogs and toads? *Urban Ecosystems* 14: 395–413.
McKinney ML (2008) Effects of urbanization on species richness: a review of plants and animals. *Urban Ecosystems* 11: 161–176.
Moss B (1998) *Ecology of Freshwaters: Man and Medium, Past to Future,* Oxford, Blackwell.
Nicolet P, Biggs J, Fox G, Hodson MJ, Reynolds C, Whitfield M and Williams P (2004) The wetland plant and macroinvertebrate assemblages of temporary ponds in England and Wales. *Biological Conservation* 120: 261–278.
Noble A and Hassall C (2015) Poor ecological quality of urban ponds in northern England: causes and consequences *Urban Ecosystems* 18(2): 649–662.
Oertli B, Joye DA, Castella E, Juge R, Cambin D and Lachavanne J-B (2002) Does size matter? The relationship between pond area and biodiversity. *Biological Conservation* 104: 59–70.
Paerl HW and Paul VJ (2012) Climate change: Links to global expansion of harmful cyanobacteria. *Water Research* 46: 1349–1363.
Papworth D (1984) *Fish-Keeper's Guide to Garden Ponds*. Birmingham: Bradshaw.
Parris KM (2006) Urban amphibian assemblages as metacommunities. *Journal of Animal Ecology* 75: 757–764.
Persson J (2000) The hydraulic performance of ponds of various layouts. *Urban Water* 2: 243–250.
Prugh LR, Hodges KE, Sinclair ARE and Brashares JS (2008) Effect of habitat area and isolation on fragmented animal populations. *Proceedings of the National Academy of Sciences* 105: 20770-20775.
Robinson P (2009) *Plants for Ponds, Rock and Water Features*. Leicester: Anness Publishing.
Rosset V, Lehmann A and Oertli B (2010) Warmer and richer? Predicting the impact of climate warming on species richness in small temperate waterbodies. *Global Change Biology* 16: 2376–2387.
Sanzo D and Hecnar SJ (2006) Effects of road de-icing salt (NaCl) on larval wood frogs (*Rana sylvatica*). *Environmental Pollution* 140: 247–256.
Smith RK and Sutherland WJ (2014) *Amphibian Conservation: Global evidence for the effects of interventions*. Exeter: Pelagic Publishing.
Sterry P (1982) *Pond Watching*. London: Severn House.
Taebi A and Droste RL (2004) Pollution loads in urban runoff and sanitary wastewater. *Science of the Total Environment* 327: 175–184.
The Footprint Trust (2014) *Pond Warden Scheme*, http://www.footprint-trust.co.uk/pondwardens.htm [accessed 01 December 2014].
Tischendorf L and Fahrig L (2000) On the usage and measurement of landscape connectivity. *Oikos* 90: 7–19.
Titchmarsh A (2013) *How to Garden: Water Gardening*. Shalbourne: Random House.
Tsihrintzis V and Hamid R (1997) Modeling and management of urban stormwater runoff quality: A review. *Water Resources Management* 11: 136–164.
Watling JI, Nowakowski AJ, Donnelly MA and Orrock JL (2011) Meta-analysis reveals the importance of matrix composition for animals in fragmented habitat. *Global Ecology and Biogeography* 20: 209–217.
Webb JR, Drewitt AL and Measures GH (2010) *Managing for species: Integrating the needs of England's priority species into habitat management. Part 1 Report. Natural England Research Reports,* Number 024, Peterborough, Natural England.

Williams P, Biggs J, Crowe A, Murphy J, Nicolet P, Weatherby A and Dunbar M (2010) *Countryside Survey: Ponds Report from 2007,* Pond Conservation and NERC Centre for Ecology & Hydrology, Technical Report No. 7/07.

Williams P, Biggs J, Whitfield M, Thorne A, Bryant S, Fox G and Nicolet P (1999) *The Pond Book: A Guide to the Management and Creation of Ponds,* Oxford, Ponds Conservation Trust.

Williams P, Whitfield M, Biggs J, Bray S, Fox G, Nicolet P and Sear DA (2004) Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in southern England. *Biological Conservation* 115: 329–341.

Winfree R, Dushoff J, Crone EE, Schultz CB, Budny RV, Williams NM and Kremen C (2005) Testing simple indices of habitat proximity. *The American Naturalist* 165: 707–717.

Wood PJ, Greenwood MT and Agnew MD (2003) Pond biodiversity and habitat loss in the UK. *Area* 35: 206–216.