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15 years of pond assessment in Britain: results and lessons learned from the work of Pond Conservation

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ABSTRACT

1. In 1986 work began which led to the foundation of Pond Conservation, the UK NGO which promotes the conservation of ponds and other freshwater habitats. In 1989 the organization initiated the UK National Pond Survey (NPS) to provide baseline data on the biota and physico-chemical characteristics of ponds.

2. Survey data have been used to demonstrate the importance of small water bodies for freshwater plants and animals, to establish techniques for assessing the ecological status of ponds and to provide the basis for a new national pond monitoring network in the UK.

3. Comparisons with extensive river and lake datasets show that, at a UK level, ponds support slightly more macroinvertebrate species than rivers, and more uncommon species. They support similar numbers of wetland plants to lakes. Farmland ponds generally have lower site diversity than rivers; however, in terms of regional diversity they make a greater contribution than other aquatic habitats.

4. Although ponds are an important biodiversity resource, studies have shown that ponds outside nature reserves are significantly degraded: thus ponds in the lowlands supported only half the number of wetland plant species that would be expected in minimally impaired ponds.

5. The environmental factors most highly correlated with species number and rarity in minimally impaired ponds were area, isolation, pH (and the related chemical measures alkalinity, calcium, conductivity) and abundance of vegetation.

6. Studies of degraded ponds showed strong negative relationships between potentially damaging environmental factors (e.g. intensive land use, nutrient levels) and species richness and rarity.

7. Although considerable progress has been made in characterizing the plant and invertebrate assemblages of ponds, comparatively little is known about the way ponds function or how they are affected by management. Given the importance of ponds in maintaining aquatic biodiversity at the landscape scale, further research is needed on ponds in the catchment context.

KEY WORDS: ponds; conservation; assessment; Water Framework Directive; invertebrates; macrophytes

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INTRODUCTION

In 1986 three British freshwater biologists, Anne Powell, Roger Sweeting and Jeremy Biggs, started to think about how they could help to promote freshwater conservation in Britain. Their answer was to initiate a new non-governmental organization in the UK that focused on the ecology of ponds. At that time, in the mid-1980s, ponds were popular with the general public, naturalists and children: it was well-known, for example, that ponds were vital for amphibians (Swan and Oldham, 1989) and water beetle enthusiasts had long been aware of the value of ponds (Balfour-Browne, 1962; Foster and Eyre, 1992). However, with a few notable exceptions (Talling, 1951; Elton, 1966; Macan, 1977), the wider ecology of ponds had been almost entirely neglected and, as a habitat, ponds were largely ignored by freshwater biologists and policy makers. The result was that the protection of small water bodies was largely a matter of chance, a by-product of nature reserve management, traditional farming practice and the concern of ordinary people. The subject lacked almost any scientific basis – the handful of scientific papers generated in the previous 50 years contrasted starkly with the hundreds of river, stream and lake related papers published annually. Textbooks, too, barely mentioned the word ‘pond’, or if they did, it was assumed that these water bodies were simply small lakes, or substandard refuges for the animals of larger wetlands.

With this background, in 1988, after a year’s planning supported by WWF-UK, Pond Action was created and launched its first project, the Oxfordshire Pond Survey. Thirteen years later, the group merged in 2001 with the Ponds Conservation Trust, now known as ‘Pond Conservation: the Water Habitats Trust’.

Throughout this time the organization’s objectives have remained essentially unchanged:

- To promote the conservation of ponds and other fresh waters by providing good technical information and advice.
- To implement this advice on the ground with practical projects reliably based in good science.

MONITORING PONDS IN BRITAIN — ESTABLISHING THE FOUNDATION

What is a pond?

From the outset of Pond Conservation’s work it was clear that a simple working definition of what constituted a pond was needed. In the previous years many pond definitions had been proposed, based on such factors as the occurrence of rooted macrophytes, the presence of wave action or the penetration of light, but none of these was satisfactory in terms of its reliability or ease of measurement (Appendix 1). For this reason a simple size-based definition was developed in the early 1990s and subsequently widely adopted. This defines ponds as:

> Water bodies between 1 m^2 and 2 ha in area which may be permanent or seasonal, including both man-made and natural water bodies.

Using this definition, Pond Conservation undertook a series of studies in the 1990s which, together, both improved understanding of the biotic assemblages present in ponds and began to highlight factors influencing their nature conservation value.

The National Pond Survey — characterizing Britain’s minimally impaired ponds

The first major survey Pond Conservation undertook was the National Pond Survey (NPS), a baseline survey that aimed to describe the plant and invertebrate assemblages of minimally impaired ponds in Britain, as free as is possible in the British landscape from damaging impacts associated with pollution and intensive management (e.g. nutrient enrichment, urban runoff, overstocking with fish and wildfowl) (Biggs *et al.*, 1998a). Essentially these comprised *ca*. 200 ponds located in areas of extensive semi-natural habitat (traditional non-intensively managed farmland, semi-natural woodland, heathland, moorland, coastal dune systems, etc.) and representative of the geology, soils and landscape of Britain. This basic descriptive phase, essential for the conservation of any habitat, had been started much earlier in Britain for lakes and rivers, being essentially complete for these habitats by the 1970s and 1980s (e.g. Pearsall, 1920; Spence, 1967; Holmes, 1983; Wright *et al*., 1984).

The methods used to undertake the National Pond Survey, which are described in detail in Biggs *et al*. (1998a), included surveys for invertebrates based on a 3-min hand-net technique, with samples collected in three seasons. This sampling methodology was developed to be closely compatible with the earlier RIVPACS methods for surveying stream and river assemblages in the UK, a decision taken deliberately to allow comparisons to be made between pond and river datasets (Wright *et al*., 1996). For invertebrates, the 3-min sampling time was divided equally between pond mesohabitats (areas of distinctive vegetation and substrates), distributed around the pond. This approach is described in detail in Biggs *et al*. (1998a). For plants, the methodology followed that previously developed in Britain for lakes by the Nature Conservancy Council (Palmer *et al*., 1992), using a standard vascular wetland plant list as the basis for recording. The NPS wetland plant list was based on that developed by Palmer *et al*. (1992) with modifications agreed with national specialists, and updated as the UK floral list has changed. Again, this has facilitated subsequent comparisons of lakes and ponds. The NPS method also incorporates information on a wide range of environmental factors. The methods for measuring these are described in detail in Biggs *et al*. (1998a).

Impacted ponds database

The NPS data were collected from minimally impaired ponds. In 1996, with funding from the UK Natural Environment Research Council, a second national study was initiated, this time from ponds in the 'wider countryside' potentially affected by agricultural pollution, urban and road runoff, overstocking with wildfowl and fish, and other impacts. Using survey methods identical to those of the NPS (Biggs *et al*., 1998a) 150 sites were investigated. Thus, standard wetland plant species lists were collected in summer along with a wide range of environmental data (as defined by the standard NPS recording sheet). A 3-min invertebrate sample was collected in summer (June–August) which was directly comparable with summer season invertebrate samples collected from the NPS minimally impaired sites.

Lowland Pond Survey 1996

The third major national study of UK ponds with which Pond Conservation was associated was the Lowland Pond Survey. Undertaken jointly with the Institute for Terrestrial Ecology (now Centre for Ecology and Hydrology), this was a thematic study of the UK government's Countryside Survey which, as a whole, aims to assess temporal trends in the UK's rural landscape, through repeated surveys of 1 km × 1 km squares at intervals of 6–8 years (Haines-Young *et al*., 2000). Since the first Countryside Survey in 1978 the number of ponds had been counted as a landscape feature but no assessment had been made of pond quality. Thus in 1996 the Lowland Pond Survey made the first overall estimate of pond quality, using wetland plants from a subset of 377 ponds in 150 lowland 1 km × 1 km squares. The data were particularly valuable because the 1 km squares were rigorously selected to be representative of the UK lowland landscape; thus, the findings could be scaled up to give accurate data on pond numbers and the botanical quality for this area of the UK as a whole. The methods of the Lowland Pond Survey, which broadly followed NPS methods (excluding invertebrates), are described in detail in Williams *et al*. (1998a).

Landscape-level aquatic biodiversity studies

The first 10 years of Pond Conservation's work mainly revolved around extensive surveys intended to characterize pond assemblages and the physico-chemical character of ponds. More recently the group has focused on regional, landscape-level studies assessing the contribution to aquatic biodiversity of different freshwater habitat types. This work started in southern Britain in the catchment of the R. Cole near Swindon, and results of this work are described below.

In the Coleshill study, which is reported in full in Williams *et al.* (2004), a stratified random sample of 80 ponds, streams, rivers and ditches was sampled in an area of approximately 10 km × 10 km of typical lowland farmland in southern England. From each water body a standard 3-min hand-net sample of aquatic macroinvertebrates was collected and a list made of wetland plants present. Samples were collected from a representative $75\,\text{m}^2$ area of each water body to eliminate species–area effects. The area chosen for sampling was selected to be characteristic of the water body as a whole: for example, in a pond that was 50% shaded and 50% open, the sample area was selected to include both shaded and open areas. Ponds with an area of less than $75\ \text{m}^2$ were excluded from the survey, three sites being rejected for this reason out of the total of 65 shown on maps of the study area. Survey methods are described in more detail in Williams *et al.* (2004). For each water-body type, alpha and gamma diversity were calculated for macroinvertebrates and aquatic macrophytes. Alpha diversity was defined as the species richness of individual sites (i.e. samples); gamma diversity was defined as the total number of species recorded in the study area (10 km × 10 km) from each of the four water-body types. Species rarity was assessed in the same way, using a Species Rarity Index, with assessments made of species rarity at site (alpha diversity) level and regional (gamma diversity) level. It should be noted that data collected using these methods are not directly comparable with those collected using the standard NPS methodology as they are derived from only one part of the water body.

Analytical methods

Datasets derived using the standard NPS methods have mainly been analysed using a combination of multivariate classification and ordination techniques to characterize assemblages, with nonparametric exploratory correlation techniques used to investigate relationships between the biota and environmental variables. The PSYM system (see below) was developed using a combination of classification, multiple discriminant analysis and nonparametric correlation methods. Analytical methods are described in full in Biggs *et al.* (2000). Landscape comparisons of aquatic biodiversity have used nonparametric methods to compare alpha and gamma diversity in different water-body types and species accumulation techniques to assess true biodiversity. Assemblages, and their relationships with environmental variables, were characterized with canonical correspondence analysis. Methods are described in detail in Williams *et al.* (2004).

LESSONS LEARNT FROM POND SURVEYS

The database of minimally impaired and impacted ponds, now extending to some 800 sites, has provided the basis for much of Pond Conservation's scientific and technical advice over the last 15 years. It has been particularly important in four main areas of activity: demonstrating the importance of ponds for biodiversity; understanding the factors influencing the nature conservation value of ponds; developing methods for assessing pond quality, and providing the foundation for the UK's first national assessment of the status of ponds; and providing the basis for the UK National Pond Monitoring Network.

Demonstrating the importance of ponds for biodiversity

The major advantage of using survey methods compatible with those used for other habitats is that it has allowed pond biodiversity to be compared with the biodiversity of other freshwater habitats. Comparison of pond invertebrate data with similar data gathered from rivers and streams by the Centre for Ecology and Hydrology, for the RIVPACS project (Wright *et al.*, 1996), is particularly informative (Table 1). The

Table 1. Pond and river invertebrate species richness and rarity comparison

	Ponds (200 sites)	Rivers (614 sites)
Number of species	431	377
Nationally Scarce species (occurring in 15–100 10-km squares)	78	41
Red Data Book species	26	13

Table 2. Pond and lake aquatic plant species richness and rarity comparison

	Ponds (200 sites)	Lakes (1100 sites)
Number of species	72	89
Nationally Scarce species (occurring in 15–100 10-km squares)	7	8
Red Data Book species	5	5

results show that, despite there being roughly three times as many sites in the RIVPACS database, approximately 10% more macroinvertebrate species, and roughly double the number of uncommon species (described as Nationally Scarce or listed in Red Data Books), were recorded in the ponds.

Comparing pond plant data with lake plant data from the UK Joint Nature Conservation Committee lake dataset, collected in the 1970s and 1980s by Margaret Palmer and colleagues (Palmer *et al*., 1992), also suggests that ponds contribute significantly to supporting the UK's wetland plant biodiversity (Table 2). Numbers of species found in ponds nationally are very similar to those recorded in lakes.

These findings have been corroborated at a finer scale. The results from the Cole catchment, where ponds, ditches, streams and rivers were compared in a 10 km × 10 km square, showed that ponds made a surprisingly large contribution to aquatic biodiversity in typical agricultural landscapes. The results in this study for alpha diversity were probably as most freshwater biologists would have expected. For macroinvertebrates, rivers supported the most species-rich assemblages, followed by ponds, streams and ditches (Figure 1). The pattern was similar for macrophytes, although there was no significant difference in richness between rivers and ponds. Gamma diversity showed a quite different picture. Ponds were the richest habitat, for both macroinvertebrates and macrophytes, supporting about 10% more species in total, and nearly 50% more uncommon species than other habitats (Figure 2). These patterns were associated with high levels of gamma diversity in the ponds, ditches and streams, with Jaccard's Index values roughly half those seen in the rivers (mean Jaccard's Index values for invertebrates: 0.18, 0.14, 0.15 and 0.36 in ponds, ditches, streams and rivers, respectively (Williams *et al*., 2004)).

The obvious conclusion from these comparisons is that, collectively, ponds provide a rich biodiversity resource. The reasons they are so rich are not known for sure, but may be at least partly linked to their catchments. Ponds are natural sinks for substances draining from their catchments and since their catchments are often small, particularly compared with large water bodies such as rivers and lakes, ponds typically reflect very local natural variations in geology, hydrology, climate, vegetation, tree-shade, etc. This suggests that ponds will generally be more varied physically and chemically than larger water bodies which, with their larger catchments, tend to 'average out' variations in catchment environmental conditions. In the R. Cole study there was indeed some evidence of greater environmental variation in the ponds, compared with running waters (Williams *et al*., 2004).

The small catchment size of ponds, compared with streams, lakes and rivers (Davies, 2005), is both a benefit and a disadvantage when it comes to protecting them. When most severely exposed to

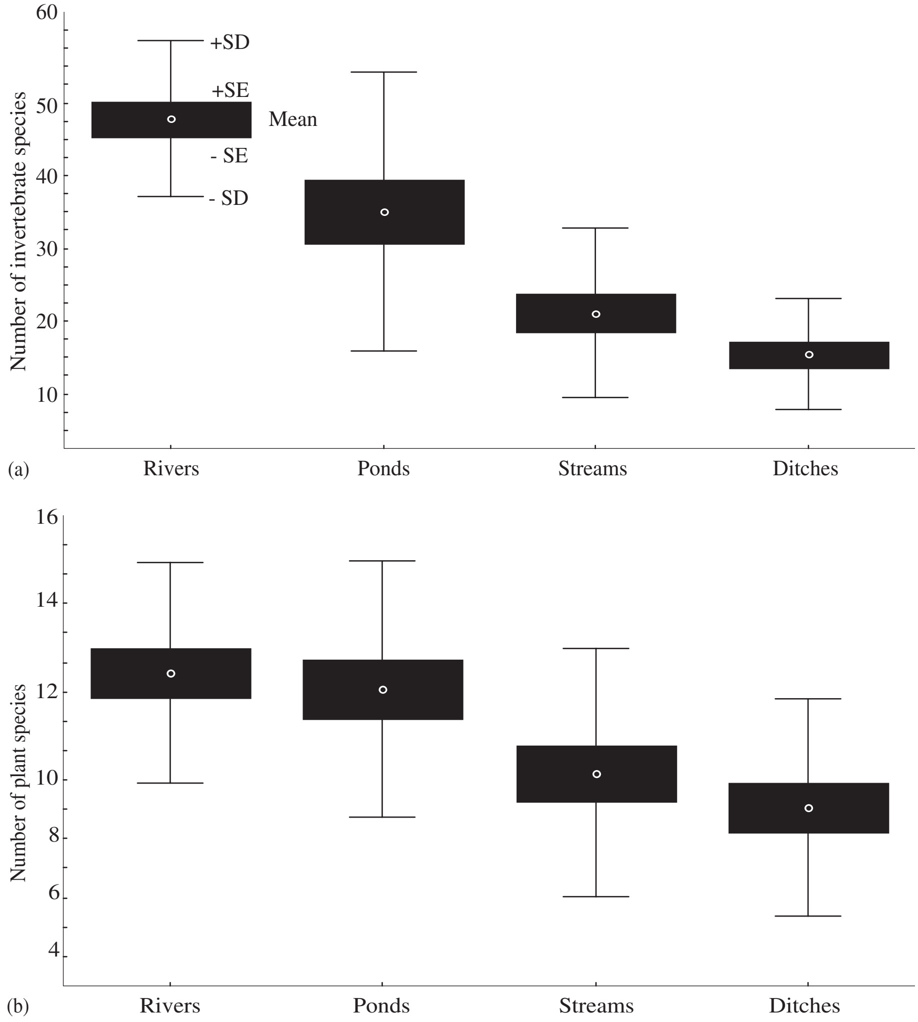


Figure 1. Box and whisker plots showing species richness (alpha diversity) in four water-body types in the R. Cole study of regional aquatic biodiversity: (a) aquatic macroinvertebrates (b) wetland macrophytes (SE = standard error, SD = standard deviation). $n = 20$ for each water-body type (Williams *et al*., 2004).

environmental impacts, ponds, with their small volumes, are highly vulnerable to degradation caused by surface water pollution derived from their surroundings, overstocking with fish or unnaturally high numbers of waterfowl. Unlike lakes and rivers, there is little possibility of dilution or buffering of pollutant inputs, so poor-quality ponds are often degraded to an extreme degree rarely seen in larger waters. Set against this, however, because of their small catchments ponds can be exceptionally high quality and often completely protected from land-derived pollutants, something which is very rare in rivers and lakes which, with their much larger catchments, are almost always exposed to a wide range of pollutants and other degrading influences. This then may also be a factor that helps to explain the relative richness of these small water bodies: sometimes they can remain near -pristine within landscapes that are widely degraded by human activity.

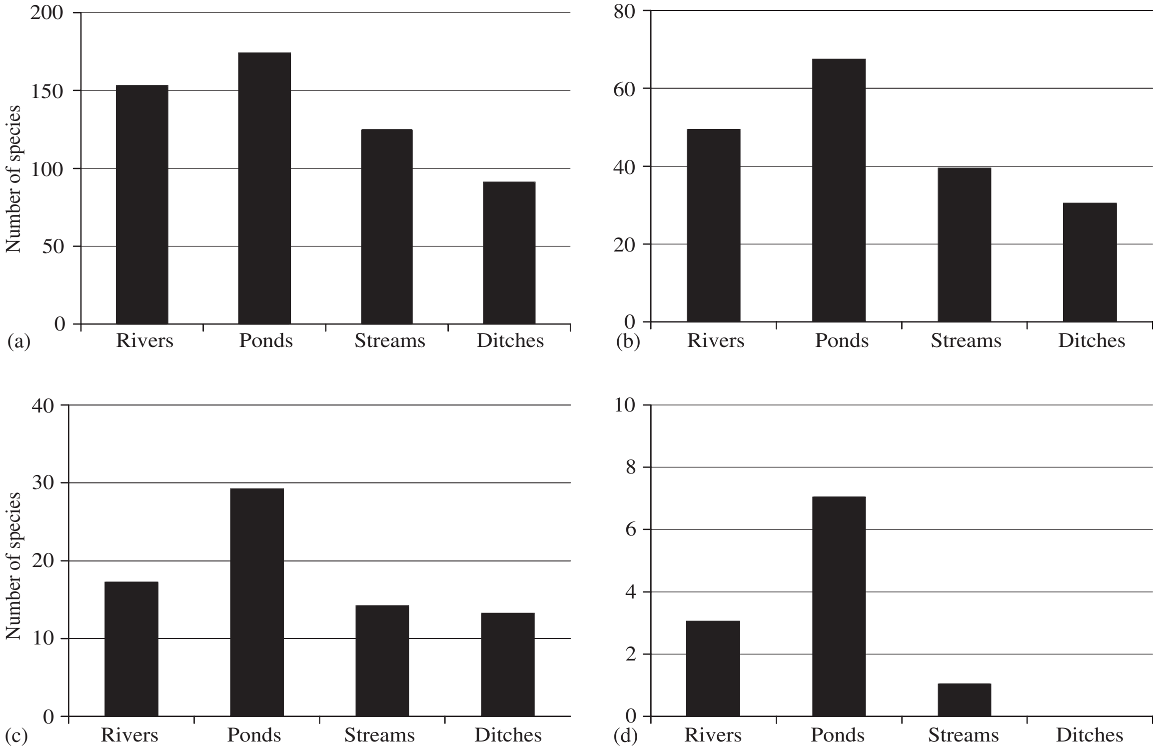


Figure 2. Gamma diversity of rivers, ponds, streams and ditches in the catchment of the R. Cole, southern England: (a) invertebrate gamma diversity; (b) plant gamma diversity; (c) uncommon invertebrate species gamma diversity; (d) uncommon plant species gamma diversity. $n = 20$ for each water-body type.

Understanding the factors influencing the nature conservation value of ponds

Data from the range of pond surveys undertaken by Pond Conservation in the 1990s have also provided some indications of the major environmental factors shaping pond communities in Britain.

Factors related to the conservation value of ponds were investigated using two datasets. The minimally impaired NPS ponds database was used to investigate which natural factors correlated with species richness and rarity in high-quality ponds in natural landscapes. The minimally impaired and variably degraded data sets were used together to investigate relationships between human influence and the conservation value of ponds (Table 3).

In both analyses, pond conservation value was assessed using two biotic communities: macroinvertebrates and wetland plants. The plant community was in turn separated into two groups — aquatic plants and emergent plants — since they tend to respond to rather different environmental factors (aquatic plants being generally held to be more responsive to water quality, and emergents to bank sediments and structure).

The results of correlations between these biotic groups and physico-chemical environmental variables in the minimally impaired NPS sites are interesting in that comparatively few of 30 or so main environmental variables measured were related to either the number of species or the occurrence of rarities. Thus altitude, location (easting/northing), geology, shade, drawdown, silt depth, presence of inflows, water source (groundwater, surface water, precipitation), bank type, grazing and 13 chemical parameters (Na, K, Mg, total oxidized nitrogen, soluble reactive phosphorus, ammonia, Cl, Al, Cu, Fe, Ni, Pb, Zn) showed no significant ($p < 0.001$) correlations with species richness or rarity. Even amongst variables which did show

Table 3. Correlations between environmental factors and species richness and rarity in minimally impaired ponds: examples of environmental factors commonly considered influential in determining the nature conservation value of ponds

	Species richness			Species rarity		
	Spearman *R*	*p*	*n*	Spearman *R*	*p*	*n*
Shade						
Emergent plants	0.142	ns	152	0.016	ns	152
Aquatic plants	0.055	ns	152	−0.088	ns	146
Macroinvertebrates	0.071	ns	149	0.049	ns	149
Silt depth						
Emergent plants	0.218	ns	152	0.076	ns	152
Aquatic plants	0.113	ns	152	−0.132	ns	146
Macroinvertebrates	0.206	ns	149	−0.020	ns	149
Pond area						
Emergent plants	0.419	0.001	152	0.385	0.001	152
Aquatic plants	0.414	0.001	152	0.166	ns	146
Macroinvertebrates	0.305	0.001	149	0.021	ns	149
Marginal complexity						
Emergent plants	0.275	0.001	152	0.277	0.001	152
Aquatic plants	0.156	ns	152	0.167	ns	146
Macroinvertebrates	0.090	ns	149	0.193	ns	149
Connectedness						
Emergent plants	0.284	0.001	152	0.248	ns	152
Aquatic plants	−0.009	ns	146	0.263	0.001	146
Macroinvertebrates	0.167	ns	149	0.175	ns	149
Seasonality						
Emergent plants	−0.187	ns	152	−0.032	ns	152
Aquatic plants	−0.190	ns	152	0.161	ns	146
Macroinvertebrates	−0.280	0.001	149	0.334	0.001	149
Chemistry: pH						
Emergent plants	0.270	ns	144	0.014	ns	144
Aquatic plants	0.201	0.001	144	−0.065	ns	139
Macroinvertebrates	0.499	0.001	142	−0.083	ns	142
% cover vegetation						
Emergent plants	0.156	ns	152	0.156	ns	152
Aquatic plants	0.283	0.001	152	0.083	ns	146
Macroinvertebrates	0.138	ns	149	0.049	ns	149

strong correlations with biodiversity (area, connectedness, pH, vegetation abundance), effects were typically limited either to richness or rarity (Table 3). This may be because the study ponds were all relatively unimpaired, with the differences between them simply reflecting natural differences that exist between ponds. Thus pond plants and animals might be expected to be good at exploiting the range of natural physical and chemical conditions in ponds.

Perhaps not unexpectedly, these findings often contradict traditional advice about the management of ponds. Trees, for example, are generally thought of as undesirable around ponds and much effort is spent cutting them back. However, in the high-quality NPS ponds, there was little evidence of detrimental effects from shade: in high-quality landscapes shaded ponds were typically as rich as unshaded ponds, and just as likely to support uncommon species. Similarly the data showed no correlation between species richness or rarity and increasing silt depth, which leads one naturally to question the value of conservation dredging of ponds (Table 3), at least in semi-natural landscapes where sediments are not contaminated with nutrients or other pollutants.

The main factors which did show correlations with number of species and the occurrence of rarities in ponds were: area, connectedness, pH (and the related chemical measures alkalinity, calcium, conductivity) and abundance of vegetation (Table 3).

Area

Not surprisingly, the NPS data showed a relationship between species richness and area, with larger ponds supporting more species. The trend was stronger for macrophytes (all wetland plants: Spearman $R = 0.45$, $p < 0.001$, Figure 3(a)) and weaker for invertebrates (Spearman $R = 0.305$, $p < 0.001$). There was little evidence of relationships between pond size and species rarity. In particular, for uncommon invertebrates there was no relationship between rarity and pond size: uncommon invertebrates were just as likely to be found in small ponds as large ponds, at least when those ponds occurred in high-quality semi-natural landscapes (Figure 3(b)). Only for emergent plants was there evidence of a positive relationship between pond area and the occurrence of uncommon species (Table 3).

Connectedness

The significance of proximity to other wetland habitats (‘connectedness’) was assessed in the NPS by ranking sites according to their proximity to streams, rivers, lakes and other wetlands, as well as ponds. Emergent plant species richness was positively correlated with proximity to other wetlands, indicating that plant assemblages were usually richer in ponds that were near to other wetlands (Table 3). Similar relationships were also found in the Lowland Pond Survey (Williams *et al.*, 1998a). It seems likely that plant assemblages are richer in areas where either the proximity of other water bodies, or the presence of long-established wetlands (such as major river valleys), facilitates colonization by a wide range of plants, including uncommon taxa. This result emphasizes the importance of maintaining the density of ponds and other wetlands in the countryside in order to maintain metapopulations of wetland species. Further, both these and other studies suggest that creating new ponds near to existing wetland areas encourages rapid establishment and the creation of very rich new ponds (Williams *et al.*, 1997).

Chemistry

The NPS is valuable in that it provides a useful chemical baseline for minimally impaired ponds in the UK (Table 4). However, within the NPS dataset there were comparatively few relationships between water chemistry and species richness and rarity. The strongest relationship was between pH and invertebrate species richness, with fewer invertebrate species in more acid waters, a fairly well-known relationship (Townsend *et al.*, 1983; Wright *et al.*, 1984; Larsen *et al.*, 1996; Nicolet *et al.*, 2004). A similar relationship was apparent for aquatic (but not emergent) plants (Table 3). However, neither plant nor invertebrate rarity was related to pH, suggesting that there are just as likely to be species of conservation concern in acid water as in base-rich water.

Vegetation abundance

Aquatic plant species richness was correlated with vegetation cover, with greater vegetation cover being associated with more aquatic plant species. Linked to the data on siltation, the findings suggest that the widespread practice of de-silting and de-weeding ponds to ‘enhance’ their conservation value is something that needs to be undertaken with some caution.

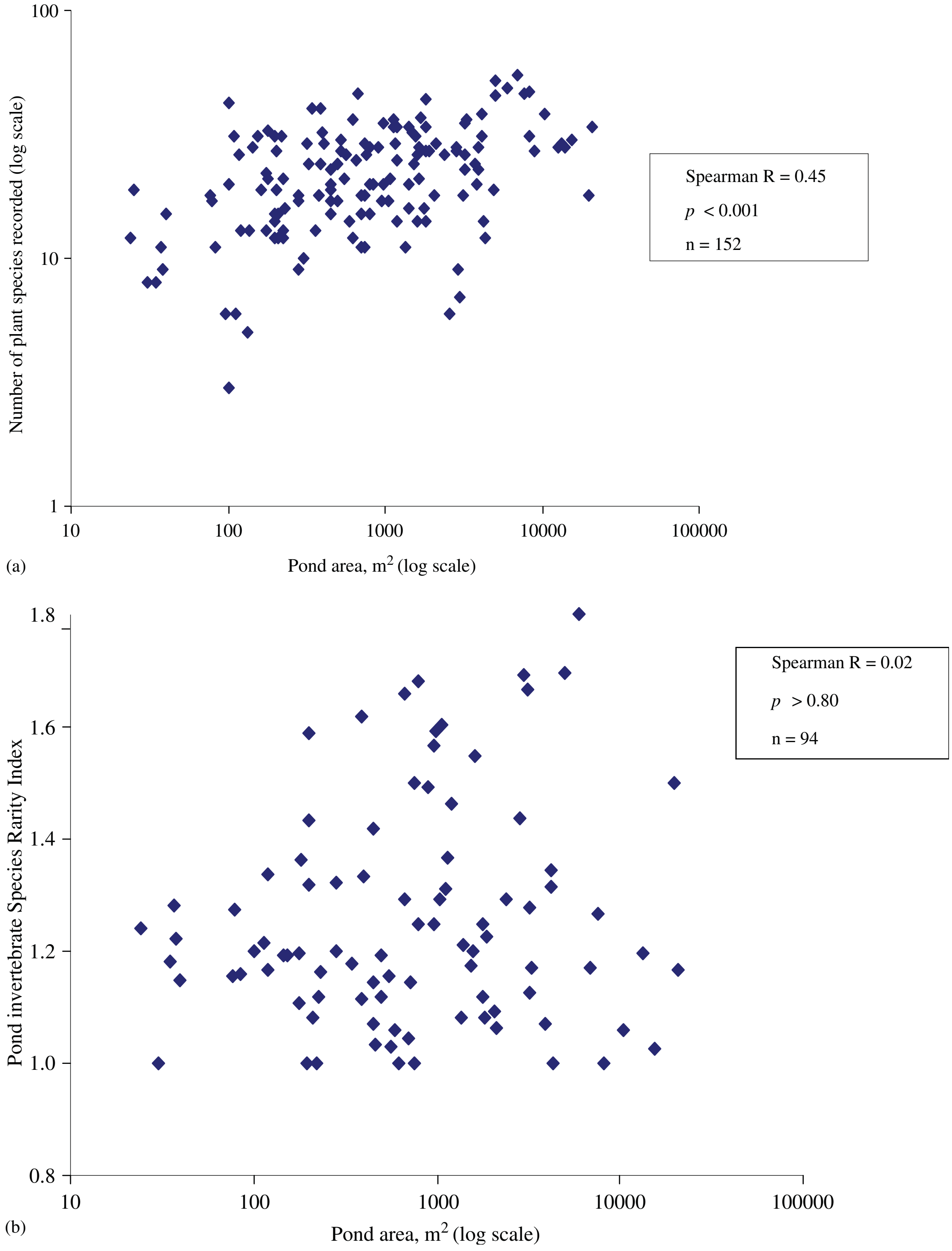


Figure 3. Relationship between pond area and (a) plant species richness; (b) macroinvertebrate species rarity in minimally impaired ponds in Britain. Note that minimum Species Rarity Index value is 1.00, i.e. all species recorded are common.

Pollution and degradation

The database of impacted ponds surveyed as part of the NPS provided a good indication of the effects of pollution and other stressors on ponds in the British landscape (Table 5). Using both indirect (land use, pollution risk) and direct (water quality parameters) measures of impact factors there was strong evidence of negative relationships between potentially damaging environmental factors (e.g. intensive land use,

Table 4. Selected water quality parameters for minimally impaired NPS ponds. Data are based on duplicate samples collected during spring 1994

	Determinand									
	Amm $\mathrm{mg\,L^{-1}}$	Cu $\mu\mathrm{g\,L^{-1}}$	Fe $\mu\mathrm{g\,L^{-1}}$	Pb $\mu\mathrm{g\,L^{-1}}$	SRP $\mu\mathrm{g\,L^{-1}}$	TN[a] $\mathrm{mg\,L^{-1}}$	TON $\mu\mathrm{g\,L^{-1}}$	TP[a] $\mu\mathrm{g\,L^{-1}}$	SS $\mathrm{mg\,L^{-1}}$	Zn $\mu\mathrm{g\,L^{-1}}$
Median	0.067	11.48	221	15.7	5	1.5	13	77	9.3	80.1
Mean	0.27	11.24	836	20.6	69	2.9	496	190	19.1	97.0
n	103	96	96	96	162	45	158	49	103	109

Key: Amm: ammonia; Cu: copper; Fe: iron; Pb: lead; SRP: soluble reactive phosporus; TN: total nitrogen; TON: total oxidized nitrogen; TP: total phosphorus; SS: suspended sediments; Zn: zinc.

[a] Values for TP and TN should be treated with caution owing to the relatively small number of sites for which data are available. Note also that some ponds are naturally hypertrophic so ponds with TPs > 100 $\mu\mathrm{g\,L^{-1}}$ are not necessarily 'impaired'.

Table 5. Human influences on pond conservation value

	Species richness	Species rarity
Aquatic plants		
Indirect		
Pollution Risk Index, land-use intensity	0.001	0.001
Pesticide, fertilizer application rate	0.001	0.05
Direct		
Phosphorus, potassium, suspended solids	0.01	0.01
Emergent plants		
Indirect		
Pollution Risk Index, land-use intensity	0.001	0.001
Pesticide application rate	0.001	0.01
Fertilizer application rate	0.01	0.01
Direct		
None	—	—
Aquatic invertebrates		
Indirect		
Pollution Risk Index, land-use intensity	0.001	0.001
Direct		
Ammoniacal nitrogen	0.001	0.001
Total oxidized nitrogen	0.001	0.001

nutrient levels) and species richness and rarity. However, this study gave no indication of the extent to which ponds were affected by such factors in the landscape as a whole.

The Lowland Pond Survey undertaken as part of the UK Countryside Survey went some way to addressing this by allowing a comparison between the quality of wetland plant assemblages in the minimally impaired NPS ponds with data from ponds in the wider countryside. The comparison indicated that ponds were extensively degraded in the lowland British landscape with ponds in 'ordinary' (predominantly farmed) landscapes supporting, on average, half the number of plant species recorded in minimally impaired ponds (Figure 4; Table 6), suggesting that they were significantly damaged by pollution, isolation or mismanagement.

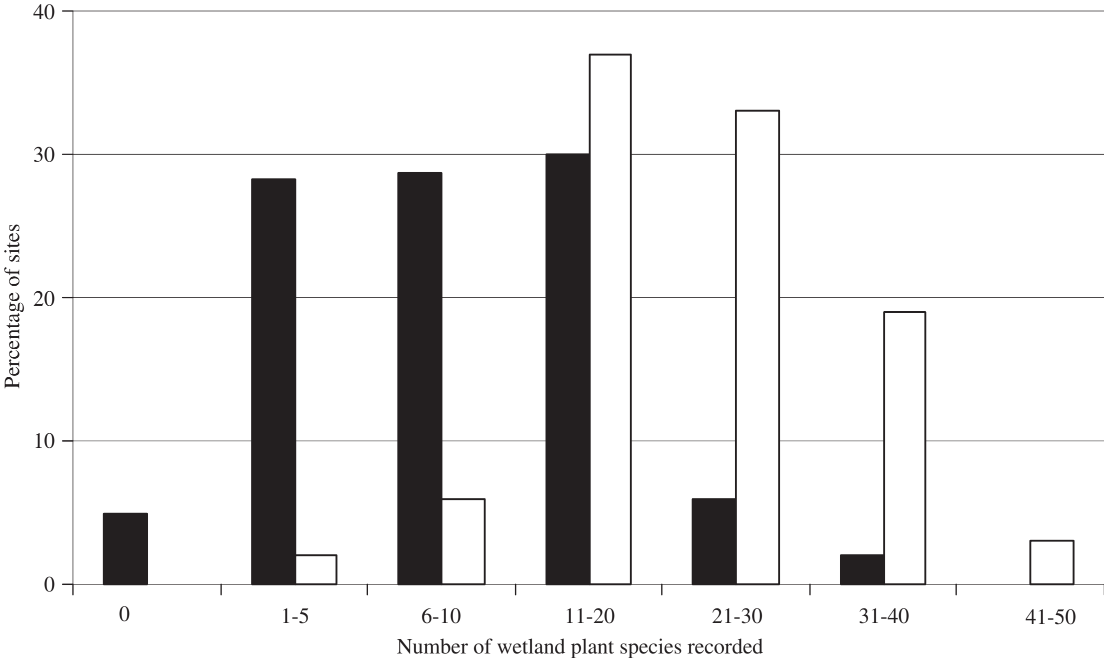


Figure 4. Comparison of plant species richness in 'ordinary', predominantly farmed, countryside in Britain compared with minimally impaired ponds in the same landscapes (black bars = 'ordinary' countryside ponds; white bars = minimally impaired ponds).

Table 6. Plant species richness in LPS 1996 ponds and NPS minimally impaired ponds. (Data derived from Williams *et al.* (1998a))

	Number of species recorded per pond	
	LPS 96 ($n = 377$)	NPS ($n = 102$)
All wetland plant species		
Mean	9.6	22.6
Range	0–35	1–46
Marginal species		
Mean	8.0	17.7
Range	0–30	1–42
Aquatic species		
Mean	1.6	4.8
Range	0–10	0–14

Developing methods for assessing pond quality

Historically, environmental organizations in the UK have undertaken relatively little monitoring of permanent and temporary ponds. This has largely reflected the fact that, until recently, small water bodies were not generally regarded as being sufficiently important to warrant regular monitoring. However, as evidence increasingly shows the value of ponds, a second obstacle has emerged: the absence of standardized and easy-to-use assessment methodologies.

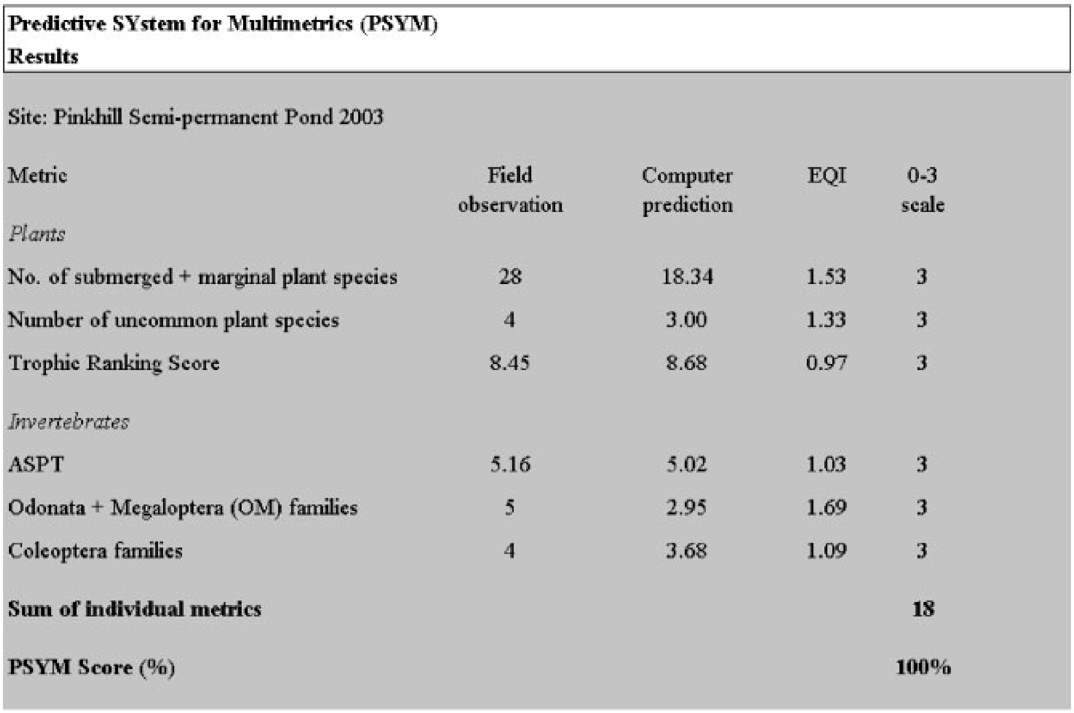
The first, fairly simple, assessment method developed using NPS data was a conservation scoring system based on the numbers of species found in ponds and the occurrence of rarities (Table 7). This was followed in the late 1990s by the development of a new standard technique for monitoring ponds, the PSYM method. PSYM, the Predictive SYstem for Multimetrics, was developed jointly with the Environment Agency of England and Wales to provide a method for assessing the biological quality of all still waters (temporary and permanent ponds, lakes, ditch systems, canals). To date, the method has been most fully developed for ponds and small lakes (up to 5 ha) and canals (Williams *et al*., 1996, 1998b; Biggs *et al*., 2000).

The PSYM method uses a number of aquatic plant and invertebrate measures (metrics), which are combined together to give a single value which represents the water body's overall quality status. Using the method involves the following steps:

1. Simple environmental data are gathered for each water body from map or field evidence (area, grid reference, geology, etc.).
2. Biological surveys of the plant and animal communities are undertaken and net samples are processed.
3. The biological and environmental data are entered into the PSYM computer program which:
   (i) uses the environmental data to predict which plants and animals should be present in the water body if it is undegraded,
   (ii) takes the real plant and animal lists and calculates a number of metrics.
4. Finally, the program compares the predicted plant and animal metrics with the real survey metrics to see how similar they are (i.e. how near the water body currently is to its ideal/undegraded state). The metric

Table 7. Provisional categories for assessing the conservation value of plant and macroinvertebrate assemblages in ponds based on data collected during standard NPS method survey. Wetland plants are those listed in the standard recording sheet of the National Pond Survey (Biggs *et al*., 1998a)

Assemblage conservation value	Qualifying characteristics
Wetland plants	
Low	Few wetland plants ($\leqslant 8$ species) and no local species (i.e. SRI = 1.00).
Moderate	Below average number of wetland plant species (9–22 species) or SRI of 1.01–1.19.
High	Above average number of wetland plant species($\geqslant 23$) or SRI of 1.20–1.49. No Nationally Scarce or Red Data Book (RDB) species.
Very high	Supports one or more Nationally Scarce or RDB species or SRI of $\geqslant 1.50$, or an exceptionally rich plant assemblage ($\geqslant 40$ species).
Macroinvertebrates	
Low	Few invertebrate species (0–10) and no local species (i.e. SRI = 1.00).
Moderate	Below average number of invertebrate species (11–30) or SRI of 1.01–1.19.
High	Above average number of invertebrate species (31–50) or SRI of 1.20–1.49. No Nationally Scarce or Red Data Book (RDB) species.
Very high	Supports one or more Nationally Scarce or RDB species or SRI of $\geqslant 1.50$, or an exceptionally rich invertebrate assemblage ($\geqslant 50$ species).



Predictive SYstem for Multimetrics (PSYM)
Results

Site: Pinkhill Semi-permanent Pond 2003

Metric	Field observation	Computer prediction	EQI	0-3 scale
Plants				
No. of submerged + marginal plant species	28	18.34	1.53	3
Number of uncommon plant species	4	3.00	1.33	3
Trophic Ranking Score	8.45	8.68	0.97	3
Invertebrates				
ASPT	5.16	5.02	1.03	3
Odonata + Megaloptera (OM) families	5	2.95	1.69	3
Coleoptera families	4	3.68	1.09	3
Sum of individual metrics				**18**
PSYM Score (%)				**100%**

Figure 5. PSYM output for Pinkhill Meadow semi-permanent pond, Oxfordshire, UK.

scores are then combined to provide a single value which summarizes the overall ecological quality of the water body. An example of the PSYM output is shown in Figure 5).

Detailed information about the project is available in three reports (Williams *et al*., 1996, 1998b; Biggs *et al*., 2000). Access to the model is provided via the internet and single predictions can be made online at www.pondnetwork.org.uk. Although functional, the PSYM method is still in the relatively early stages of development. In particular, the underlying database needs more sites: PSYM is currently based on 150 sites compared with 614 sites for RIVPACS (Wright *et al*., 1996) and at present the method only covers England and Wales.

National Pond Monitoring Network

Despite evidence of pond value and now an available monitoring method there is still no routine monitoring of a single pond in the UK. As a result of this it is not possible to determine whether the national asset of approximately 400 000 ponds (Haines-Young *et al*., 2000) is declining or improving in quality. Similarly, no information is available on the value of agri-environment schemes for ponds, the effect of climate change, or of atmospheric pollution.

To help address this, the most recent development of the NPS has seen its transformation into the UK National Pond Monitoring Network, with the Environment Agency of England and Wales and others. The NPMN was launched in May 2004 to coordinate pond monitoring in the UK. The NPMN website can be viewed at www.pondnetwork.org.uk. The project is also part of the UK's National Biodiversity Network, and is linked to the Freshwater*Life* project (www.freshwaterlife.info).

The NPMN has three main objectives:

1. To promote a national, statistically rigorous, pond monitoring programme, probably based on the Countryside Survey methodology.
2. To promote or undertake targeted studies dealing with particular pond conservation issues (e.g. changes in the distribution of amphibians, the quality of new ponds, the effectiveness of agri-environment schemes for pond conservation).
3. To establish a national inventory of ponds bringing together all the data available on UK ponds in a collaboratively managed database.

The NPMN has already collated a range of major datasets and is gradually making these accessible through the website. It has been estimated that *ca.* 20 000 pond sites have been surveyed over the last 10 years (PCTPR, 2004). Only during the work to establish the NPMN has it become clear how extensive the existing, largely uncoordinated, pond survey effort has been in Britain.

The NPMN has just completed its establishment phase – it is now possible to see pond locations on a UK base map and obtain original data about those sites. Perhaps the most important use of the data so far has been in identifying 'Important Pond Sites', and preparing a list of ponds for the UK government's conservation body in England (English Nature, shortly to become Natural England) which should be considered under the provisions of the Water Framework Directive. This initial list covers some 500 sites or complexes of ponds and includes areas such as the New Forest ponds, ponds with large assemblages of great crested newts, ponds supporting species that are rare or declining in Europe (such as the freshwater tadpole shrimp *Triops cancriformis*) and even one pond supporting the only known population in the world of the ribbon worm *Prostoma jenningsi*.

However, despite the valuable progress made towards establishing a programme to monitor ponds, at the time of writing no routine survey has been agreed by the relevant UK authorities.

DISCUSSION: WHERE NEXT FOR POND CONSERVATION IN BRITAIN?

The work of the last 15 years by Pond Conservation and others means that the current status of ponds and their importance in the UK for aquatic biodiversity is beginning to be understood. In terms of numbers, it is clear that ponds are at an historic low in Britain, although there is good evidence that, at a national level, net pond numbers have probably stabilized (Figure 6). This figure for pond numbers, however, conceals a very high turnover: approximately 1% of ponds per annum are filled in by natural and artificial processes, to be replaced by new ponds (Williams *et al.*, 1998a). The net effect on the conservation value of the pond resource of this rapid turnover is not known.

Even less is known about trends in the quality of existing ponds, although there seems little doubt that this must also be at an historic low, given the widespread impact of pollution, particularly diffuse pollution derived from agricultural land and other sources. The Lowland Pond Survey results make it clear that ponds are impaired in quality on a large scale, although, again, with no trend data it is currently impossible to say whether the situation is getting better or worse. The basic statistics of the LPS can mask the reality of the situation – in some parts of lowland Britain one may have to travel for kilometres to find a pond which is not affected by water pollution. In a county survey of ponds in Oxfordshire, for example, few sites were found in a study of 150 locations which were not degraded by pollutants (Pond Action, 1994). In that county, unpolluted ponds are now more or less restricted to a small number of nature reserves, the only areas of the landscape remaining where diffuse and point-source surface water pollution are not all-pervasive. In contrast, in the less intensively managed parts of Britain it is still possible to find large numbers of high-quality ponds.

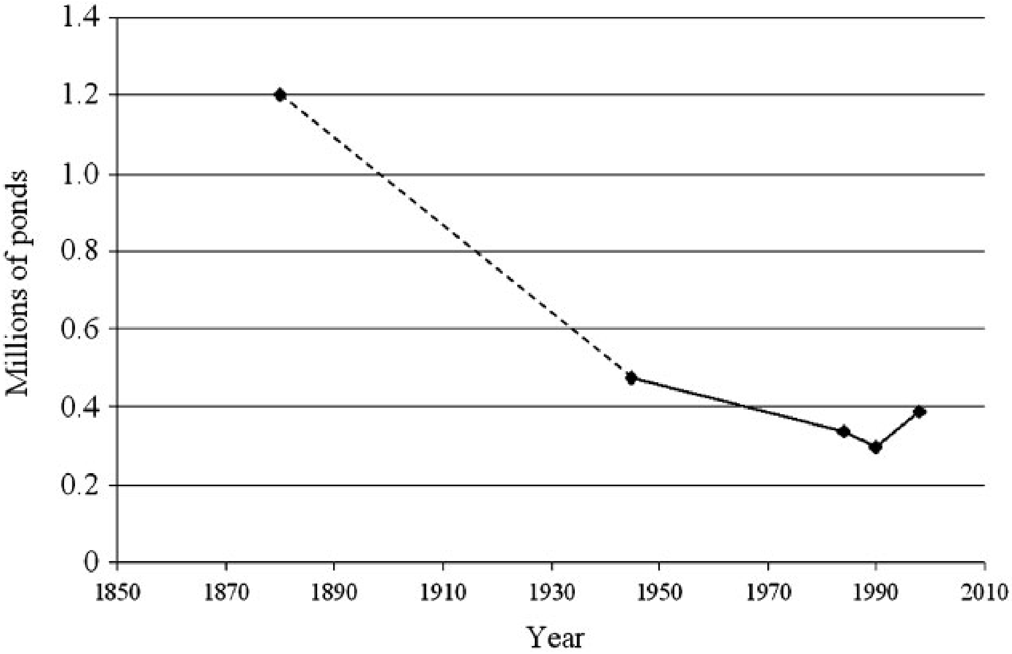


Figure 6. Change in pond numbers over the last 120 years in Great Britain (England, Wales and Scotland). Sources of data: 1880. Total number of ponds: 1 200 000. Derivation: Rackham (1986) estimated that there were about 800 000 ponds in England and Wales in 1880. In modern surveys Scotland has at least half as many ponds as England and Wales (58% in 1998 – Haines-Young *et al.* 2000) so an estimate for the total number of ponds in Scotland in 1880 of 400 000 seems not unreasonable. 1948. Total number of ponds: 473 000. Derivation: estimate made by Swan and Oldham (1989). 1984. Total number of ponds: 337 200. Derivation: the number of discrete standing water bodies up to 1.0 ha in area, plus one-quarter of the water bodies in the 1.0–5.0 ha size class, as estimated by Countryside Survey 1984, Inland Water Bodies study (Barr *et al.*, 1994). 1990. Total number of ponds: 297 300. Derivation: the number of discrete standing water bodies up to 1.0 ha in area, plus one-quarter of the water bodies in the 1.0–5.0 ha size class, as estimated by Countryside Survey 1990, Inland Water Bodies study (Barr *et al.*, 1994). 1998. Total number of ponds: 385 769. Derivation: total number of discrete standing water bodies (ponds and lakes) estimated in Countryside Survey 2000 (397 000) multiplied by 0.97 (the proportion of water bodies up to 2 ha in area in 1990). This correction was made because no breakdown of the different water-body size classes was published by Haines-Young *et al.* (2000).

There is, therefore, now a reasonable amount of information available in the UK about the importance and state of ponds, and how to make new ponds which will be valuable wildlife habitats. Much less is known about how ponds function in detail. Two gaps are of particular importance: the management of individual water bodies and the role of ponds in the network of freshwater habitats.

Pond management

Almost nothing is known about the effects of management on ponds, even though managing ponds is one of the most popular conservation activities. Ten years ago Pond Conservation used available survey data to recommend new approaches to pond management (Biggs *et al.*, 1994), advice that was later expanded as a practical manual (Williams *et al.*, 1999). Both guides emphasized the fact that although there was a variety of widely held beliefs about what constituted good pond management they had never been tested or examined scientifically or experimentally. These tended to focus mainly on reversing successional processes (desilting, removing vegetation, cutting down trees) whilst paying little or no attention to water quality.

This led us to reshape the advice about pond management to emphasize that:

1. Ponds are essentially natural habitats that are commonly and widely recreated by human activity.
2. Ponds are naturally numerous, and also likely to have been widely and constantly available to biota throughout geological time.
3. Succession has occurred in thousands of ponds over the millennia, and biota might be expected to have adapted to exploit these different successional stages.

This in turn led to the idea that water quality was likely to be of paramount concern in pond conservation, just as it is in all other freshwater habitat management, and that all successional stages could potentially be valuable wildlife habitats (Williams *et al.*, 1999).

These basic ideas seemed to be broadly supported by the available evidence – of course some biotic groups seem to be particularly associated with the early successional stages (e.g. stoneworts, some amphibians), maintenance of which had previously been the primary objective of pond management. Clearly these groups require management techniques which allow sufficient early stage ponds to persist at the landscape level. In fact, later successional stages may not only be useful but actually the most biologically rich of any stage, when Diptera and invertebrates associated with wetland plants are taken into account (Drake, 2001). That this is not known for certain reflects the fact that there has, as yet, never been a pond survey which adequately surveyed the groups of organisms specializing in the later successional stages of ponds.

Crucially, the advice given about pond management is largely based on empirical data – observing the factors that affect pond quality, and deducing appropriate management methods. In practice there are virtually no experimental data to show what actually happens when ponds are managed. Although there is a large body of data relating to the management of shallow lakes, much of this is of limited relevance to ponds as it focuses on biomanipulation of fish, control of algal blooms and management of catchment inputs of pollutants. Because ponds are generally much more influenced by their near surroundings, and are far easier to manage physically than lakes, different approaches to management are also required. Thus key questions in pond management are:

- How to design landscapes in which whole, but generally very small, pond catchments can be taken out of intensive land management to create surface water catchments that do not generate pollutants.
- What are the effects of management to reverse successional processes? The effect of all management techniques require investigation (desilting, vegetation removal, adding/removing grazing, management of woody vegetation) in ponds of differing quality.
- How effective are techniques for improving water quality in ponds – for example, do buffer strips or biological filters work?
- How should new ponds be used in pond management strategies? The extensive surveys of new ponds undertaken by Pond Conservation, and particularly more intensive post-creation colonization studies done at Pinkhill Meadow in Oxfordshire (UK), make it quite clear now that new ponds that are unpolluted, near to other wetlands and physically varied in structure, will provide excellent wildlife habitats (Biggs *et al.*, 1995, 1998b). Making good new ponds in areas where there are no pollution inputs is, therefore, a potentially excellent management strategy which could lead to major improvements to the stock of ponds in the British landscape if widely implemented. However, much less is known about how to design ponds in more difficult situations, where ponds are likely to be affected by pollutants (for example on farmland or on the urban fringe).

The role of ponds in the network of freshwater habitats

Understanding how ponds relate to other freshwater habitats is now one of the key challenges of freshwater conservation. In particular, the role of ponds as 'stepping stones', well recognized for amphibians, needs to be examined more carefully for other components of the biota.

Recent work, described above, makes it clear that small water bodies harbour a significant proportion of aquatic biodiversity in agricultural landscapes, but less is known about their role in more natural landscapes. It seems likely that they would also be significant in these situations. How important are ponds to the maintenance of populations of freshwater plants and animals at the landscape level? Since many species found in ponds also occur in other freshwater habitats (both still and flowing) are there significant interactions between habitats?

The irony of pond conservation is that, despite being the least studied branch of freshwater biology, it is the area where there is the greatest potential to make significant long-lasting improvements through protection of existing (small) pond catchments and the establishment of large numbers of well-designed new ponds. The challenge for researchers is to provide the tools needed for this work.

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APPENDIX 1: DEFINITIONS OF PONDS

Definitions of the term ‘pond’ given in books, reports and journals were reviewed, mainly in preparation for the Lowland Pond Survey 1996, the UK Government’s first attempt to assess the ecological quality of ponds (Williams *et al*., 1998a). Although there was no universal agreement on what constituted a pond it was possible to recognize four broad categories of definition, reflecting the main concepts most frequently repeated: (i) it is difficult (if not impossible) to define a pond, (ii) ponds are small and shallow, (iii) ponds are shallow enough for rooted plants to grow throughout, (iv) a miscellany of other physical characteristics.

It is difficult (if not impossible) to define a pond

‘... in general, no scientific distinction can be made [between ponds and lakes].’	Macan and Worthington, 1972
‘There is no satisfactory definition of a pond for the term covers such a wide variety of freshwater habitats.’	Clegg, 1974
‘No firm boundaries exist between the various sorts of standing water ...’	Williams, 1983
‘There is no point at which a definitive line can be drawn between a pond and a lake or even between a puddle and a pond.’	Fitter and Manuel, 1986
‘... it is impossible to provide a precise, technical difference.’	Jeffries and Mills, 1990
‘... it is probably better to think of ponds as a special class of lakes than as something separate.’	Ashworth, 1991
‘The discrimination between large lakes and small lakes or ponds is difficult to establish as the lake size gradient comprises an environmental continuum without any clear delimitation.’	Søndergaard *et al*., 2005

Ponds are small and shallow

‘... lakes of slight depth.’	Forel, 1892 (in Horne and Goldman, 1994)
‘A body of standing water that is smaller than a lake.’	Ashworth, 1991
‘... bodies of water small enough that a rainstorm will significantly change the water chemistry ...’	Ashworth, 1991
‘A small body of still water of artificial formation, its bed being either hollowed out of the soil or formed by embanking and damming up a natural hollow.’	Simpson and Weiner, 1989
‘A fairly small body of still water formed naturally or by hollowing or embanking.’	Allen, 1990
A smaller version of lakes.	Moss, 1988
‘A pond is a small freshwater lake.’	Porter, 1988

‘... ponds are shallow enough to allow light to penetrate to most of their depths.’	Porter, 1988

Ponds are shallow enough for rooted plants to grow throughout

‘... a body of water which is so shallow that rooted plants can grow all the way across it.’	Morgan, 1930
‘... very small, shallow bodies of standing water in which the relatively quiet water and extensive plant occupancy are common characteristics.’	Welch, 1952
‘A pond can be described as a body of still water which is sufficiently shallow to enable attached water plants to grow all over it. This cannot hold true for all ponds ...’	Brown, 1971
‘... they are small bodies of shallow, stagnant water, usually well supplied with aquatic plants.’	Clegg, 1974
‘... small bodies of freshwater, shallow enough for vegetation to grow across the whole surface area.’	Sterry, 1982
‘Ponds are of many kinds but typically are small bodies of shallow, stagnant water in which rooted plants can grow even in the deepest parts.’	Clegg, 1974
‘A pond, then, is likely to be a small body of water, shallow enough for plants rooted on the bottom to grow all over it (though this also depends on the clarity of the water) and to ensure a fairly even temperature throughout.’	Fitter and Manuel, 1986
‘... shallow, but often thermally stratified waters, with abundant growths of rooted and floating macrophytes.’	Horne and Goldman, 1994

A miscellany of other physical characteristics

‘... a typical pond is virtually a self-contained system, a closed biotope, a world within itself ...’	Coker, 1968
‘Ponds are much less stable than lakes. Heavy rain may change completely the water in a pond. In dry weather it may disappear.’	Macan, 1973
Small pond: between the size of a tree-hole and 20 sq. yards (17 sq. m.) Pond: <1 acre (0.4 hectares)	Elton and Miller, 1954
Water bodies up to a size of about $2000\,\mathrm{m}^2$.	MAFF, 1985
‘... stillwaters no deeper than 3 metres and ranging in size from a few square metres to 0.405 hectares.’	Probert, 1989
‘... a pond [is] anything less than 50 m (165 feet) or so across ...’	Beebee, 1991

'Ponds' includes water bodies up to 0.5 hectares. Water bodies of 1.5 hectares are called 'large' by Fryer. No upper or lower size limits defined.	Fryer, 1993
NRA lake classification study referred to water bodies '. . . greater than about 1 ha . . .' (p. 2) and '. . . lakes greater than 2 ha.' (p. 13); by implication, ponds are smaller than this.	Johnes *et al.*, 1994