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The effects of amenity management for angling on the conservation value of aquatic invertebrate communities in old industrial ponds

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Abstract

The conservation value of aquatic macroinvertebrate assemblages in old industrial mill ponds was examined within the urban environment. Of the 60 pond sites identified, 18 (31%) have been drained and/or redeveloped since 1985. Canonical correspondence analysis identified differences between the invertebrate communities of managed and unmanaged ponds. Community composition was strongly influenced by the percentage of vegetation cover and the presence of stocked fish for recreational angling. Managed/stocked ponds have communities dominated by burrowing Oligochaeta and Chironomidae. Unmanaged sites had higher macroinvertebrate diversity compared to managed/stocked ponds and were typified by larval Trichoptera, Coleoptera and Zygoptera. However, unmanaged and 'derelict' sites are at greater risk of drainage and redevelopment in the urban environment. The potential conflict between active management of old industrial mill ponds for recreational angling and the conservation of macroinvertebrate biodiversity is explored.

Keywords: Industrial ponds; Aquatic invertebrates; Angling; Amenity management

1. Introduction

Ponds, small water bodies between 1 m^2 and 2 ha in area, which normally hold water for at least 4 months of the year (Pond Action, 1993), provide habitat for many species of aquatic flora and fauna (e.g. Collinson et al., 1995; Gee et al., 1997; Linton and Goulder, 2000). Ponds are a natural element of the landscape and have been created by processes such as glaciation, land subsidence, river action and tree falls for millions of years (Biggs et al., 1994). However, a significant number of ponds have been created anthropogenically for a multitude of purposes including mineral extraction (Andrews and Kinsman, 1990), watering livestock, irrigation for agriculture, fish for food (Rees, 1997), as landscape and amenity features (Williams et al., 1997), and even to drive industrial processes (Giles and Goodall, 1992).

In the contemporary landscape, humans are the dominant force influencing the creation and elimination of ponds in temperate latitudes (Rackham, 1986). Major concerns have been raised concerning the loss of ponds in agricultural areas as a result of land drainage and the decline in many of the traditional functions associated with them at the national and international scale (Williams, 1997; Everard et al., 1999). In some agricultural areas of the UK the rate of pond loss has been in excess of 55% since 1850 (Jeffries and Mills, 1990; Heath and Whitehead, 1992; Boothby and Hull, 1997). Without management, ponds quickly fall into 'disrepair', allowing rapid sedimentation and vegetation encroachment. However, this 'decline' or 'dereliction' is also a natural part of the pond landscape and succession, leading to the loss of open water and a reduction in depth. This is common throughout geological time and should not necessarily be seen as a negative process since all stages in the successional sequence are utilised by biological communities (Biggs et al., 1994).

The ecological value of industrial ponds in the urban environment has been difficult to quantify (Wood and Barker, 2000). They are unlike most ponds with relatively small catchments, since many have both inflowing and outflowing streams to facilitate utilisation of water in the industrial process and its removal after use, and have elements of both lentic and lotic biological communities (Wood and Barker, 2000). Many ponds were created for specific functions, for example, to clean or

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dye raw materials or to drive machinery in industrial processes (Giles and Goodall, 1992). However, since their creation, many have become important habitats for waterfowl, fish, amphibians, invertebrates and plants, largely by accident. As a result, many have acquired considerable aesthetic, recreational and conservation value (Rees, 1997).

Many old industrial ponds still exist in some parts of Britain, particularly old textile mill ponds, with some dating back to the start of the industrial revolution ca. 1750. Industrial ponds were typically constructed by digging out a small depression and building two or more vertical retaining walls, and diverting water from a small tributary source into the depression via an artificially cut channel. The water was collected from a 'clean' source but as a result of industrial processes it could be heavily contaminated when returned to the environment (Giles and Goodall, 1992; Edwards and Johnston, 1996). Today, old industrial ponds are largely archaeological features that are either managed and utilised as amenity features, primarily for angling purposes, or left to successional processes with the abandonment of the site. Old industrial ponds used for recreation/amenity and angling ponds tend to have well maintained steep banks (almost vertical). Vegetation may be removed periodically to keep areas of open water for fishermen and fine sediment accumulations are removed to maintain water depth in some places.

Because of the ephemeral nature of ponds in the landscape it has been argued that 'man-made' ponds provide an essentially natural environment (Biggs et al., 1994). The importance of ponds for the amphibian and invertebrate fauna of Britain is widely recognised (Duigan and Jones, 1997; Griffiths, 1997) with ca. 150 of the 280 wetland invertebrates listed in the UK Red Data Book (Shirt, 1987; Bratton, 1991) occurring in ponds. However, most ponds, natural, agricultural or industrial, do not have any statutory protection in the UK (Drake and Pickering, 1997; Mackay, 1997) and little if any routine monitoring of their biological resources has taken place historically.

This paper examines the effects of stocked fish on the aquatic invertebrate communities of old urban industrial ponds. The factors influencing community composition in industrial ponds and threats to their survival are examined in detail. Ponds associated with the traditional woollen industry around the town of Huddersfield, West Yorkshire, UK, are used to examine the issues associated with their conservation.

2. Study site

Industrial mill ponds were created in Yorkshire during the early stages of the industrial revolution, ca. 1750, and by 1850 there were > 2000. Approximately 70% (1450) were involved in the processing of raw wool, the production of woollen textiles or the dying of finished products. During the twentieth century the industry declined significantly, leading to the abandonment and/or redevelopment of a large number of sites (Giles and Goodall, 1992). Huddersfield was one of the most important centres for woollen textiles production throughout the history of the industry. It is a large town, ca. 22 km south-west of Leeds and 30 km north-west of Manchester on the eastern edge of the Pennines, and the northern boundary of the Peak District National Park. A total of 60 pond sites that have current or historic associations with woollen textile mills were identified from maps and field reconnaissance trips (Fig. 1). Each pond obtained water from a small tributary and water was returned to the stream/river via a sluice. The age of each pond was determined from local archive sources. From this preliminary survey, 42 sites with one or more pond were identified but only 36 of these ponds were subsequently sampled, because of access restrictions and concerns regarding safety at several sites.

3. Methods

Macroinvertebrates were sampled from all sides of the pond that could be accessed at each site. Samples were obtained from the edge and within the ponds (wading depth) during the summer and autumn of 1997. Samples were collected using a standard pond net (250 μm mesh), which was swept through the water within the discrete aquatic habitats present at each site, over a 3-min period following the UK nation pond survey guidelines (Biggs et al., 1998). In addition, soft benthic samples were collected at each site using a small Ekman grab sampler (Blomqvist, 1990). Samples were preserved in the field with 70% industrial methylated spirits and returned to the laboratory for sorting, identification and quantification of fauna. Where possible, invertebrates were identified to species level, although some taxa such as Ostracoda, Copepoda and most Diptera larvae were left at a higher taxonomic level.

During each site visit, the current status of the pond was recorded. Information collected included: management practices (e.g. any vegetation management, bank maintenance and any angling/stocking activity), the presence of any water-fowl and physical habitat details such as maximum water depth (m), substratum composition (per cent gravel, sand and silt), area of the pond, and macrophyte abundance (per cent cover). The importance of vegetation in structuring invertebrate communities in ponds is widely recognised (Palmer, 1973, 1981; Friday, 1975; Soszka, 1975). Details of macrophyte structure, including approximate area of emergent vegetation (e.g. *Carex* spp. and *Juncus* spp.),

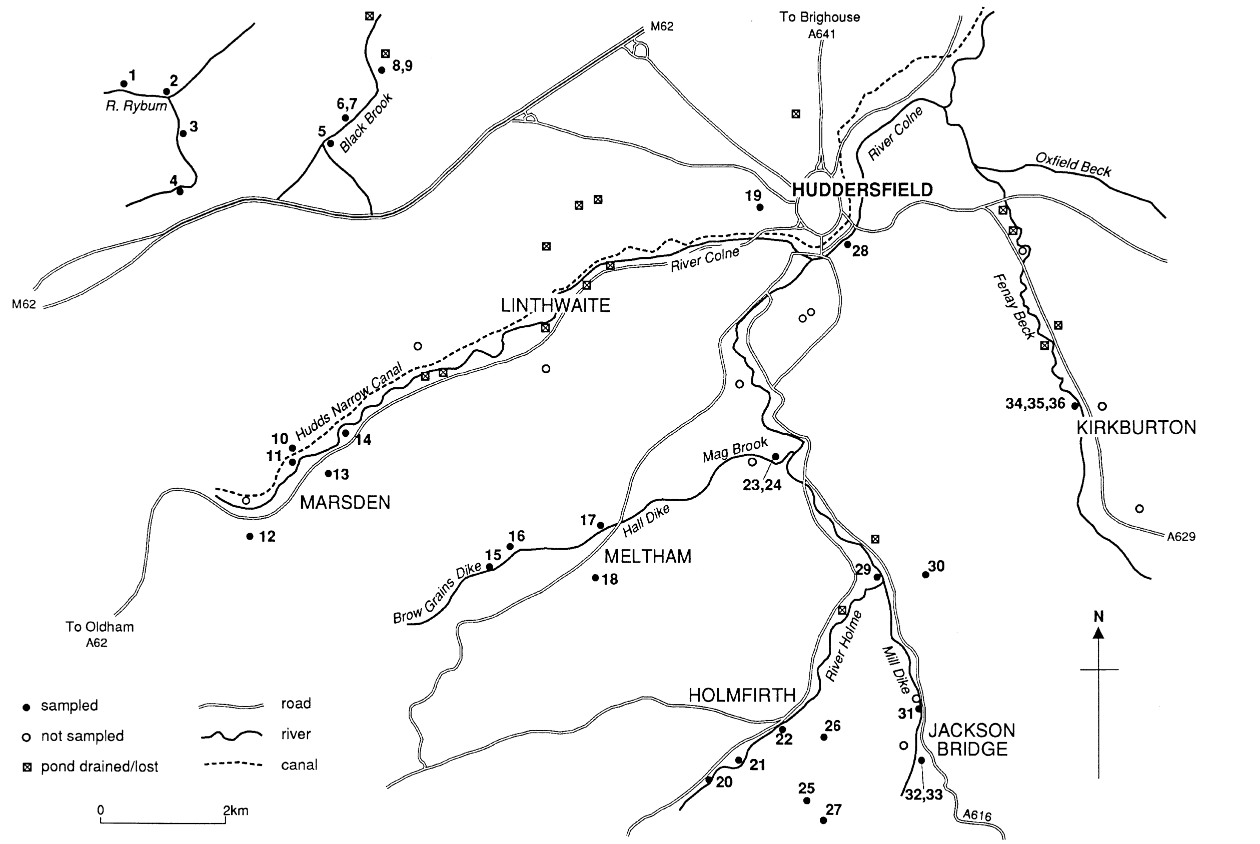

Fig. 1. Location of old industrial ponds around Huddersfield showing those ponds sampled, those not sampled, and those where the waterbody has been drained or redeveloped.

submerged vegetation (e.g. *Callitriche* spp., *Elodea* spp. and *Potamogeton* spp.) and floating leaved plants (e.g. *Lemna* spp. and *Nuphar* spp.) were recorded. However, a full floristic survey was beyond the scope of the present investigation. Water conductivity ($\mu s\ cm^{-1}$), pH and dissolved oxygen ($mg\ l^{-1}$) were measured using portable meters and replicate water samples collected and returned to the laboratory for analysis of nitrate ($mg\ l^{-1}\ NO_3^-$) and phosphate ($mg\ l^{-1}\ PO_4^{3-}$) concentrations using a spectrophotometer.

Macroinvertebrate community data and environmental data were analysed using canonical correspondence analysis (CCA) within the programme CANOCO (ter Braak, 1988). This technique produces ordination axes that are products of the variability of both environmental and species data (Kent and Cocker, 1992; ter Braak and Verdonschot, 1995). In addition, the significance of any relationships between the species ordination and environmental variables, as well as the axes, can be tested within the forward selection procedure, using a Monte Carlo random permutations test (ter Braak, 1988). Prior to analysis, ecological data were transformed ($\log_e + 1$) to give less weight to dominant and/or very abundant taxa, which may cause the majority of other taxa to be clustered at the centre of the ordination (Castella et al., 1995). This process makes interpretation of the results easier and allows some qualitative aspects of the data to be examined.

To examine any influence of environmental parameters on community structure, relative abundance (RA), Shannon–Wiener diversity index (H), Simpson index (D), Berger Parker dominance index, Evenness or Equitability (J) and Species number were calculated using the α Species Diversity and Richness software (Pisces Conservation, 1998). The variables derived were then offered as independent variables in correlation and regression analysis. Analysis of variance (ANOVA) was used to examine the influence of pond management and in particular the presence of stocked fish for angling purposes.

4. Results

The preliminary survey of industrial pond sites indicated that 18 (out of 60) had been lost as a result of drainage and or redevelopment; three were drained within the 2 years prior to the study and an additional two sites were drained shortly after the survey. Twenty-eight (77%) of the sites sampled were over 150 years old and only two ponds were constructed during the twentieth century. The majority of the ponds examined have either been maintained by the mill owners (30%) and/or have been purchased or leased by angling clubs (25%). Twenty of the ponds sampled had been stocked with fish, and of these, nine are owned/leased by local angling clubs, with angling occurring at an additional 10 sites. The majority of the sites utilised for angling purposes contained coarse fish (Table 1), but goldfish (*Carassius auratus*) have been introduced at one site, and several of the ponds were stocked with brown trout (*Salmo trutta*) by local mill owners. However, no quantitative survey of fish abundance was undertaken. Fourteen ponds were not managed in any way and access was restricted by the owner. The majority of these sites displayed signs of heavy siltation, degradation of retaining walls and hydrosereal succession. Of the two remaining sample sites, one was managed as a nature reserve and the other was utilised by a dairy for cooling machinery. Safe access could not be obtained for the other sites identified during the preliminary investigation.

A total of 124 invertebrate taxa, from 55 different families were recorded from the ponds examined (Table 2 and Appendix). The most diverse group was Trichoptera, followed by Coleoptera and Hemiptera. The greatest number of taxa associated with a single pond was 37 and the lowest seven, with an average of 16 invertebrate taxa per pond. CCA, incorporating faunal data and environmental variables, clearly identified those sites that were managed and stocked with fish, and those that have undergone vegetation succession (Fig. 2). The first four canonical axes explained 21% of the species data and 39% of the species environment relations (Table 3). Forward selection of environmental variables within CANOCO identified five significant variables: per cent vegetation cover ($P=<0.005$), phosphate mg l^{-1} ($P=<0.05$), nitrate mg l^{-1} ($P=<0.05$), % sand substratum ($P=<0.05$) and % gravel substratum ($P=<0.05$). The first canonical axis was significant (F ratio = 7.15, $P=<0.05$) and reflected a gradient from the highly vegetated ponds to deep (>1.5 m) ponds where aquatic vegetation was limited. The second axis reflected a gradient from sandy substrates to coarse substrate, although this was not found to be statistically significant.

The species biplot identified several species of Trichoptera (e.g. *Agrypnia obsoleta*, *Phryganea bipunctata, Mystacides azurea* and *Mystacides longicornis*), Coleoptera (e.g. Haliplidae — six species) and Zygoptera (e.g. *Coenagrion puella* and *Enallagma cyathigerum*) that were associated with ponds having a large percentage of the surface covered by emergent, submerged or floating leaved vegetation (Fig. 3). Relatively high numbers of benthic and burrowing taxa were found to be associated with the angling ponds, e.g. Oligochaeta, tube-building Chironomidae, the bivalves *Pisidum casertanum*, *Pisidum subtruncratum* and the alder fly *Sialis lutaria*. Taxa occurring in at least 25% of the samples and demonstrating a greater frequency of occurrence in the managed/stocked ponds or the unmanaged ponds are shown in Table 4.

A significant relationship was recorded between the per cent vegetation cover and the Shannon–Wiener diversity index (H), Simpson index (D), Berger Parker dominance index, Evenness or Equitability (J) and Species number (SPN) (Table 5 and Fig. 4). However, no significant relationships were recorded between relative community abundance (RA), pond age, pond size or

Table 1
Fish known to occur in the old industrial ponds within the study area

Common name	Species	No. Ponds
Brown trout	*Salmo trutta*	5
Common carp	*Cyprinus carpio*	14
Crusian carp	*Carassius carassius*	5
Goldfish	*Carassius auratus*	1
Gudgeon	*Gobio gobio*	6
Tench	*Tinca tinca*	11
Bream	*Abramis brama*	18
Minnow	*Phoxinus phoxinus*	13
Rudd	*Scardinius erythropthalmus*	10
Roach	*Rutilus rutilus*	19
Chubb	*Leuciscus cephalus*	3
Dace	*Leuciscus leuciscus*	11
Three-spined stickleback	*Gasterosteus aculeatus*	28
Perch	*Perca fluviatilis*	7
Pike	*Esox lucius*	1

Table 2
Overall aquatic macroinvertebrate biodiversity recorded in old industrial ponds at the family and species level

Invertebrate group	Families	Species
Mollusca		
Gastropoda (snails)	6	14
Bilvalvia (mussels)	3	8
Annelida		
Oligochaeta (worms)	1	1[a]
Hirudinea (leeches)	3	7
Crustacea (e.g. shrimps and ostracods)	6	6[a]
Insecta		
Plecoptera (stoneflies)	1	2
Ephemeroptera (mayflies)	5	10
Megaloptera (alderflies)	1	2
Neuroptera (spongeflies)	1	1
Lepidoptera (moths)	1	1
Odonata (dragonflies and damselflies)	1	4
Trichoptera (caddis flies)	7	21
Hemiptera (e.g. waterboatmen and water crickets)	4	18
Coleoptera (beetles)	6	19
Diptera (e.g. Chironomidae)	10	10[a]
Total	55	124

[a] Indicates taxa identified to family level only.

any of the physico-chemical variables with the exception of temperature (Table 5). ANOVA indicated that there was a significant difference between the biotic indices in those ponds that contained stocked fish populations and those that did not (Table 6). Further analysis indicated there is a significant interaction between the per cent vegetation cover and the presence of stocked fish and the Shannon–Wiener diversity index (H; F ratio = 3.521, $P = <0.05$; Table 6). None of the other variables examined indicated a significant interaction between the two factors. Stepwise multiple linear regression indicated that the per cent vegetation cover was the best predictor of Shannon–Wiener diversity index (H), Simpson index (D), Berger Parker dominance index and Equitability (J), and was the only variable incorporated within the model (Table 7). The presence of stocked fish was the best predictor of Species number (SPN). None of the variables examined on its own, or in combination with

Table 3
Eigenvalues, cumulative per cent of variance explained on the first four axes and significance of the first axis within the canonical correspondence analysis of old industrial pond data

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.375	0.330	0.309	0.280
Species–environment correlations	0.972	0.974	0.961	0.956
Cumulative % variance				
a. Species data	6.0	11.3	16.2	20.7
b. Species environment relation	11.2	21.1	30.3	38.6
Significance of first canonical axis	F ratio = 7.15		P value <0.05	

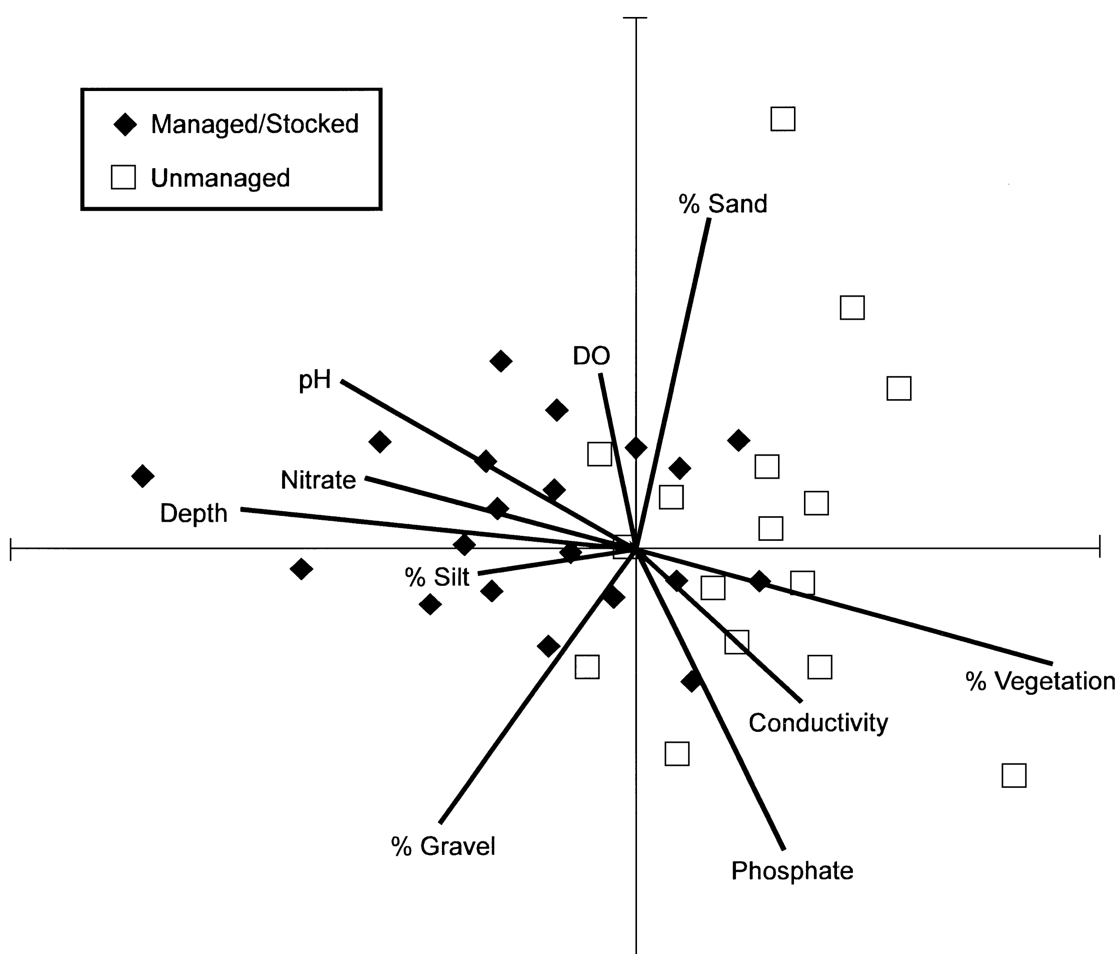

Fig. 2. Canonical correspondence analysis of old industrial pond samples indicating selected environmental variables, those sites which are managed and contain stocked fish populations, and those that are unmanaged.

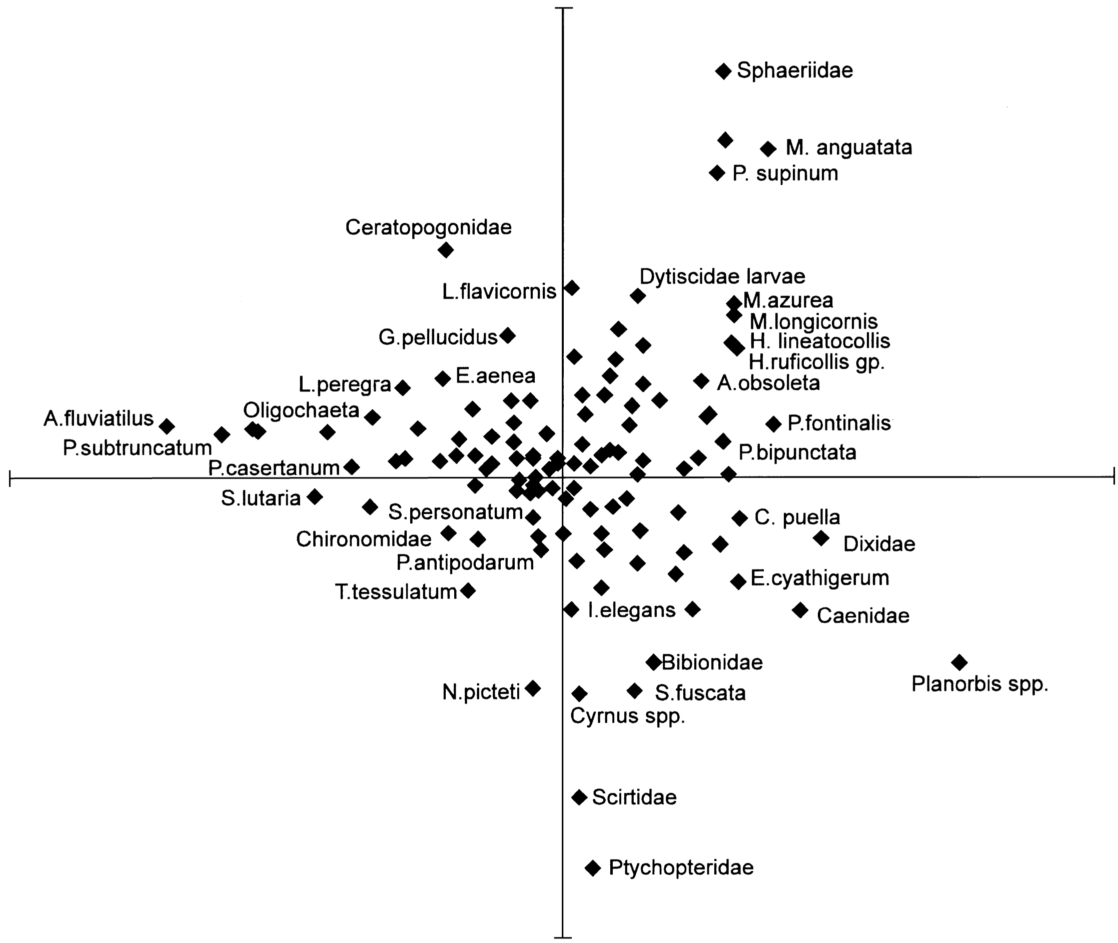

Fig. 3. Canonical correspondence analysis species biplot of old industrial pond macroinvertebrate samples.

others were able to model the relative community abundance (RA).

5. Discussion

Of the 60 sites identified during this study, 18 (31%) have been drained and/or redeveloped since 1985 (the date of the last full 1:10 000 cartographic survey of the area). This is almost certainly an underestimate since many sites historically supported multiple ponds and most small industrial ponds have probably never been mapped. The old industrial ponds examined in the current investigation cover a broad range of managed and unmanaged sites within a relatively small geographical area. Some intensively managed sites had vertical banks on all sides and little macrophyte growth, while several unmanaged sites had a very limited area of open water and were surrounded by dense emergent vegetation.

The conservation of old industrial ponds and their invertebrate communities poses a number of problems, since one of the best ways to ensure the continued existence of the water body is to encourage stewardship by interest groups. This usually facilitates greater access to

Table 4
Invertebrate fauna frequently associated with managed/stocked and unmanaged old industrial ponds (all fauna included occur in at least 25% of all samples collected)

Managed/stocked	Unmanaged
Pisidium subtruncatum	*Bathyomphalus contortus*
Pisidium casertanum	*Gyraulus albus*
Oligochaeta[a]	*Planorbis planorbis*
Piscicola geometra	*Glossiphonia complanata*
Sialis lutaria	*Asellus aquaticus*
Chironomidae[a]	*Nemoura cinerea*
	Nemurella picteti
	Caenis horaria
	Cloeon dipterum
	Cyrnus trimaculatus
	Mystacides azurea
	Phryganea bipuncatata
	Coenagrion puella
	Enallagma cyathigerum
	Ischnura elegans
	Haliplus confinis
	Haliplus lineatocollis
	Haliplus ruficollis group

[a] Oligochaeta and Chironomidae were found in both groups of ponds but were significantly more abundant in managed/stocked ponds.

the site and may provide a focal point for the local community (Boothby et al., 1995) but may also lead to intense management and heavy utilisation if the pond is leased or owned by local angling clubs. The result of the current investigation suggests that managed/angling ponds have a different community structure (Figs. 2 and 3) and reduced diversity of aquatic macroinvertebrates when compared to unmanaged old industrial ponds.

Table 5
Summary of Pearson correlation coefficients between ecological indices and environmental parameters[a]

	RA	*H*	*D*	BP	*J*	SPN
Area (m^2)	−0.18	0.17	0.13	−0.06	0.17	−0.01
Age (years)	0.03	0.24	0.19	−0.20	0.14	0.27
Depth (m)	−0.08	−0.12	−0.09	0.20	−0.12	−0.07
Temperature (°C)	0.19	−0.34*	−0.38*	0.27	−0.35*	−0.19
Conductivity (μSm^{-1})	−0.02	0.15	0.21	−0.29	0.15	−0.04
pH	0.21	0.13	0.18	−0.20	0.13	0.12
Dissolved oxygen (mg l)	0.02	0.06	0.02	0.09	0.06	0.17
Nitrate (mg l)	−0.07	0.11	0.06	−0.05	0.11	0.11
Phosphate (mg l)	0.25	−0.07	0.01	−0.05	−0.07	−0.13
Bank angle	−0.01	−0.08	−0.07	0.17	−0.08	−0.09
% Gravel substratum	0.03	0.10	0.03	0.02	0.10	0.18
% Sand substratum	0.25	0.09	0.12	−0.15	0.09	0.12
% Silt substratum	−0.04	−0.09	−0.10	0.05	−0.09	−0.08
% Vegetation cover	−0.14	0.91***	0.85***	−0.83***	0.91***	0.47**

[a] Ecological indices are: Relative abundance (RA), Shannon–Wiener (*H*), Simpson (*D*), Berger Parker (BP), Equitability (*J*) and Species number (SPN).
*$P<0.05$.
**$P<0.01$.
***$P<0.001$.

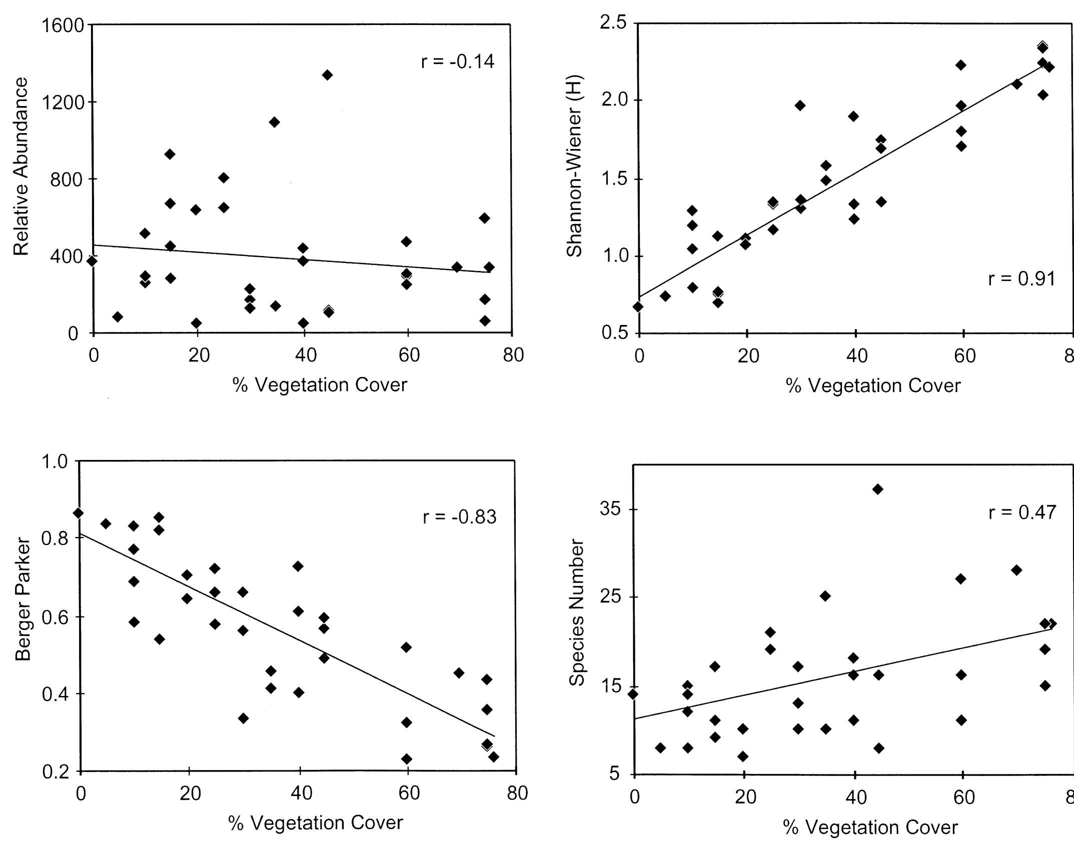

Fig. 4. Selected scatter plots of relationship between per cent vegetation cover and invertebrates: (a) relative abundance; (b) Shannon–Wiener diversity index; (c) Berger Parker dominance index; and (d) Species number.

This is almost certainly due to a combination of factors including the management practices frequently associated with angling ponds; for example, vegetation dredging, removal of accumulations of fine sediment and management of marginal vegetation, and a whole range of biological interactions, including predation by fish and competition for resources (Wetzel, 1983).

Pond area/size (50–16 000 m^2) was not found to be a significant variable in any of the community analyses undertaken and reflects the relatively limited variability between the majority of the industrial ponds. Some authors have identified an influence of water body size on some invertebrate groups, for example, Gastropoda (Brönmark, 1985), Hemiptera (Savage, 1982) and Coleoptera (Nilsson, 1984). However, the effect on the entire community is less clear (Gee et al., 1997).

Pond age has been found to be important in determining macrophyte (Jeffries, 1991) and invertebrate (Barnes, 1983; Fairchild, 2000) species richness in some ponds, while no relationship has been identified in others (Gee et al., 1997). No relationship between invertebrate abundance or diversity and pond age was identified in the current investigation. This probably reflects their management history, with many being utilised and/or managed until at least the middle of the twentieth century for industrial purposes. As part of their management regime, industrial ponds experienced relatively rapid variations in water level each day reflecting production schedules. Fine sediment accumulations and vegetation would be routinely removed since this could 'contaminate' production, particularly in dying processes (Giles and Goodall, 1992). In addition, a large proportion of ponds are still managed for recreational/angling purposes today. Grayson (1992/1993) has suggested that the absence of any direct relationship between invertebrate biodiversity and pond age at sites in north-west England could be attributed to the wide range of 'catastrophes' which older ponds have experienced. These catastrophic events may include both natural and anthropogenic impacts such as drought (Jeffries, 1994) and stocking with fish, as recorded in the present study.

The strongest relationships recorded were between the percentage of the pond surface covered with vegetation

Table 6
Analysis of variance of ecological indices, stocked fish and per cent vegetation cover in old industrial ponds

	Sum of squares	d.f.	Mean square	*F*-ratio
(a)				
Relative abundance (RA)	23392.80	1	23392.80	0.25
Shannon–Wiener (*H*)	5.39	1	5.39	48.41***
Simpson (*D*)	61.92	1	61.92	37.27***
Berger Parker (BP)	0.64	1	0.64	31.75***
Equitability (*J*)	0.22	1	0.22	48.42***
Species number (SPN)	437.11	1	437.11	13.87**
(b)				
Fish	83.06	2	41.53	1493.41***
% Vegetation cover	2.92	13	0.23	8.08***
Fish ×% vegetation cover	0.39	4	0.10	3.52*
Residual	0.47	17	0.03	
Total	86.84	36		

(a) One-way analysis of variance for ecological indices and the presence of stocked fish; (b) Two-way factor analysis of variance for the presence of stocked fish, per cent vegetation cover, and stocked fish × per cent vegetation cover.

* $P<0.05$.
** $P<0.01$.
*** $P<0.001$.

Table 7
Summary of stepwise multiple regression analysis of old industrial pond data

Model	Adjusted R^2	*n*	Predictor plus sign
Relative abundance (RA)	–	36	None
Shannon–Wiener (*H*)	0.828***	36	+% Vegetation cover
Simpson (*D*)	0.713***	36	+% Vegetation cover
Berger Parker (BP)	0.672***	36	+% Vegetation cover
Equitability (*J*)	0.828***	36	+% Vegetation cover
Species number (SPN)	0.269**	36	−Fish

** $P<0.01$.
*** $P<0.001$.

and invertebrate community diversity, dominance and species number. Macrophytes were most abundant at the edges and this appears to confirm the popular observation that it is the margins of the pond that contain most species (e.g. Sansom, 1993; Andrew, 1995), although relatively little quantitative data exists. However, no relationship between the relative abundance of invertebrates and any of the other variables investigated was identified. This reflects the fact that even in ponds largely devoid of vegetation, large numbers of benthic burrowing taxa, especially Chironomidae and Oligochaeta can be found.

The relationship between macrophyte cover and species diversity was very striking to the extent that even ponds in close proximity to each other, but with varying quantities of vegetation, had markedly different invertebrate communities. A similar pattern was recorded in dragonfly communities in newly created ponds with varying quantities of vegetation in Cambridgeshire, UK (Moore, 1991). Detailed analysis of the fauna from different types of vegetation was not undertaken as part of this study. However, historic data from other sites suggests that the structure of the macrophyte community is important to macroinvertebrates (Krull, 1971; Palmer, 1981; Friday, 1987) and clearly warrants further investigation to determine specific macrophyte and faunal associations.

It has been suggested that the introduction of fish into ponds is a major detriment to the conservation value of invertebrates in ponds (Kirby, 1992), and may overshadow the effects of other habitat variables, including vegetation, on invertebrate community structure, biomass and trophic relationships (Fairchild et al., 2000). Predation by fish has been noted to have a marked impact on zooplankton communities at the base of the foodchain (Macan, 1977) and coleoptera populations (Foster, 1991; Fairchild et al., 2000). Insectivorous fish are known to have a major impact on some species, particularly large Odonata larvae (Crowder and Cooper, 1982; McPeek, 1990). However, in Dyfed and Powys, Wales, the presence of stocked fish, primarily rainbow and brown trout, had no detectable impact on the invertebrate community present in ponds created within the previous 5 years (Gee et al., 1997). In the present study, the stocking of predominantly cyprinid populations does appear to have an impact on the invertebrate community (Table 6). Cyprinid fish, especially large carp, may have a greater impact on stocked ponds since they have omnivorous feeding habits and can be very effective in modifying the substratum to the point of eliminating macrophytes (Wetzel, 1983). Detailed assessment of the fish populations of the ponds was beyond the scope of the current investigation, although this could provide further valuable information on the impact of different species on macrophytes and faunal groups.

During the survey of industrial ponds no invertebrate fauna protected under schedule 5 of the Wildlife and Countryside Act (1981) or fauna listed as rare or nationally scarce (Shirt, 1987; Bratton, 1991) were recorded, although it is acknowledged that they may have been overlooked. In addition, most are of limited value for amphibian populations because of their large fish populations and steep/vertical banks (Griffiths, 1997). The most biologically diverse ponds were those where access was limited. At almost all of these sites the mill buildings were in the advanced stages of dereliction and the ponds were heavily silted and/or contained large volumes of aquatic and marginal vegetation. Many landowners and property developers are unaware of the biological value of these sites, and with little biological monitoring and limited statutory protection (Wood and Barker, 2000), they are prime 'brown field' sites for drainage and redevelopment in urban locations. However, old industrial ponds provided a diverse array of high quality habitats for aquatic fauna especially when compared to adjacent urban riverine systems with a history of contamination and river engineering (Edwards and Johnston, 1996).

There is clearly a need to closely examine the biodiversity and conservation value of small water bodies not currently monitored by statutory organisations in the UK, such as the Environment Agency, Scottish Environment Protection Agency, Countryside Commission for Wales, English Nature and Scottish Natural Heritage. The results presented in this study highlight some of the problems associated with pond conservation. Active management and the stocking of ponds with fish may facilitate greater public access and create aesthetically pleasing ponds, but this has to be balanced against a potential reduction in invertebrate species diversity. Those industrial ponds that are largely neglected and may appear to be overgrown and 'worthless' contained the greatest diversity of invertebrates in this study. The conservation of existing ponds is an important process, but should be incorporated into a wider strategy that encourages the creation of new ponds (Williams et al., 1997). This should reflect some of the natural processes that have lead to the creation and succession of ponds within the landscape over geological time.

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Appendix. Aquatic invertebrate taxa recorded and number of ponds at which they were recorded

	Taxa	No. Ponds	Taxa	No. Ponds
MOLLUSCA				
GASTROPODA				
Ancylidae	*Ancylus fluviatilis*	2		
Lymnaeidae	*Lymnaea palustris*	2	*Lymnaea peregra*	18
	Lymnaea stagnalis	5		
Physidae	*Physa fontinalis*	2	*Physa heterostropha*	1
Planorbidae	*Bathyomphalus contortus*	13	*Gyraulus albus*	18
	Gyralus crista	1	*Planorbis carinatus*	1
	Planorbis planorbis	12		
Hydrobiidae	*Potamopyrgus antipodarum*	15		
Succinea	Succinea	2		
Zonitidae	Zonitoidea	2		
BIVALVIA				
Unionidae	*Anodonta cygnea*	1		
Pisidiidae	*Pisidium casertanum*	15	*Pisidium hibernicum*	4
	Pisidium nitidum	3	*Pisidium subtruncatum*	18
	Pisidium supinum	1		
Sphaeriidae	*Sphaerium corneum*	3	*Sphaerium rivicola*	2
ANNELIDA				
OLIGOCHAETA	Oligochaeta	31		
HIRUDINEA				
Erpobdellidae	*Erpobdella octoculata*	8	*Erpobdella testacea*	2
Glossiphoniidae	*Glossiphonia complanata*	14	*Glossiphonia heteroclita*	3
	Helobdella stagnalis	9	*Theromyzon tessulatum*	4
Piscicolidae	*Piscicola geometra*	17		
CRUSTACEA				
AMPHIPODA				
Crangonyctidae	*Crangonyx pseudogracilis*	3		
Gammaridae	*Gammarus pulex*	26		
CLADOCERA	Cladocera	18		
COPEPODA	Copepoda	21		
ISOPODA				
Asellidae	*Asellus aquaticus*	17	*Asellus meridianus*	6
OSTRACODA	Ostracoda	10		
INSECTA				
PLECOPTERA				
Nemouridae	*Nemoura cinerea*	14	*Nemurella picteti*	12
EPHEMEROPTERA				
Baetidae	*Baetis rhodani*	2	*Cloeon dipterum*	14
	Cloeon simile	13		
Caenidae	*Caenis horaria*	17	*Caenis luctuosa*	3
	Caenis rivulorum	2	*Caenis robusta*	5
Ephemeridae	*Ephemera danica*	2	*Ephemera vulgata*	1
Leptophlebiidae	*Leptophlebia marginata*	10		
MEGALOPTERA				
Sialidae	*Sialis fuliginosa*	2	*Sialis lutaria*	18

NEUROPTERA				
Sisyridae	*Sisyra fuscata*	2		
LEPIDOPTERA				
Pyralidae	*Cataclysta lemnata*	5		
ODONATA				
Coenagriidae	*Coenagrion puella*	15	*Enallagma cyathigerum*	12
	Ischnura elegans	14	*Phyrrhosoma nymphula*	1
TRICHOPTERA				
Polycentropodidae	*Cyrnus flavidus*	2	*Cynus trimaculatus*	13
Psychomyiidae	*Lype reducta*	3	*Tinodes waeneri*	6
Leptoceridae	*Athripsodes aterrimus*	1	*Mystacides azurea*	13
	Mystacides longicornis	2	*Mystacides nigra*	2
	Oecetis lacustris	4	*Oecetis ochracea*	2
Limnephilidae	*Glyphotaelius pellucidus*	6	*Halesus radiatus*	1
	Limnephilus centralis	6	*Limnephilus extricatus*	1
	Limnephilus flavicornis	15	*Limnephilus rhombicus*	5
	Micropterna lateralis	1		
Molannidae	*Molanna angustata*	3		
Phryganeidae	*Agrypnia obsoleta*	7	*Phryganea bipunctata*	16
Sericostomatidae	*Sericostoma personatum*	5		
HEMIPTERA				
Corixidae	*Callicorixa praeusta*	5	*Callicorixa wollastoni*	2
	Corixa dentipes	1	*Corixa panzeri*	1
	Corixa punctata	2	*Cymatia coleoptrata*	1
	Hesperocorixa linnaei	3	*Hesperocorixa sahlbergi*	7
	Sigara dorsalis	11	*Sigara fossarum*	2
	Sigara lateralis	2	*Sigara nigrolineata*	2
	Sigara scotti	5		
Gerridae	*Gerris lacustris*	4		
Hydrometridae	*Hydrometra gracilenta*	1		
Notonectidae	*Notonecta glauca*	6	*Notonecta maculata*	1
	Notonecta obliqua	2		
COLEOPTERA				
Dytiscidae	*Agabus arcticus*	1	*Agabus bipustulatus*	1
	Agabus congener	1	*Ilybius fenestratus*	1
	Nebrioporus depressus/elegans	2	*Platambus maculatus*	3
	Stictonectes lepidus	2	*Stictotarsus duodecimpustulatus*	2
Elmidae	*Elmis aenea*	1		
Gyrinidae	*Gyrinus substriatus*	4		
Haliplidae	*Haliplus confinis*	18	*Haliplus fluviatilis*	2
	Haliplus lineatocollis	15	*Haliplus obliquus*	4
	Haliplus ruficollis	7	*Haliplis wehnckei*	1
Hydrophilidae	*Hydrobius fuscipes*	6		
Scirtidae	Scirtidae	2		
DIPTERA				
Bibionidae	Bibionidae	1		
Ceratopogonidae	Ceratopogonidae	3		
Chironomidae	Chironomidae	36		
Culicidae	Culicidae	4		
Dixidae	Dixidae	7		
Psychodidae	Psychodidae	6		
Ptychopteridae	Ptychopteridae	2		
Simuliidae	Simuliidae	1		
Stratiomyidae	Stratiomyidae	5		
Tipulidae	Tipulidae	8		

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