Baseline ecological assessment of 40 gravel pit lakes in the Lower Windrush Valley (Oxfordshire)

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Summary

This report describes the results of a Baseline Ecological Assessment of 40 lakes in the Lower Windrush Valley, in West Oxfordshire, undertaken by the Ponds Conservation Trust: Policy & Research (PCTPR) for the Lower Windrush Valley Project. The main aims of this project were to:

(i) Assess the ecological value of the gravel pits in terms of wetland plants and macroinvertebrates, placing them in a local, regional and national context;

(ii) Inform decisions about the future management of the gravel pits; and

(iii) Identify opportunities for habitat creation and enhancement as part of future gravel pit restoration activities.

All 40 lakes were visited once between 13 July and 15 September 2004 to record wetland plants and lake physico-chemical characteristics, and to collect macroinvertebrate samples. Biological survey methods followed those of the National Pond Survey (NPS), which have also been widely applied to lakes. For the NPS, wetland plant recording is based on a standard plant species list and invertebrates are sampled using a standard 3 minute hand net technique, with laboratory sorting of samples and identification of major invertebrate groups to species level. Water samples for chemical analysis were collected between 1 and 7 September 2004. Specific crayfish surveys were carried out from 27 September to 4 November 2004.

The data collected was analysed using a range of statistical techniques and where possible, the results were assessed in the context of other data sets from comparable studies. A complete review of other available data was, however, beyond the scope of this report. Additional bird data from the Oxfordshire Ornithological Society (OOS) has also been included in this report for an initial assessment. A full analysis of the relationship between birds, wetland plants and macroinvertebrates was, however, also beyond the scope of this report.

Physical characteristics such as size, adjacent land use, shading, bank profile, after use, and the management of the lakes were found to be varied across the LWV complex. Lake water quality was generally very good and most lakes were classified as either mesotrophic or on the mesotrophic/eutrophic boundary, based on Total Phosphorus concentrations. Nitrogen concentrations were also close to the levels seen in other minimally impaired lakes. Heavy metal concentrations were generally low or undetectable. Although water quality was generally good there was some evidence of local water quality impairment at individual sites suggesting the occurrence of localised diffuse and point source pollutant inputs.

Overall the Lower Windrush Valley gravel pits supported a very diverse wetland plant assemblage, with a total of 122 species (c. 35% of the wetland plant species occurring in Britain). All of the lakes fell into Group I of the JNCC lake classification ("widespread, mostly moderately large, base-rich lowland lakes, with *Chara* spp., *Myriophyllum spicatum* and a diversity of *Potamogeton* species"). Mean lake plant species richness was 35.7 ± 7.7 species for all wetland plants, 6.4 ± 2.8 for submerged species and 27.7 ± 6.3 for emergent species. Comparisons with data from the Cotswold Water Park and other gravel pits in southern England confirmed that the LWV gravel pits were of high value in terms of their wetland plant biodiversity. A

total of 27 uncommon wetland plant species were recorded in the survey, the stonewort assemblage being of particular interest with 8 uncommon species. Stonewort species richness and the presence of a Nationally Scarce BAP species, Lesser Bearded Stonewort (*Chara curta*), confirmed the value of the LWV as a nationally "Important Stonewort Area" (Stewart, 2004). Plant species richness and rarity was primarily related to water quality, lake age, lake size and bank characteristics; intensively stocked angling lakes tended to support fewer species overall. Also of concern was the presence of two invasive species in a small number of sites: New Zealand Pigmyweed (*Crassula helmsii*) and Indian Balsam (*Impatiens glandulifera*).

The Windrush Valley gravel pits also supported a very diverse macroinvertebrate assemblage. In total, 191 macroinvertebrate species were recorded, which represents c. 25% of the aquatic species occurring in Britain in the groups surveyed. Diversity was particularly high for water snails (23 species), crawling water beetles (Haliplidae, nine species) and dragonflies (12 species breeding, the minimum required for designation of sites as SSSI on the basis of dragonflies). On average, individual lakes supported 56.2 ± 12.8 species per 3 minute sample and were similar in richness to other high quality minimally impaired lakes and gravel pits in England and Wales. A total of eleven Nationally Scarce species were recorded, all water beetles, as well as 18 nationally local species. All 40 gravel pits supported at least one uncommon species, with c. 90% having at least one Nationally Scarce species. Of particular interest was a new record for White-clawed Crayfish (*Austropotamobius pallipes*) in the oldest gravel pits in the LWV. Unfortunately signal crayfish are fairly widespread in the complex, occurring in over a quarter of the lakes. Macroinvertebrate species richness and rarity were primarily related to lake age, the degree of marginal complexity and the amenity use of the lakes. Generally, heavily used pits were less diverse. Also of concern was the presence of the invasive Zebra Mussel (*Dreissena polymorpha*), which was found in about 25% of the lakes.

Although birds were not included in the Baseline Ecological Assessment, the data from the Wetland Bird Survey (WeBS) showed the Lower Windrush Valley to be of national importance for certain species including Gadwall, Pochard, Tufted Duck and Coot. The pits attracting the greatest wildfowl numbers and diversity were observed to have some or all of the following features: large area, limited tree cover, presence of islands, extensive margins and shallows.

Overall the results of the Baseline Ecological Assessment indicate that the Lower Windrush Valley gravel pits are of regional and probably national importance for their nature conservation interest. A number of factors were identified that influence the nature conservation value of these lakes, including after use, water quality, size, age, design and management of the lake margins. In light of the results of this study, the main management objectives for nature conservation purposes in the LWV should be to:

- Maintain, and where possible improve, water quality.
- Maintain and enhance habitat diversity for both aquatic species, and the terrestrial wildlife associated with the gravel pits.

On existing lakes, including those where nature conservation is not the primary objective, the potential for implementing further wildlife sympathetic management on- and off-pit should be investigated systematically and incorporated into a lake-by-lake management plan. On-pit improvements should focus on:

- Identifying areas where bank profiles can be modified and extensive marginal draw down zones created to improve habitat availability.
- Additional zoning of lakes to reduce the impact of intensive amenity use.
- Controlling local point and diffuse sources of pollution to eliminate, or at least reduce, water quality impairment.

Off-pit, improvements should mainly focus on the creation of new small-scale wetland and aquatic habitats adjacent to existing pits to complement the existing deep and permanent water habitats provided by the lakes (e.g. temporary and semi-permanent ponds and pools, wet grassland, areas of wet woodland).

For newly excavated gravel pits, the main objective should be to continue to develop and improve techniques in the design, restoration and aftercare of gravel pits, thus maximising the nature conservation potential of all sites, whatever their designated after use.

In addition to management in which relatively small-scale improvements are made on a site-by-site basis, the current project could also provide the foundation for a larger-scale national project demonstrating good practice in wetland creation and restoration. Although gravel pit restoration schemes are generally improving there are, as yet, no well-monitored demonstrations assessing the value of the full range of techniques, which can be applied to maximise the nature conservation value of gravel pit complexes. The Lower Windrush Valley would, therefore, provide an excellent opportunity for such a project, combining as it does an excellent baseline dataset with opportunities to demonstrate a range of management techniques on existing lakes. There may also be the possibility of further wetland habitat creation in association with future mineral extraction both within existing permissions and those that may arise in the future.

The data generated by this study has dramatically increased understanding of the aquatic communities supported by the lakes in the Lower Windrush Valley and effectively creates a foundation for a wider biodiversity strategy in the valley. This report recommends that an ongoing monitoring programme should be set up in the LWV for both existing and newly restored gravel pits. It also identifies the need for further information relating to a wide range of habitats and species.

Acknowledgements

We would like to thank:

- The landowners who gave permission to access their property, often on a number of occasions.
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- Oxon Ornithological Society (OOS) for their contribution of information on the importance of the Lower Windrush Valley for birds.
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1. Introduction

1.1 The Lower Windrush Valley (LWV)

The Lower Windrush Valley (LWV), in West Oxfordshire, is an area that incorporates the floodplain of the River Windrush from the town of Witney to its confluence with the River Thames at Newbridge. Over the last 60 years, the valley has been extensively modified by mineral extraction, with large areas of the riverside pasture transformed into a mosaic of open water. In 2004, there were 45 lakes in the valley that had been created through the restoration of gravel pits (Map 1). These comprise a total of c.357 ha of standing open water. This area continues to increase each year with approximately 17 lakes approved within current planning permissions for future mineral extraction in the valley.

The Lower Windrush Valley Project (LWVP), which covers an area of some 28 km^2, was established by Oxfordshire County Council to create and implement an environmental strategy for this area. Officially launched in 2001, the project works closely with mineral operators, landowners and the local community to co-ordinate, implement and help manage a range of initiatives that aim to strengthen the landscape, protect and enhance the biodiversity and improve public access in the valley.

1.2 A biodiversity strategy for the LWV

One of the major objectives` for the LWVP is to develop its own biodiversity strategy. This ambitious project aims to undertake an assessment of habitats throughout the whole valley, highlighting priority habitats, identifying the status and requirements of key Biodiversity Action Plan (BAP) species and ultimately producing targeted management plans for the most important sites. This information will then be used to identify key projects that can be taken forward to contribute to the national, regional and local BAP targets. Priority habitats that are likely to become the focus of this strategy include standing open water, reed beds, neutral grassland, rivers and ditches.

Nationally, gravel pits fall within the remit of the UK BAP priority habitat for ‘Standing open water and canals’. Within Oxfordshire a local ‘Gravel pits and other lakes’ BAP exists as part of the Wetland BAP (PCT, 2000). The LWVP is a major delivery agent for the targets for gravel pits in the Oxfordshire Wetland BAP.

The first step towards producing a LWV Biodiversity Strategy was the creation of the Oxfordshire Gravel Pits Database, produced in 2000 by the Ponds Conservation Trust, with funding from English Nature. This database pulled together all the existing information available for the Lower Windrush Valley and created a framework that would allow new data to be inputted and made accessible. The creation of this database revealed that, despite the major changes to the environment of the valley, there was relatively little survey data available. Of the existing records, the only comprehensive data set related to wintering wildfowl with most of the gravel pits surveyed by Oxfordshire Ornithological Society (OOS) as part of the Wetland Bird Survey. Many other organisations, working in partnership with the LWVP, have concluded that additional survey work is vital in order to assess the quality of the gravel pit communities and discover how these communities are evolving over time. This is shown in the many publications that state this as a priority (Table 1). It was, therefore, evident that further survey work was an essential next step in the development of the strategy.

In 2003 an application was made to English Nature for funding for a Baseline Ecological Survey through the Aggregates Levy Sustainability Fund (ALSF) and in May 2004, the LWVP was offered a grant for this work to be undertaken. The majority of this grant was used to employ the services of the Ponds Conservation Trust and this report details all aspects of their work on this project. The grant also enabled other activities to take place in the LWV:

- The production of summary sheets for each lake to provide a simple, accessible overview of each lake (produced by a collaboration between the Ponds Conservation Trust and LWVP).

- The presentation of the survey data collected in the present study within a GIS framework, as a first step towards making the findings of the Baseline Ecological Survey more accessible (produced by the Thames Valley Environmental Records Centre, TVERC)

- Assistance to local volunteer groups to undertake survey work in the valley and by liasing with landowners to secure access to sites, collating survey data and communicating results to the landowner and other interested groups. The work of the OOS and the Ashmoleon Rare Plants Group are two examples of volunteer surveys, which are contributing to the LWV biodiversity strategy.

1.3 Background: biodiversity and mineral extraction

Gravel pit lakes are bodies of open water that are left following the excavation of sand, gravel or clay for the aggregates industry. They are one of the few wetland habitats to have increased in extent during the 20th century (PCT, 2000) and in southern England particularly, their creation has significantly increased the extent of large open water bodies present in the region.

Restored gravel pits can potentially provide a valuable wetland habitat which may include not only open water, but also extensive stands of emergent vegetation and, more rarely, marginal fen and carr. A survey of six counties in England showed that mineral workings were associated with an average of 13% of the biological SSSIs in these counties (Box *et al*., 1996).

Those lakes with unpolluted water may support diverse communities of aquatic plants, and where water quality is highest, assemblages rich in pondweeds (*Potamogeton* spp.) and stoneworts. They can provide important habitats for aquatic invertebrates, especially where marginal habitats are diverse and water quality is good. Gravel pits are widely recognised as an important habitat for wetland and water birds, including some species whose traditional habitats (e.g. fens, marshes, wet grassland), have been declining. They can also be of particular value to otters (food supply and as refuge sites if islands are present), water vole (where there are good marginal habitats), and feeding sites for bats and other mammals.

In the past, restoration plans for gravel pits were generally not designed with wildlife in mind. Lakes that were restored in the 1970’s and 1980’s were frequently landscaped for amenity purposes only, and these older sites tend to have a number of common features that reduce their value for nature conservation. These include (i) steep margins, (ii) low shoreline complexity, (iii) few islands, (iv) lack of adjacent pond, marsh and terrestrial habitats, (v) minimal waterfowl nesting habitat, and (vi) lack of sheltered areas where disturbance is limited. In some areas restoration back to agriculture was the main priority where the land was of sufficiently high grade to justify this approach and so no wetland habitat was retained.

The standards of gravel pit restoration have now improved and some new sites have been designed specifically to provide a nature conservation after-use. Within Oxfordshire this has been facilitated by policies within the Minerals and Waste Local Plan, which not only help to identify sites where the priority after-use is nature conservation but also make provisions for their long-term management through the use of S106 agreements.

Semi-natural habitat is now scarce in the UK, and the minerals industry can make a significant contribution towards safeguarding those areas that remain, and help create new aquatic habitats. Creation of new habitats can potentially mitigate the historical legacy of loss and fragmentation of natural habitats that occurred in the last century.

1.4 Aims and objectives of the Baseline Ecological Survey

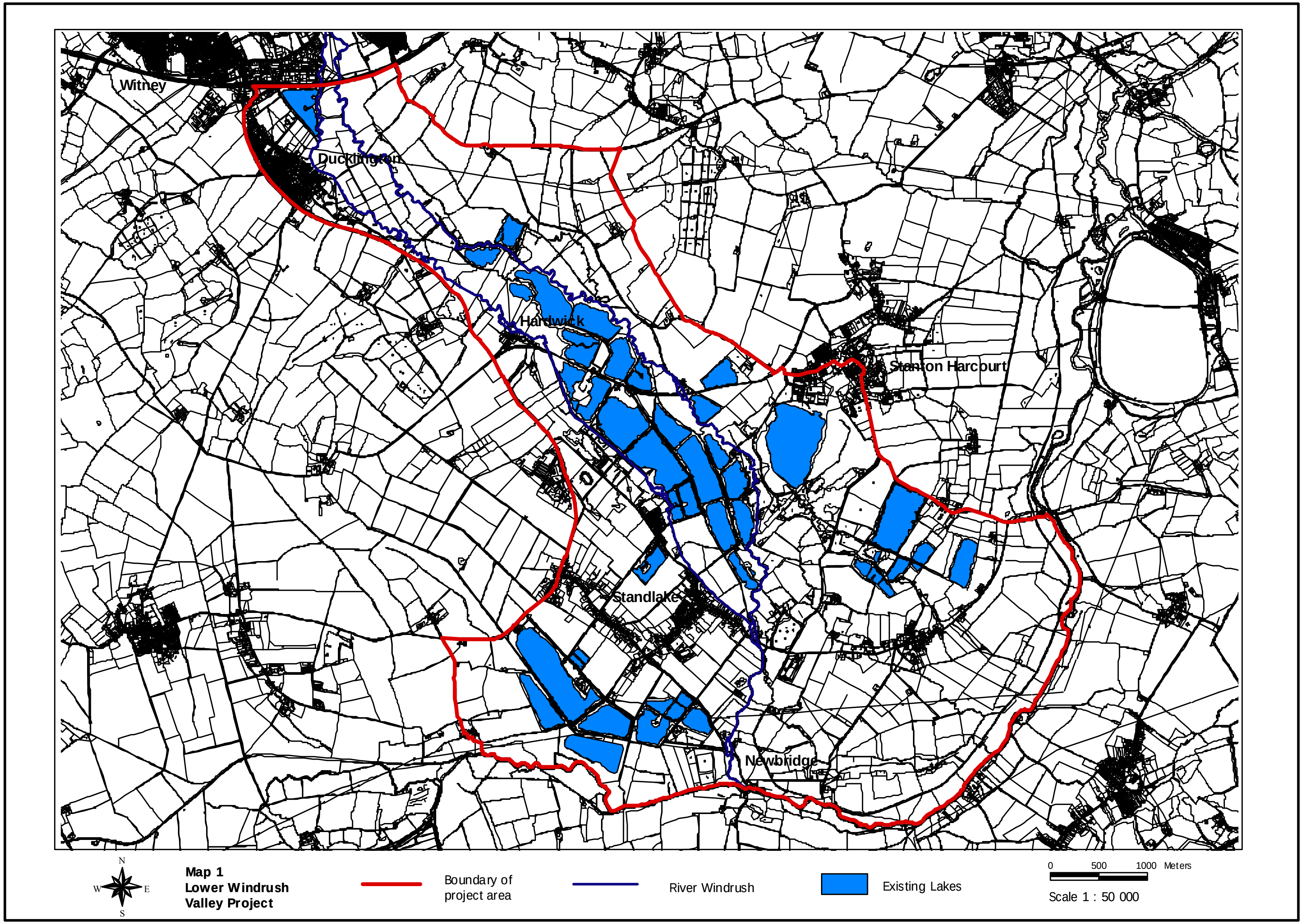
In May 2004, the Ponds Conservation Trust: Policy & Research (PCTPR) was commissioned by the Lower Windrush Valley Project to carry out a Baseline Ecological Survey of 40 lakes in the area. The main aims of this project were to:

(i) Assess the ecological value of the lakes in terms of wetland plants and macroinvertebrates, placing them in a local, regional and national context.
(ii) Inform decisions about the future management of the gravel pits.
(iii) Identify opportunities for habitat creation and enhancement as part of future gravel pit restoration activities.

This study primarily looks at wetland plants and macroinvertebrates, with additional fieldwork undertaken for White Clawed Crayfish, a UK BAP priority species. An initial assessment of the value of the gravel pits for birds, based on surveys by OOS was also included. However, a full analysis of the relationship between wetland plant and macroinvertebrate data and those for birds and other groups, such as mammals, was beyond the scope of the current study. Similarly, the inclusion of mammal have been noted as areas of further study.

Table 1 Summary of nature conservation objectives relevant to the LWV

Organisation	Objectives in support of the LWVP activities
English Nature (EN)	**Thames and Avon Vales – Natural Area Profile** • Ensure that the most important gravel pits for nature conservation are identified and protected from unsuitable development and recreational use, particularly in the Cotswold Water Park and the Lower Windrush Valley.
Environment Agency (EA)	**River Thames LEAP Windrush & Evenlode** • Consider need for any species specific surveys to comply with Regional Agency Biodiversity Action Plans. • Monitor status and distribution of non native crayfish. Consider the need for a pro active survey to establish current distribution.
Oxfordshire Nature Conservation Forum (ONCF)	**Oxfordshire Habitat Action Plan for Gravel Pits and Other Lakes** • Undertake a monitoring programme, which assesses the value of key gravel pits (i.e. pits of high nature conservation value) for flora and fauna, in particular BAP Priority species.
Environment Agency & Oxfordshire Nature Conservation Forum (ONCF)	**Upper Thames Wetland Project** • Scoping Study (Undertaken by Pond Action, now The Ponds Conservation Trust, for the EA and ONCF). • Survey, research and assessment: developments in information gathering are recognised as essential by practically all of the organisations working in the study area. • Monitor gravel pits, maintaining record of changes in wildlife communities that use or inhabit them. • By 2005 grade the gravel pits in terms of their bird interest, aquatic communities and wetland plants. • Protect best gravel pits from unsuitable development. • Find an acceptable infill material that would allow some gravel pits to be restored as shallow wetlands rather than lakes - lack of inert fill is a major practical problem.
Lower Windrush Valley Project (LWVP)	**Lower Windrush Valley Report** • NC2 – Where possible improve the wildlife interest of existing lakes. • Survey to identify species/habitats of nature conservation interest. • Create new areas of shallows and reedbeds.
Joint Nature Conservation Committee (JNCC)	**Mesotrophic Lake HAP (similar objectives exist for the Eutrophic Standing Waters HAP)** • Maintain the conditions of all important sites currently judged in favourable conditions. • By 2005, iniate action to restore to favourable condition (typical plant and animal communities present) of important sites that have been damaged by human activities. • Ensure that no further deterioration occurs in the water and wildlife of the remaining sites.



Map 1 The Lower Windrush Valley (LWV)

2. Methods

2.1 Survey sites

A total of 40 gravel pits were included in the baseline ecological assessment (Map 2). Landowner permission to access the site was not given for 4 lakes in the area, and these were not included in the survey.

2.2 Survey period

All 40 gravel pit lakes were visited once between 13 July and 15 September 2004 to record wetland plants and the physico-chemical variables and to collect macroinvertebrate samples. Water chemistry samples were collected in three batches (1, 6 and 7 September 2004) by Alison Hopewell of the Lower Windrush Valley Project. The crayfish survey was carried out from 27 September to 4 November 2004.

2.3 The National Pond Survey methods

The methods used for the wetland plant and macroinvertebrate surveys were based on standard techniques developed for the National Pond Survey (Appendix 1). These are described briefly below.

2.3.1 Physical variables

A wide range of physical variables were recorded in the field for each gravel pit lake. These included the surrounding landuse, the bank characteristics, and the amount of shade (recording sheet included in Appendix 1). Other variables, such as the surface area and the age of the lakes were supplied by the LWV GIS database.

2.3.2 Water chemistry

Water samples were collected from each gravel pit and sent to the Environment Agency's National Laboratory Service for analysis of the major chemical determinands. Conductivity and pH were recorded in the field using hand-held meters. A list of chemical determinands included in the analyses and their detection limits is shown in Table 2 below.

2.3.3 Wetland plants

Wetland plants[1] were surveyed by walking and wading the perimeter and open water areas less than 1 m deep noting the species present. Deeper areas were sampled using a grapnel. Only those species included in the standard wetland plant list of the National Pond Survey method were recorded (Appendix 1). Most species were identified in the field, but critical specimens were returned to the laboratory for detailed examination. Stonewort species were preserved and sent to the national referee, Nick Stewart, to confirm identification.

[1]The term 'wetland plant species' refers to species defined as wetland plants on the National Pond Survey field recording sheet list. Terrestrial plant species are not recorded.

Table 2 Chemical determinands and detection levels as set by the Environment Agency National Laboratory Service

Determinands	Detection limits
Suspended solids	3 mg/l
Alkalinity	10 mg/l
Chloride (Cl)	1 mg/l
Sodium (Na)	2 mg/l
Calcium (Ca)	1 mg/l
Potassium (K)	0.1 mg/l
Total Oxidised Nitrogen (TON)	200 µg/l N
Nitrogen Kjeldahl	500 µg/l N
Nitrogen digested (sum of TON and N Kjedahl)	n/a
Orthophosphate (Soluble Reactive Phosphorus)	4 µg/l P
Total Phosphorus	4 µg/l P
Copper (Cu)	2.5 µg/l
Iron (Fe)	30 µg/l
Lead (Pb)	2 µg/l
Magnesium (Mg)	300 µg/l
Nickel (Ni)	5 µg/l
Zinc (Zn)	5 µg/l
Chlorophyll a	1 µg/l

2.3.4 Macroinvertebrates

Invertebrates were collected using a three-minute hand net sample from the major habitats in the waterbody (stands of different wetland plants, distinctive substrates, tree roots etc.). An additional 1 minute was spent searching for animals which might otherwise be missed by the three-minute sample, for example those under stones and logs (e.g. flatworms), or at the waterbody surface (e.g. pond skaters). The material collected was returned preserved to the laboratory for sorting and identification to species level. All major macroinvertebrate groups were recorded except for True Flies (Diptera), for which there is little information on species level identification and national distribution. The invertebrate groups recorded were: Coleoptera (water beetles), Ephemeroptera (mayflies), Mollusca (snails and bivalves, excluding *Pisidium* spp.), Hemiptera (water bugs), Hirudinea (leeches), Malcostraca (shrimps, slaters and crayfish), Megaloptera (alderflies), Odonata (dragonflies and damselflies), Plecoptera (stoneflies), Trichoptera (caddisflies) and Tricladida (flatworms).

2.4 Crayfish survey

A number of methods were used to ascertain the presence of crayfish species in the gravel pits of the Lower Windrush Valley. Visual searches and netting were used as part of the macroinvertebrate survey (above). In addition, traps were placed in those lakes where the presence of crayfish had not been established during the macroinvertebrate survey.

Standardised methods to survey crayfish are currently unavailable for standing waters. The trapping method used in this survey was devised based on advice from the Environment Agency, and from David Rogers, the lead partner for the White-clawed Crayfish (*Austropotamobius pallipes*) Species Action Plan (SAP), who also supplied the vole friendly traps. White-clawed Crayfish is protected under Schedule 5 of the Wildlife and Countryside Act 1985, and a licence to trap was obtained from English Nature (Licence number: 20042138).

Traps were baited with smoked fish and laid in suitable habitats, such as stands of sedges or stonewort for between 18 to 24 hours. Traps were laid both in the shallows, and at depth. The number of traps per lake was a function of (i) the extent of suitable habitat and (ii) the size of the gravel pit. Up to 16 traps were laid in the larger gravel pits. Specimens of non-native crayfish caught in the traps were killed. All equipment and traps used in this survey were disinfected between sites to prevent the spread of the crayfish plague.

2.5 Data analyses

The data collected was analysed using standard univariate and multivariate statistical techniques. The conservation value of ponds was assessed on the basis of their species richness and rarity. The latter was investigated using a Species Rarity Index (SRI), which is conceptually derived from the Species Quality Score developed by Foster *et al.* (1990), and which is now in common use in freshwater studies (e.g. Williams *et al.*, 2003). The SRI is derived by (i) giving each species a numerical value according to its distribution and conservation status (Table 3), (ii) summing all values for each sample to give the Species Rarity Score (SRS), and (iii) dividing the Species Rarity Score by the number of species to give the SRI.

Table 3 Definition of terms used to describe the distribution pattern and conservation score of wetland plant and macroinvertebrate species in Britain

Description	Score	Distribution and/or conservation status
Common	1	Generally regarded as common.
Local	2	Invertebrates: either (a) confined to certain limited geographical areas, where populations may be common or (b) of widespread distribution, but with few populations. Plants: recorded from between 101 and 700 10x10km squares.
Nationally Scarce	4	Recorded from 15-100 10x10km squares.
RDB NT, CD	8	Red Data Book: Near Threatened and Conservation Dependent.
RDB VU	16	Red Data Book: Vulnerable.
RDB EN, CR	32	Red Data Book: Endangered and Critically Endangered.

Status data from: Shirt (1987), Bratton (1990), Bratton (1991), Wallace (1991), Stewart (2003), Preston *et al.* (2002), Kerney (1999), Foster (2000). Species with no distribution data were regarded as common.

Non-parametric univariate statistical tests were used to assess trends between biotic and non-biotic variables. Classification (TWINSPAN, Hill, 1994) and ordination techniques were used to (i) analyse the characteristics of the gravel pits in relation to each other, (ii) analyse community composition of the assemblage identifed, and (iii) assess the relationship between the physico-chemical variables and the biota. The gravel pits were relatively homogenous in terms of both their biotic and abiotic variables, so Detrended Correspondance Analysis (DCA, Hill, 1994) was used to carry out an indirect gradient analysis. Statistical analyses were carried out using standard computer programmes: Community Analysis Package (CAP, version 2.1, Pisces Conservation Ltd, Lymington, UK), and Statistica 6.0 (Statsoft, Tulsa, Oklahoma, USA).

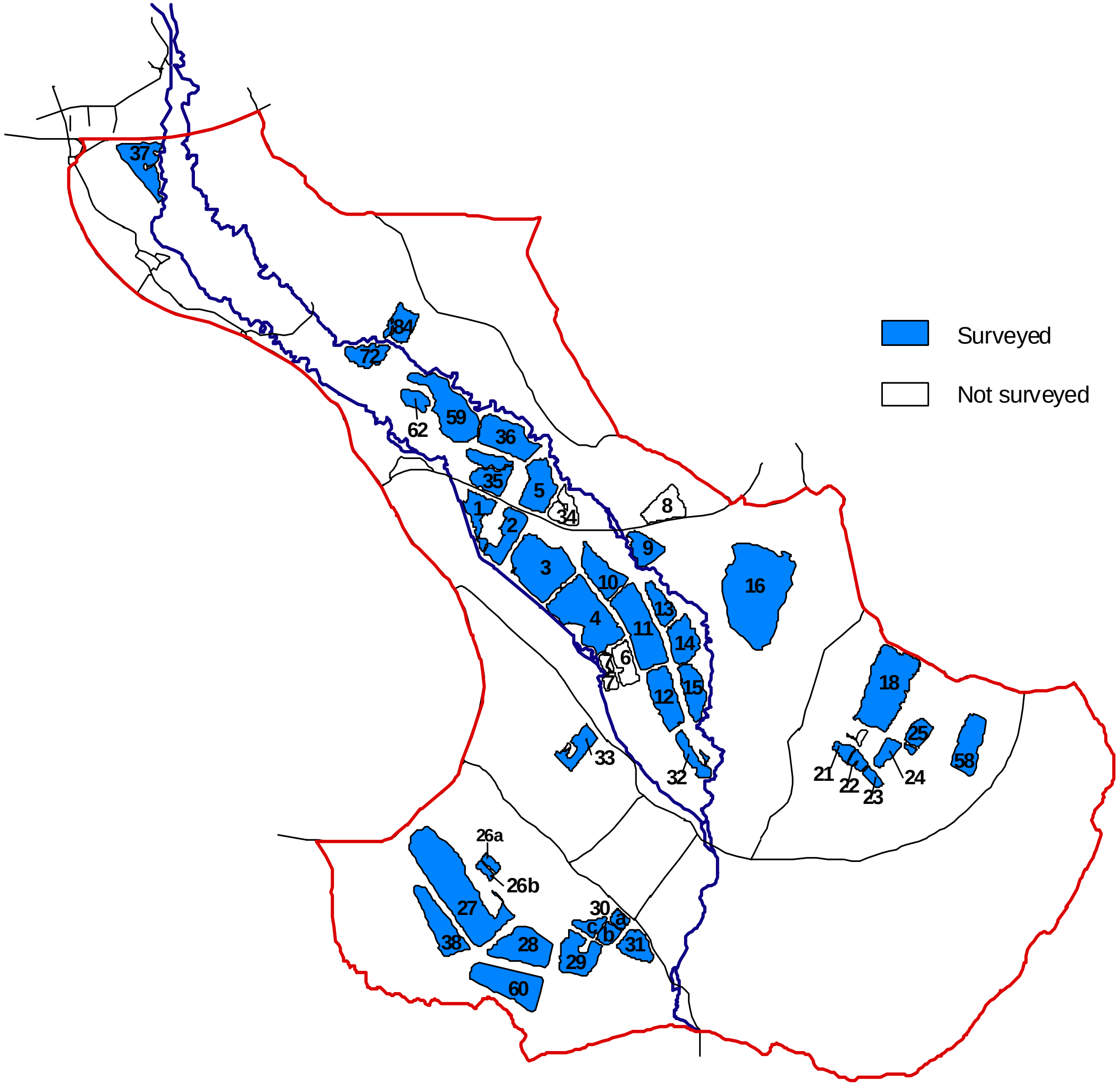
2.6 Supporting information

A complete review of available data on gravel pit lakes in the UK is beyond the scope of this report. Nonetheless, where possible, the results of the current study were assessed in the context of other data. Unfortunately, there is currently no monitoring programme for gravel pit lakes biodiversity in the UK. In addition, existing data on wetland plants and macroinvertebrates for nationally important sites, such as the Swanholme Gravel Pit SSSI is often uncollated and/or unpublished (Steve Clifton, pers. com.). Comparisons between the wetland plants and macroinvertebrate survey results were made primarily with:

- The recently revised Joint Nature Conservation Committee (JNCC) Lake Classification, which is based on aquatic plant assemblages (Duigan *et al*., 2004).
- The Cotswold Water Park review of recent data, which included information about both wetland plants and macroinvertebrates (Bell, 1995). Note, however, that differences in survey methods meant that some information was not always directly compatible with the results of the present survey.
- Plant and macroinvertebrate data for some 30 gravel pits in the Caversham and Datchet-Chertsey complexes, from a survey carried out in the early 1990s by PCTPR (partly published in Pond Action, 1991).
- Macroinvertebrate data from 15 minimally impaired lakes in England and Wales surveyed by PCTPR as part of the development of standard biological methods for assessing still waters for the Environment Agency (Biggs *et al*., 1999).

At present there are no data describing the chemical quality of minimally impaired lakes in Britain. To assess the chemical quality of the Lower Windrush lakes, therefore, water quality data from the study were compared with information on the chemical quality of minimally impaired (i.e. unpolluted), standing waters derived from three main sources:

- For nutrients, the widely recognised OECD lake classification, which is an internationally recognised classification of lake nutrient status.
- For other determinands, the PCTPR database of water chemistry from minimally impaired standing waters derived from the National Pond Survey, which includes water bodies up to 5 ha in area; these sites are generally as free from surface water pollutants as is possible in the UK landscape.
- International standards defined by the US EPA and the European Inland Fisheries Advisory Commission (EIFAC).



Lower Windrush Valley Gravel Pits

01 - Manor Farm Lake
02 - St John's Lake
03 - Hardwick Leisure Park 1
04 - Hardwick Leisure Park 2
05 - Darlow Water
06 - Newlands Specimen Lake
07 - Newlands Surman Lake / Bents Pool
08 - Vicarage Pit
09 - Vauxhall Lake
10 - West Oxon Sailing Club 1
11 - West Oxon Sailing Club 2
12 - Oxlease Lake
13 - Yeomans Lake
14 - Unity Lake
15 - Gaunt Lake
16 - Dix Pit
18 - Stoneacres Lake
19 - Linch Hill Silt Ponds
21 - Linch Hill complex 3
22 - Linch Hill complex 4
23 - Linch Hill complex 5
24 - Willow Pool
25 - Christchurch Lake
26 - Lincoln Lake
27 - Three T's Lake
28 - Windsurfing Lake
29 - Standlake Common 1
30 - Standlake Common 2
31 - Barnes Lake
32 - Hunts Corner
33 - Downs Road Trout Lake
34 - States Lagoon
35 - Smiths Pool / Hardwick Lake
36 - Brasenose Lake
37 - Witney Lake
38 - Shifford Lake
58 - Watkins Farm
59 - Gill Mill Lake
60 - Standlake Common Nature Reserve
62 - Founders Lake
72 - Graham Water
84 - Claire Lake

Map 2 Gravel pit lakes included in the 2004 survey

3. Survey results

3.1 Physico-chemical characteristics of the gravel pits

3.1.1 Physical characteristics

The Lower Windrush Valley (LWV) gravel pits range in size from 1 to 35 ha (Figure 1). Most are, however, small with three-quarters less than 10 ha in area. The majority of the lakes are between 11 and 40 years old (62%) with smaller numbers over 40 and less than 10 years old (respectively, 20% and 18%) (Figure 2). The immediate surroundings of the pits (up to 5 m from the water margin) are mainly woodland and grassland. Further afield (up to 100m), there is a greater proportion of more intensive landuses, such as arable land, quarrying, and urban areas.

Approximately half the gravel pits surveyed had low to moderate levels of marginal shade (up to 50% cover), and 15% of pits had heavily shaded margins (75-100% cover) (Figure 3). Correlations between environmental variables (see Appendix 3 for correlation coefficients) showed that, as would be expected, older pits tended to be more shaded. Older pits also had a higher proportion of intensive landuse in their surroundings.

The bank profiles of the lakes were generally quite steep with a mean of 28° (± 16°). There were, however, some notable exceptions, particularly for the newly restored pits: for example Pit 60 (Standlake Nature Reserve) and Pit 62 (Founders Lake) had relatively shallow and gently sloping edges.

In terms of amenity use, many LWV gravel pits have multiple uses (Map 3). Overall, angling is the main afteruse, and 35 (c. 90%) of the pits are used for either coarse or trout fishing. It should be noted that some pits are more intensively stocked than others although, unfortunately, specific data on fish biomass are not available. Water sports are practised in six gravel pits and five lakes are managed for nature conservation purposes. Unsurprisingly, almost all the sites surveyed were actively managed, mainly for angling. The main management practice observed in the field was the cutting or mowing of marginal vegetation with this activity occurring in around 85% of the sites.

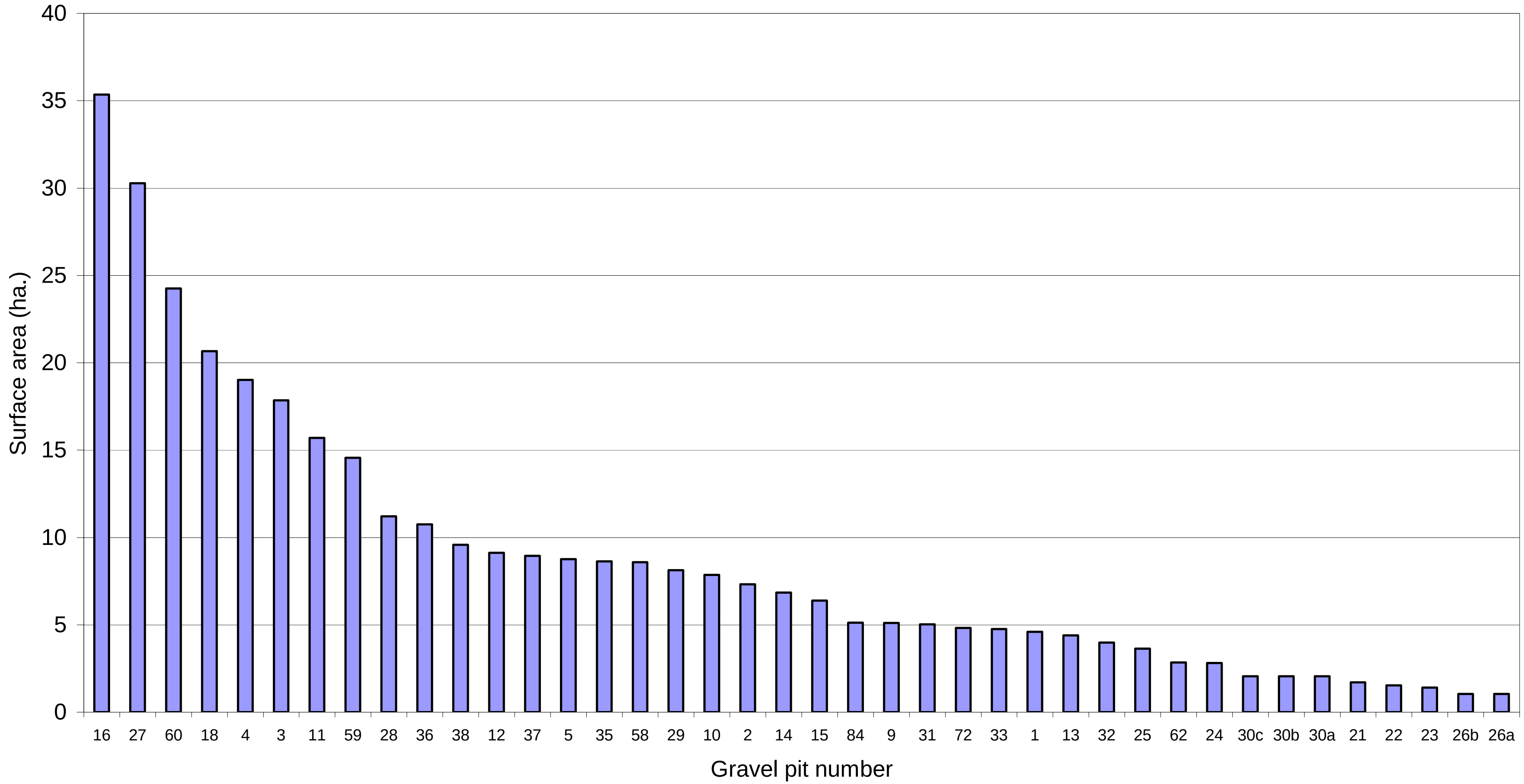
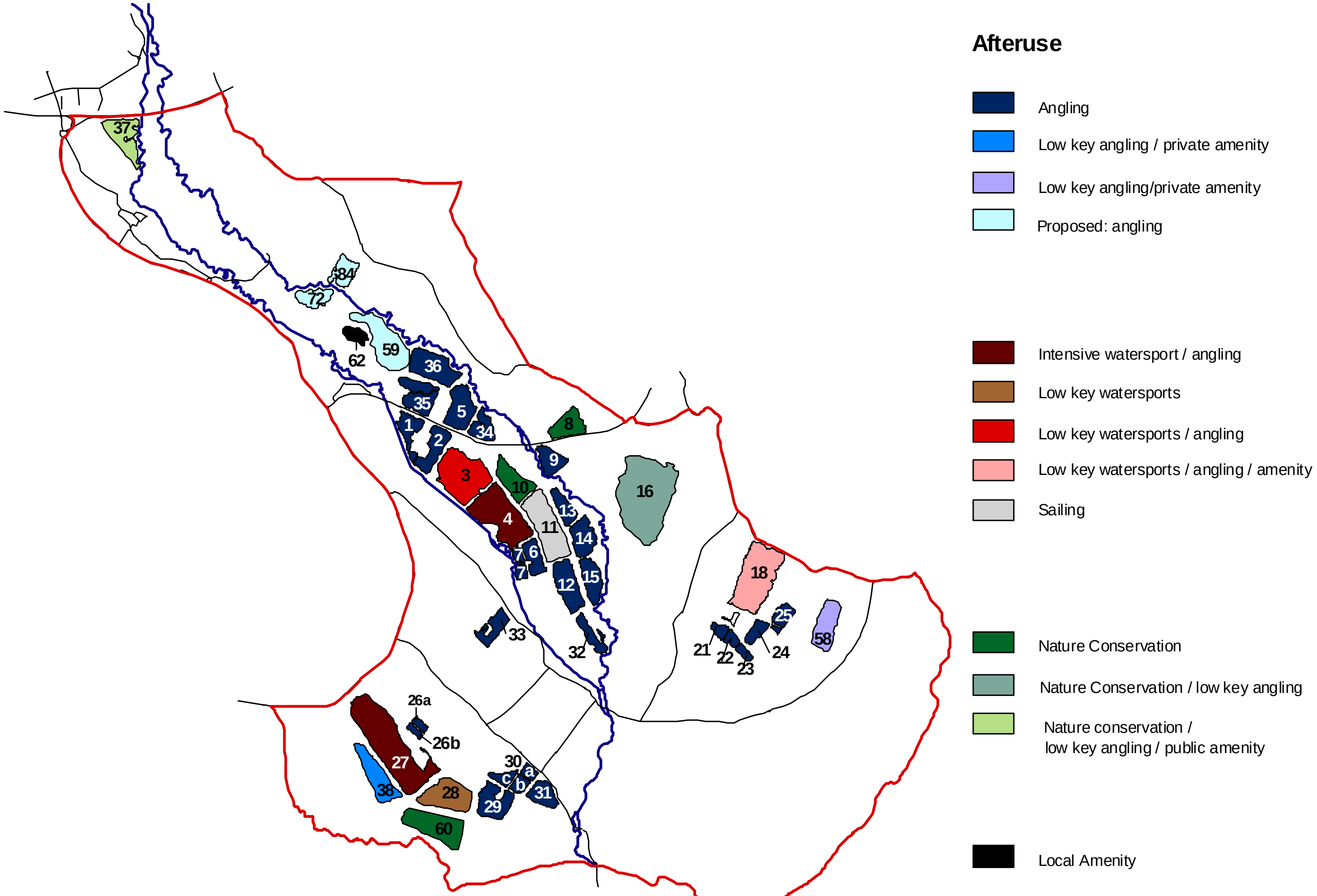


Figure 1 Surface area of the LWV gravel pits



Map 3 Amenity use in the LWV gravel pits

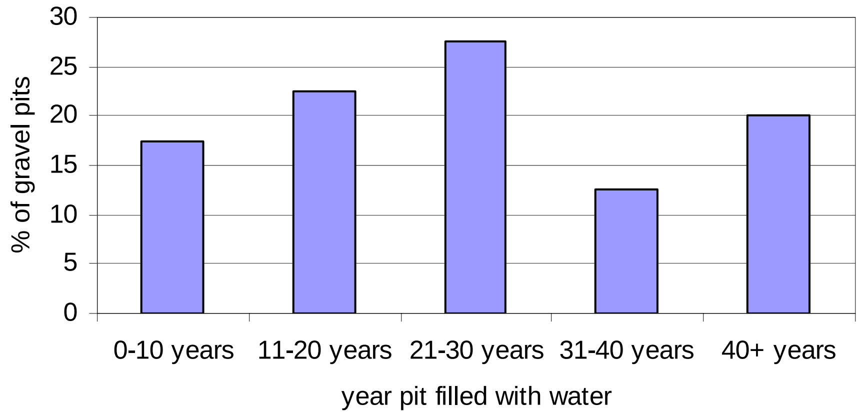


Figure 2 Age of the LWV gravel pits

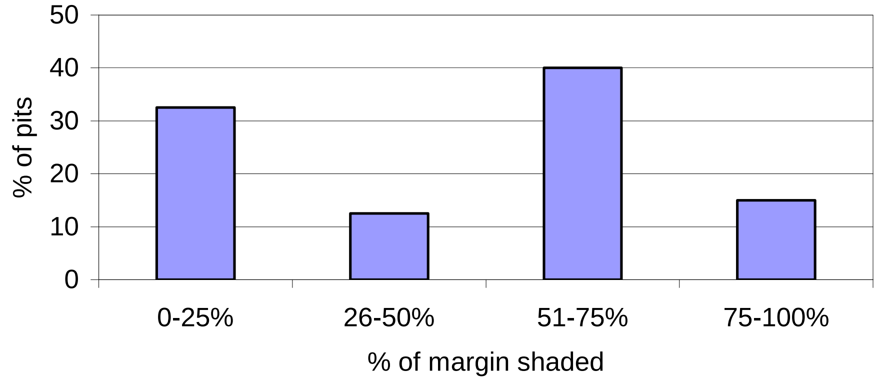


Figure 3 Percentage of shaded margin for the LWV gravel pits

3.1.2 Water chemistry

3.1.2.1 Introduction

The results of the water chemistry analysis show that the gravel pit lakes in the Lower Windrush Valley had generally very good water quality. A summary of the results of the water chemistry analyses is given in Table 4 and histograms of the most relevant variables are given at the end of this section (Figures 4 to 18). The full results are included in Appendix 2.

At present there are no data describing the quality of minimally impaired lakes in Britain. To assess the chemical quality of the Lower Windrush lakes, therefore, water quality data from the study were compared with information on the chemical quality of minimally impaired (i.e. unpolluted), standing waters derived from three main sources:

(i) For nutrients, the widely recognised OECD lake classification, which is an internationally recognised classification of lake nutrient status.

(ii) For other determinands, the PCTPR database of water chemistry from minimally impaired standing waters derived from the National Pond Survey, which includes water bodies up to 5 ha in area; these sites are generally as free from surface water pollutants as is possible in the UK landscape.

(iii) International standards defined by the US EPA and the European Inland Fisheries Advisory Commission (EIFAC).

3.1.2.2 Results

Water quality in the Lower Windrush Valley gravel pits is generally very good with low, or undetectable, concentrations of most chemical determinands regarded as indicative of water pollution.

The gravel pits were circumneutral to alkaline (Figure 4) and moderately solute-rich, with conductivity ranging from 171 to 653 µS/cm (Figure 5). This conductivity range was similar to that for 15 minimally impaired small lakes investigated for the Environment Agency PSYM project (Biggs *et al*., 1999). The water was soft on average (86 mg/l), and ranged from soft to slightly hard (Figure 6).

The suspended solids concentration was relatively low (mean 6.3 mg/l), but showed wide variation between sites, with a range from <3 mg/l to 34 mg/l (Figure 7). Although there are no specified minimally impaired levels for suspended sediments, generally EIFAC regards concentrations below 25 mg/l as unlikely to be injurious to fish.

In terms of nutrients, the lakes were generally of very good quality with the majority of sites (27) either mesotrophic or on the mesotrophic/eutrophic boundary (Figure 8, Table 3). Three sites had exceptionally low nutrient levels and were in the oligotrophic/ mesotrophic category. One site (Site 22) was clearly impaired in terms of nutrients, being classified as hypereutrophic. Concentrations of bio-available phosphorus (Soluble Reactive Phosphorus, SRP) were low, and at only four sites were concentrations above the detection limit of <0.004 µg/l (Figure 9). This reflects the fact that in unpolluted lakes normal phytoplankton growth takes up most bio-available phosphorus during the summer months, so that it cannot be detected in the water column.

Nitrogen concentrations were also generally well below the mean for minimally impaired standing water bodies (Figure 10 and 11). For Total Oxidised Nitrogen (TON), the mean concentration in the LWV lakes was 342 µg/l compared to 496 µg/l in minimally impaired ponds (Table 3). Only four of the pits had TON concentrations above 500 µg/l with only one site (Site 84) having a relatively high TON concentration of 1390 µg/l, which might be associated with significant impairment. Mean Total Nitrogen concentrations were also well below the mean for minimally impaired ponds. Chlorophyll a concentrations ranged from 1.0 to 34.5 (Figure 12).

Average concentrations of calcium, magnesium, potassium, sodium and chloride were generally comparable to those of the National Pond Survey data (Table 3, Figure 12-16). Of these chemical parameters, calcium and magnesium concentrations naturally vary according to the geology of the region in which the waterbody occurs and are not greatly modified by human activity. Calcium concentrations ranged from 17.1 mg/l in Pit 9 (Vauxhall Lake), to 121.0 mg/l in Pit 35 (Hardwick Lake) (Figure 12).

Magnesium, which is naturally present in base-rich waters and is also not normally regarded as a pollutant, was present in concentrations very similar to those seen in minimally impaired standing waters (Figure 13). The mean magnesium concentration in the lakes was 4.4 mg/l, significantly below the mean for minimally impaired NPS ponds of 8.7 mg/l.

Concentrations of potassium, sodium and chloride may vary as a result of human activity. Potassium, an essential plant nutrient, is an important component of agricultural fertilisers and probably leaches into freshwaters, although it is not clear whether this has any detrimental impact. In the present study potassium concentrations were generally similar to those seen in minimally impaired waterbodies, ranging from below the detection limit in Pit 36 to 8 mg/l in Pit 9 (Figure 16). Sodium and chloride concentrations were also similar to those seen in minimally impaired water bodies (Table 3). Elevated sodium concentrations can occur where road runoff enters waterbodies after de-icing but there is little evidence that this is occurring in the LWV gravel pits. One site, Pit 16 (Dix Pit), did have unusually high concentrations of sodium, chloride and potassium compared to the remainder of the sites. This may reflect the fact that Dix Pit has a landfill site and an industrial estate nearby. This site is also one of the oldest pits in the complex, perhaps indicating that there has been an accumulation of these elements over time.

Heavy metal concentrations were generally low in the gravel pits with copper, lead, nickel and zinc concentrations below the detection limits in all sites (Table 3). Iron concentrations ranged from 30 µg/l to 810 µg/l, all values being below the level (1000 µg/l) regarded by the US EPA as likely to cause biological effects (Figure18).

Overall, the relatively low nutrient concentrations in the lakes, combined with the generally low level of other pollutants, indicate that the complex has generally high water quality. This is the probably the single most important factor underpinning the value of the Lower Windrush Valley lakes, both as wildlife habitats and a public amenity.

As would be expected, gravel pits with high concentrations of algae in the water column tended to be more turbid, as shown by the strong correlation between chlorophyll a and suspended solids. Pits with higher chlorophyll a also tended to be relatively alkaline, and to have higher concentrations of nitrogen and phosphorus and of ions such as iron, sodium and chloride. The influence of summer phytoplankton growth on lake chemistry was also demonstrated by the negative correlation between chlorophyll a and concentrations of bio-available phosphorus (SRP).

Analysis of the correlations between physical and chemical environmental variables showed that gravel pits more intensively used for angling had significantly greater alkalinity, chlorophyll a, suspended solids and nitrogen concentrations. The older, shaded gravel pits also tended to have higher phosphorus, suspended solids and nitrogen concentrations.

Table 4 Lower Windrush Valley (LWV) water chemistry results compared with levels for minimally impaired waterbodies, including US EPA values for minimum concentrations causing observable biological effects.

Determinands	Measure	LWV	NPS	Minimum concentration causing biological effects
pH pH varies naturally over a wide range, and so values between 4.0-10.0 can be encountered in minimally impaired waters. Generally: - pH 1.0 to 5.9 acid water - pH 6.0 to 8.0 circumneutral water - pH 8.1 to 14.0 alkaline water	Median Mean	**8.1** **8.2** **n=40**	7.2 6.9 n=129	n/a
Conductivity (µS/cm) A measure of the overall quantity of dissolved substances (i.e. major ions such as calcium, sodium, potassium) in water.	Median Mean	**389 µS/cm** **382 µS/cm** **n=40**	241µS/cm 347µS/cm n=129	n/a
Alkalinity (mg/l CACO3) A measure of the buffering capacity of water. Alkalinity contributes to the hardness of water. Generally: - 0-50 mg/l Soft - 0-100 mg/l Moderately soft - 100-500 mg/l Slightly hard - 150-200 mg/l Moderately hard - 200-300 mg/l Hard - over 300 mg/ Very hard	Median Mean	**86 mg/l** **88 mg/l** **n=40**	85 mg/l 142 mg/l n=129	n/a
Suspended sediments (mg/l)	Median Mean	**6.3 mg/l** **3.3 mg/l** **n=40**	9.3 mg/l 19.1 mg/l n=103	25 mg/l (Source: EIFAC, 1964)
Calcium (Ca, mg/l) Calcium concentrations vary naturally over a wide range. Variations in calcium concentration are not normally due to pollution.	Median Mean	**57.8 mg/l** **58.2 mg/l** **n=40**	41.5 mg/l 70.6 mg/l n=77	n/a
Potassium (K, mg/l)	Median Mean	**3.1 mg/l** **2.8 mg/l** **n=40**	2.7 mg/l 4.1 mg/l n=129	n/a
Sodium (Na, mg/l)	Median Mean	**14.4 mg/l** **15.6 mg/l** **n=40**	14.6 mg/l 23.5 mg/l n=68	n/a
Chloride (Cl, mg/l)	Median Mean	**22.7 mg/l** **26.6 mg/l** **n=40**	26.0 mg/l 32.5 mg/l n=96	n/a

Table 4 (continued) Lower Windrush Valley (LWV) water chemistry results compared with levels for minimally impaired waterbodies, including US EPA values for minimum concentrations causing observable biological effects.

Determinands	Measure	LWV	NPS	Minimum concentration causing biological effects
Soluble Reactive Phosphorus (PO_4-P, µg/l) A measure of the phosphorus available for plant growth.	Median Mean	**5µg/l** **7 µg/l** **n=4**	5 µg/l 69 µg/l n=162	n/a
Total Phosphorus (P, µg/l) Trophic classification system (OECD, 1982): 0-12 µg/l Oligo/Mesotrophic 12-25 µg/l Mesotrophic 25-40 µg/l Meso/Eutrophic 40-100 µg/l Eutrophic 100-400 µg/l Hypertrophic >400 µg/l Strongly hypertrophic	Median Mean	**37 µg/l** **30 µg/l** **n=40**	77 µg/l 190 µg/l n=49	n/a
Total Oxidised Nitrogen (N, µg/l) A measure of the nitrogen available for plant growth (nitrate and nitrite).	Median Mean	**305 µg/l** **342 µg/l** **n=40**	13 µg/l 496 µg/l n=158	n/a
Nitrogen Kjeldahl (N, µg/l)	Median Mean	**755 µg/l** **814 µg/l** **n=40**	No data available	n/a
Total Nitrogen (N, mg/l)	Median Mean	**1.1 mg/l** **1.6 mg/l** **n=40**	1.5 mg/l 2.9 mg/l n=45	n/a
Chlorophyll a (µg/l)	Median Man	**6.6 µg/l** **8.8 µg/l** **n=40**	No data available	n/a
Copper (Cu, µg/l)	Median Mean	**All value** **<2.5µg/l** **n=40**	0.02 µg/l 5.5 µg/l n=46	1.1 µg/l
Zinc (Zn, µg/l)	Median Mean	**All values** **<5 µg/l** **n=40**	80.1 µg/l 97.0 µg/l n=107	30 µg/l
Iron (Fe, µg/l)	Median Mean	**140 µg/l** **199µg/l** **n=40**	221 µg/l 836 µg/l n=96	1000 µg/l
Lead (Pb, µg/l)	Median Mean	**All values** **<2 µg/l** **n=40**	15.7 µg/l 20.6 µg/l n=96	12.26 µg/l
Magnesium (Mg, mg/l)	Median Mean	**4.2 mg/l** **4.4 mg/l** **n=40**	4.1mg/l 8.7 mg/l n=77	n/a
Nickel (Ni, µg/l)	Median Mean	**All value** **<5 µg/l** **n=40**	0.01µg/l 0.02 µg/l n=18	n/a

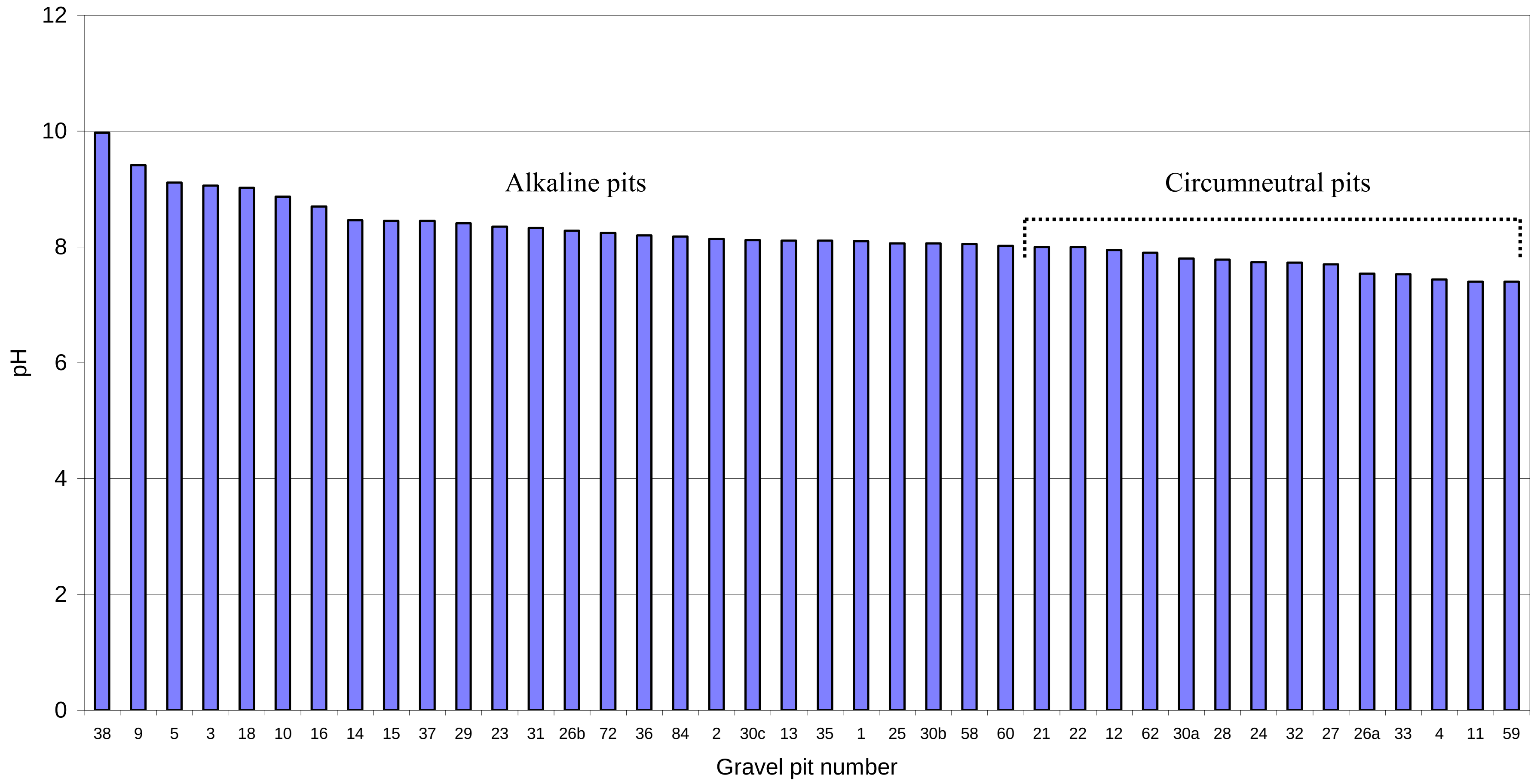


Figure 4 pH values for the LWV gravel pits

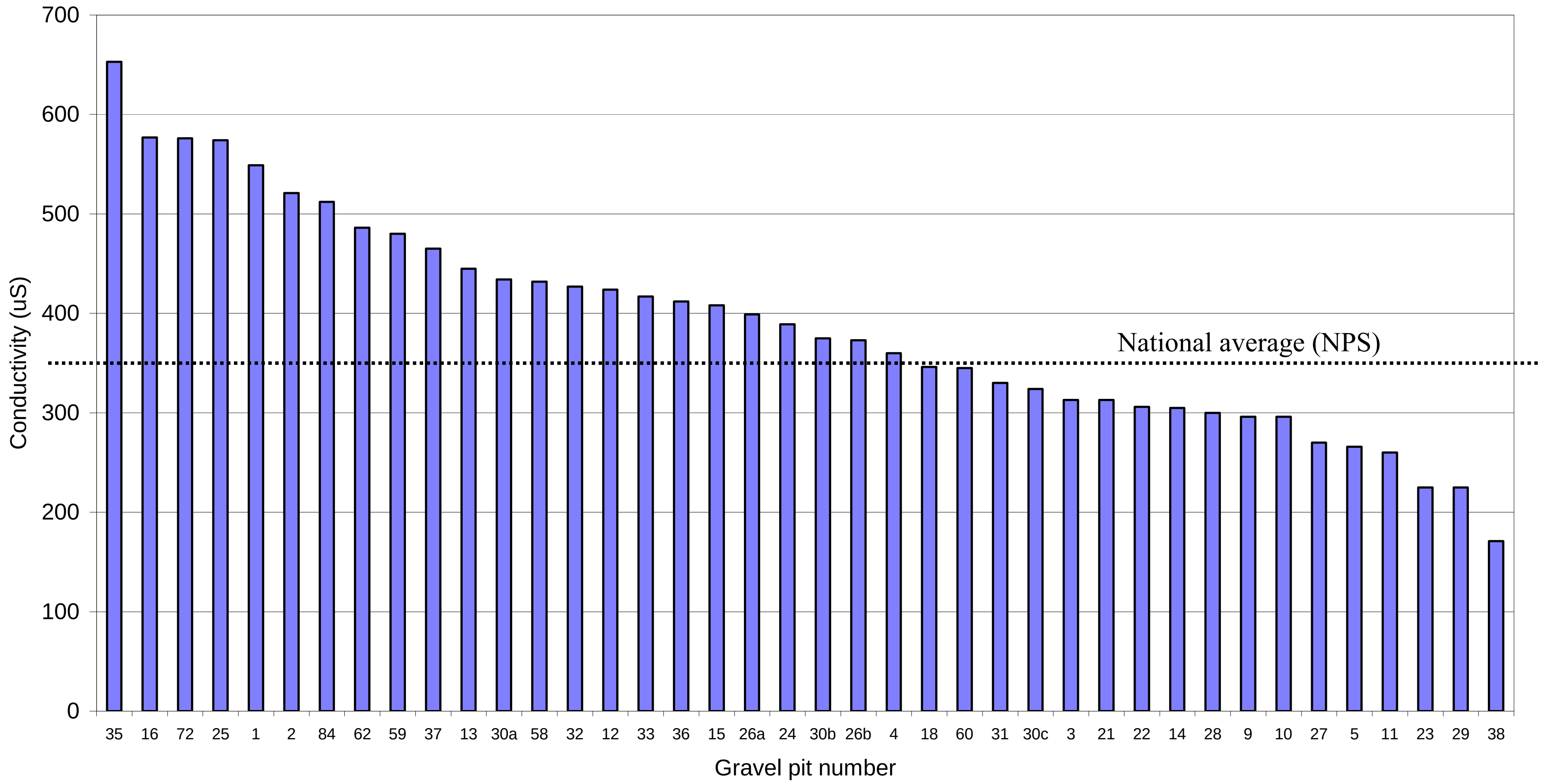


Figure 5 Conductivity values for the LWV gravel pits

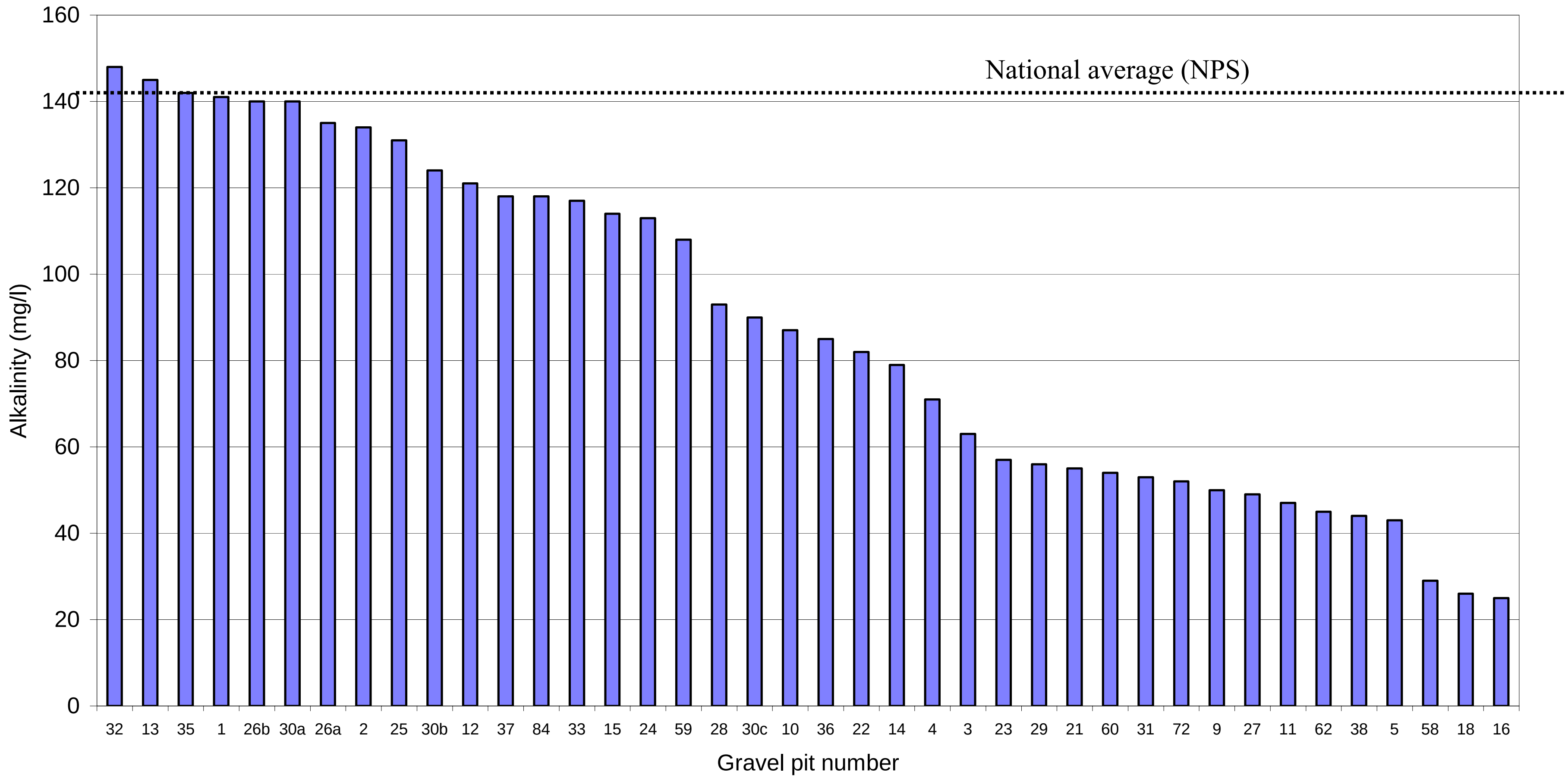


Figure 6 Alkalinity values for the LWV gravel pits

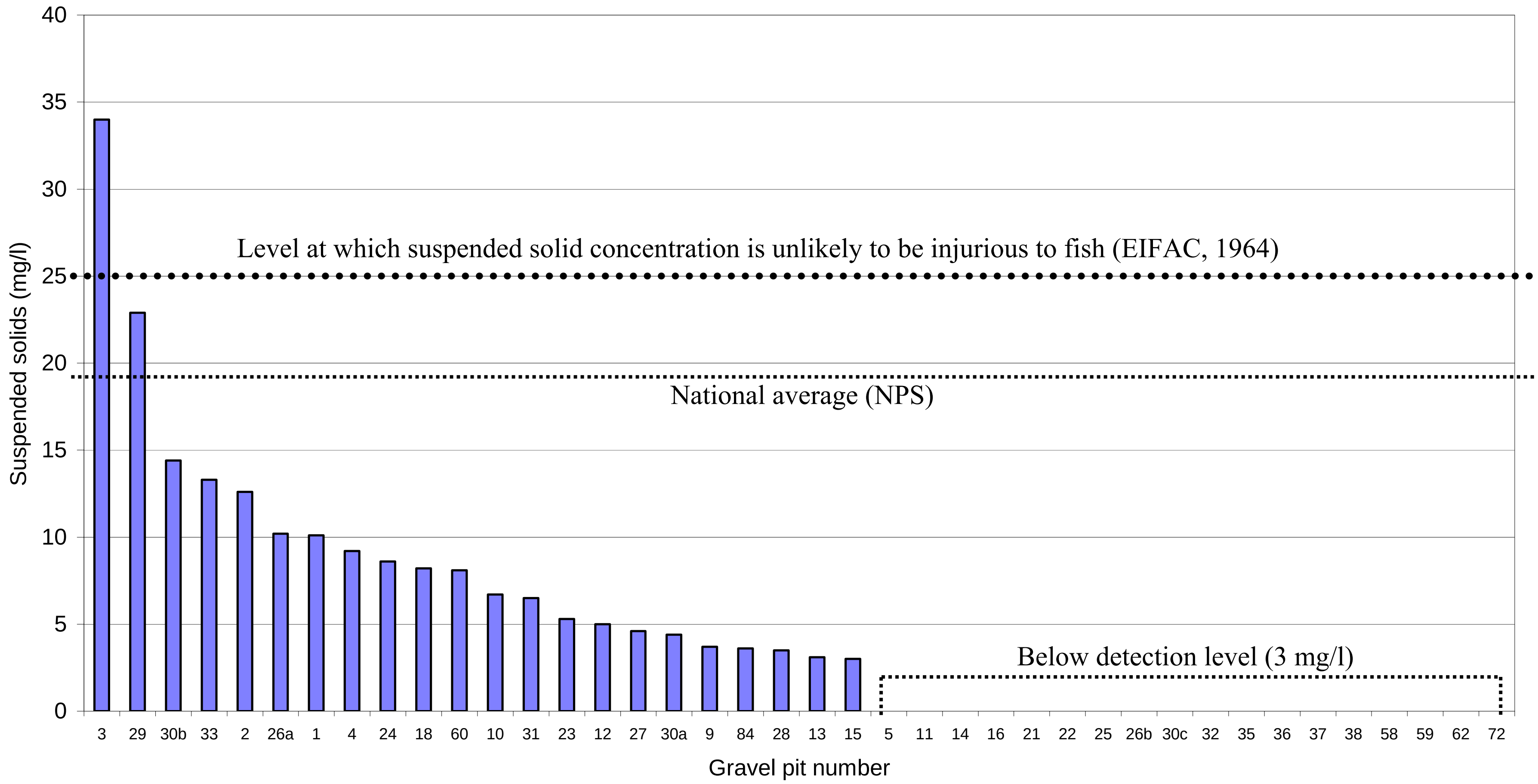


Figure 7 Suspended solids concentrations for the LWV gravel pits

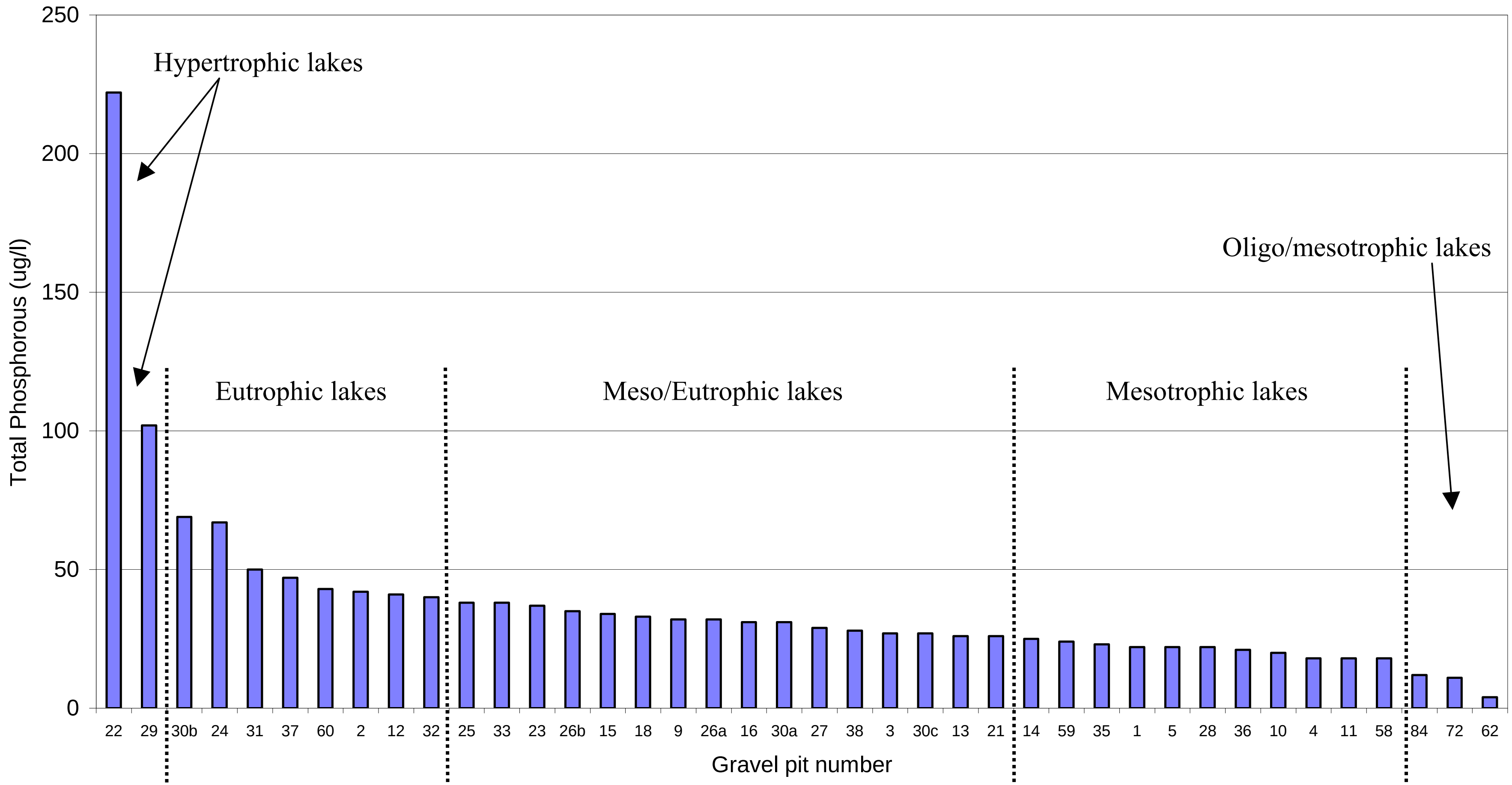


Figure 8 Total Phosphorus concentrations for the LWV gravel pits

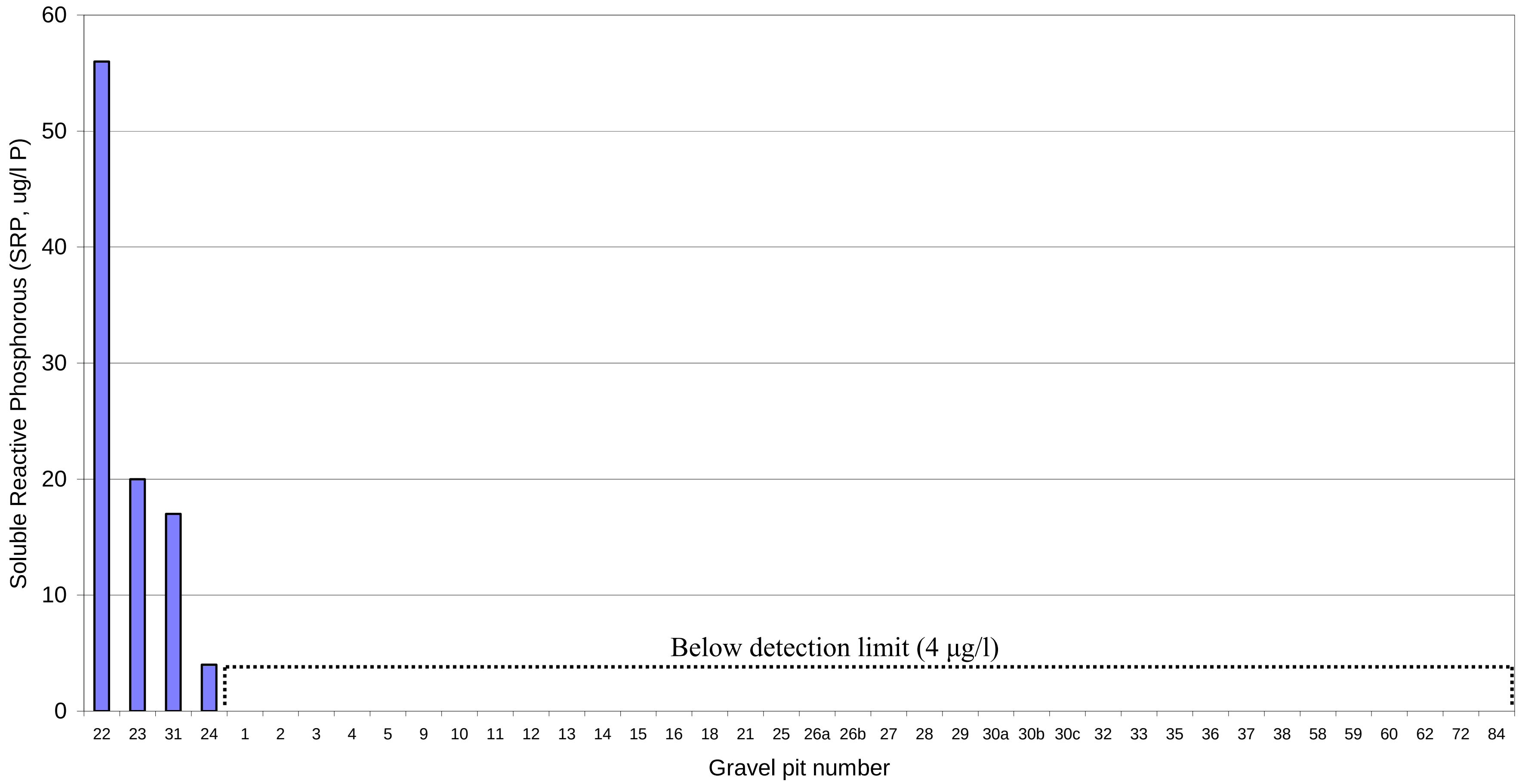


Figure 9 Soluble Reactive Phosphorus (SRP) concentrations for the LWV gravel pits

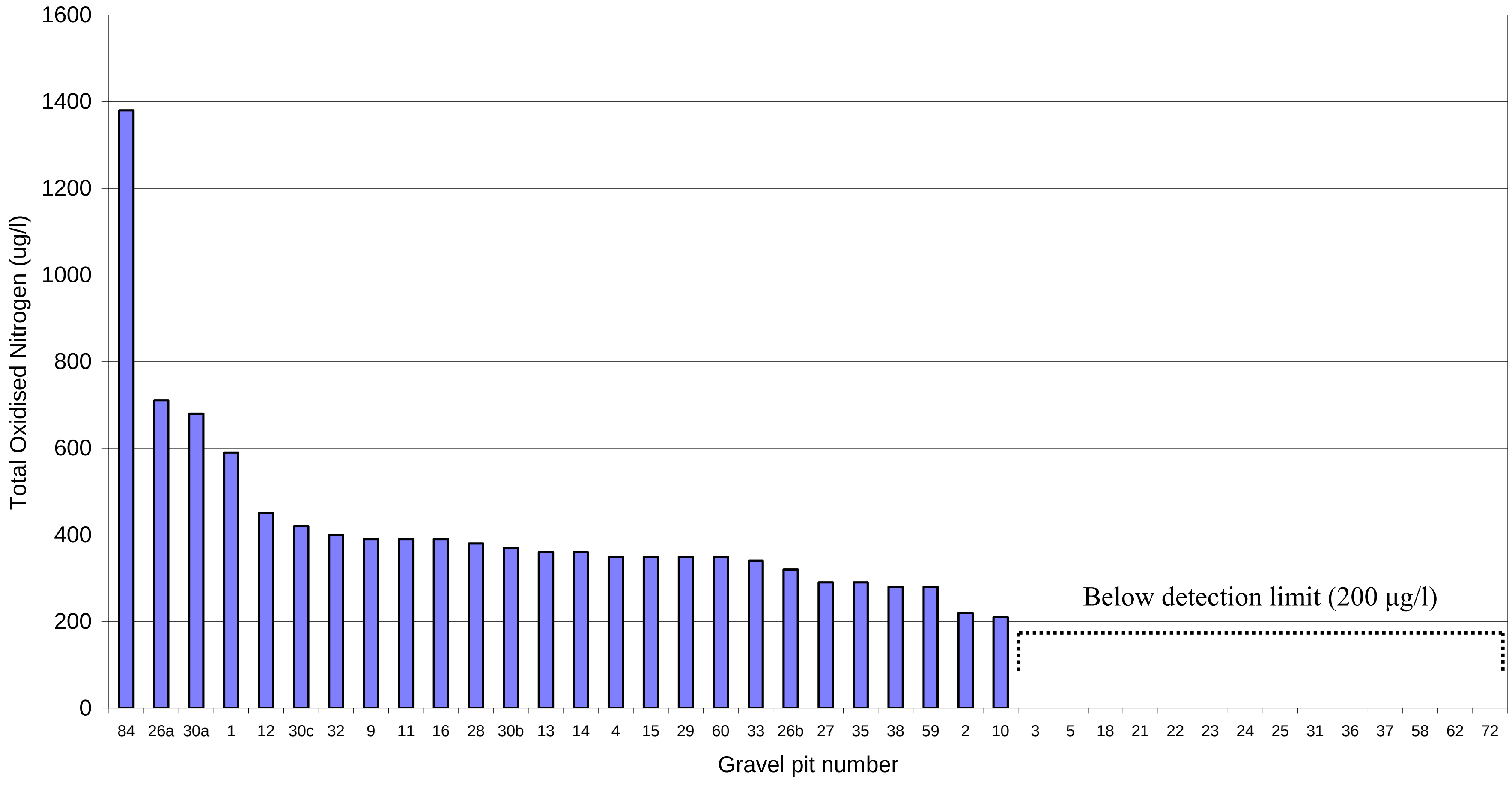


Figure 10 Total Oxydised Nitrogen (TON) concentrations for the LWV gravel pits

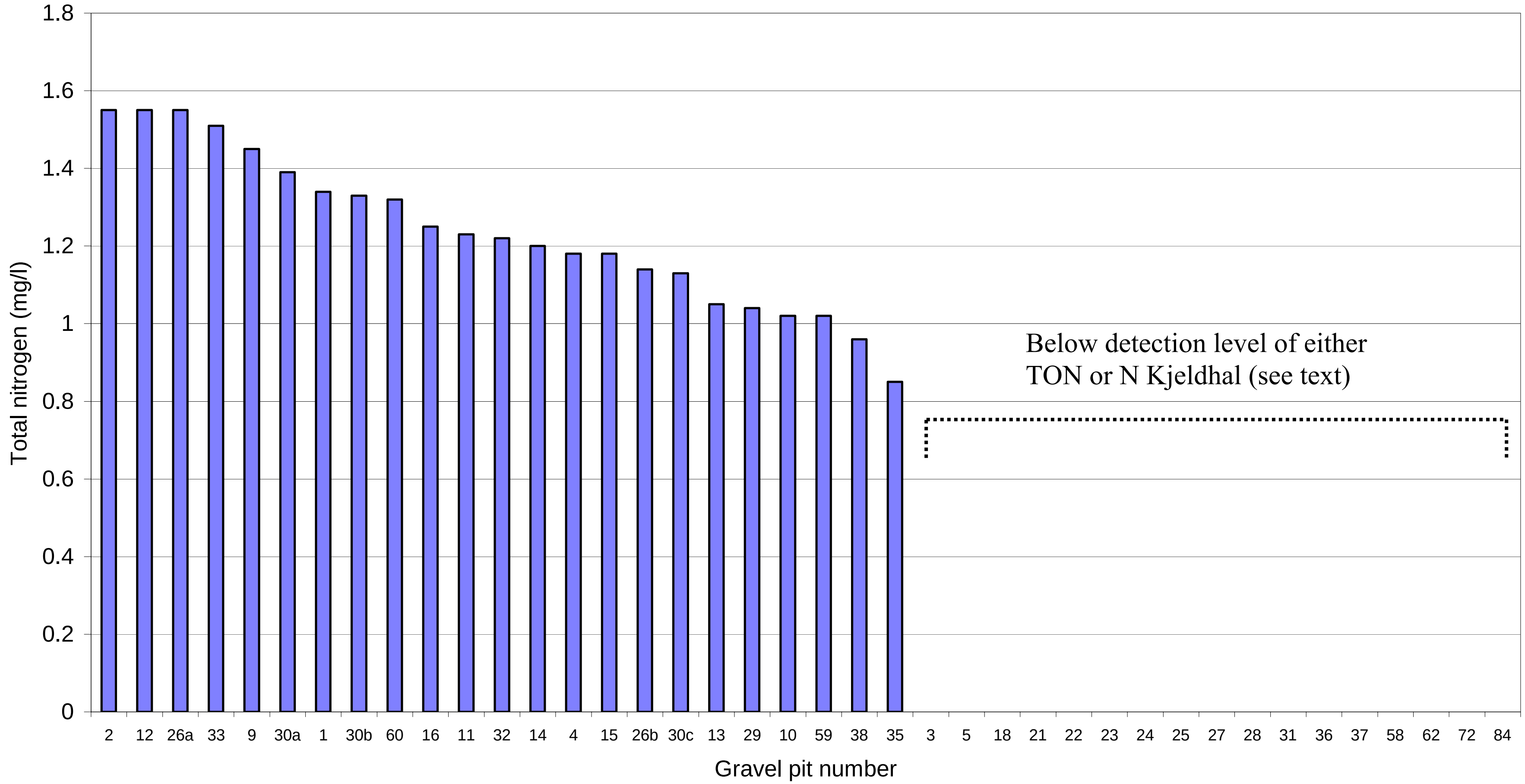


Figure 11 Total Nitrogen concentrations for the LWV gravel pits

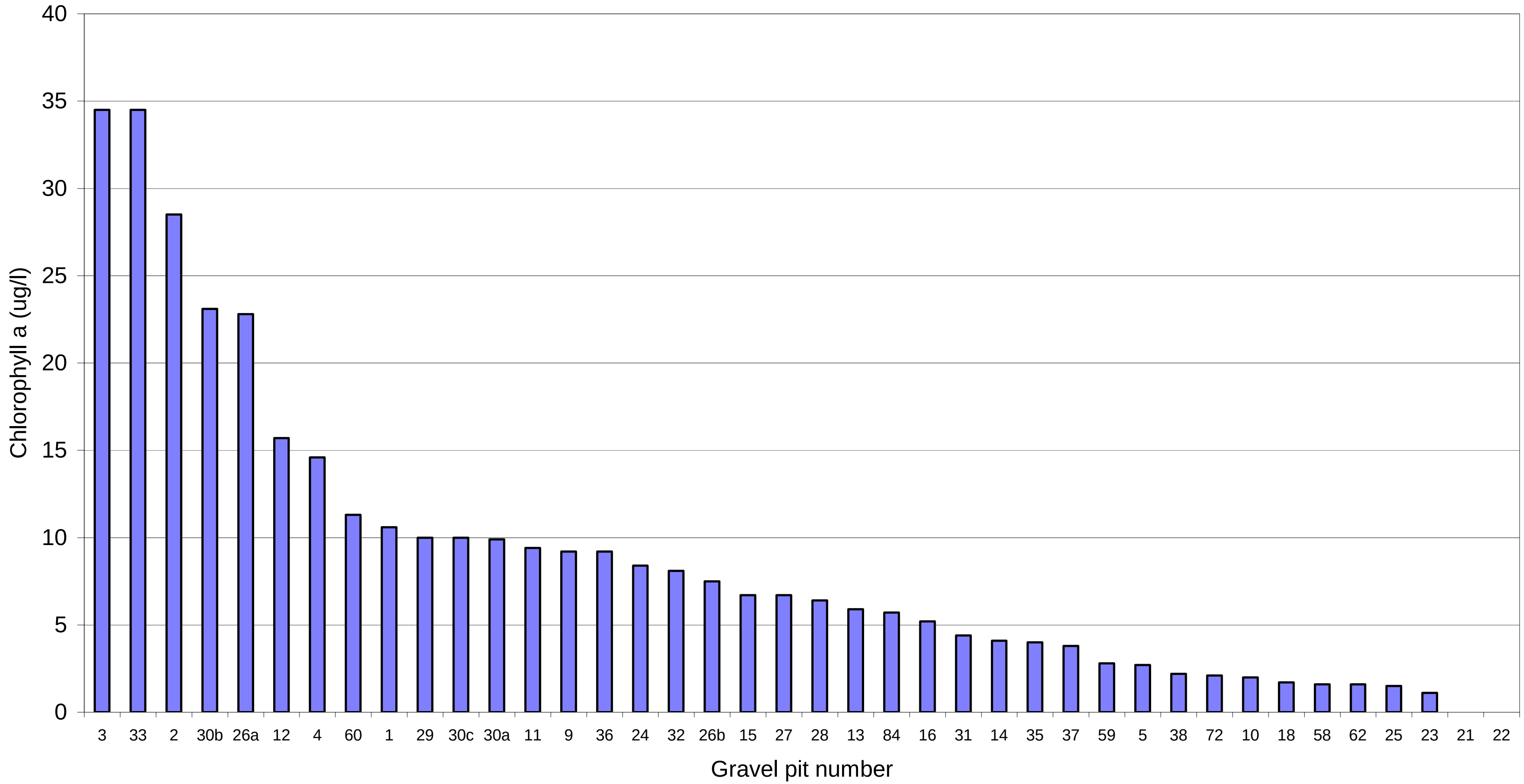


Figure 12 Chlorophyll a concentrations for the LWV gravel pits

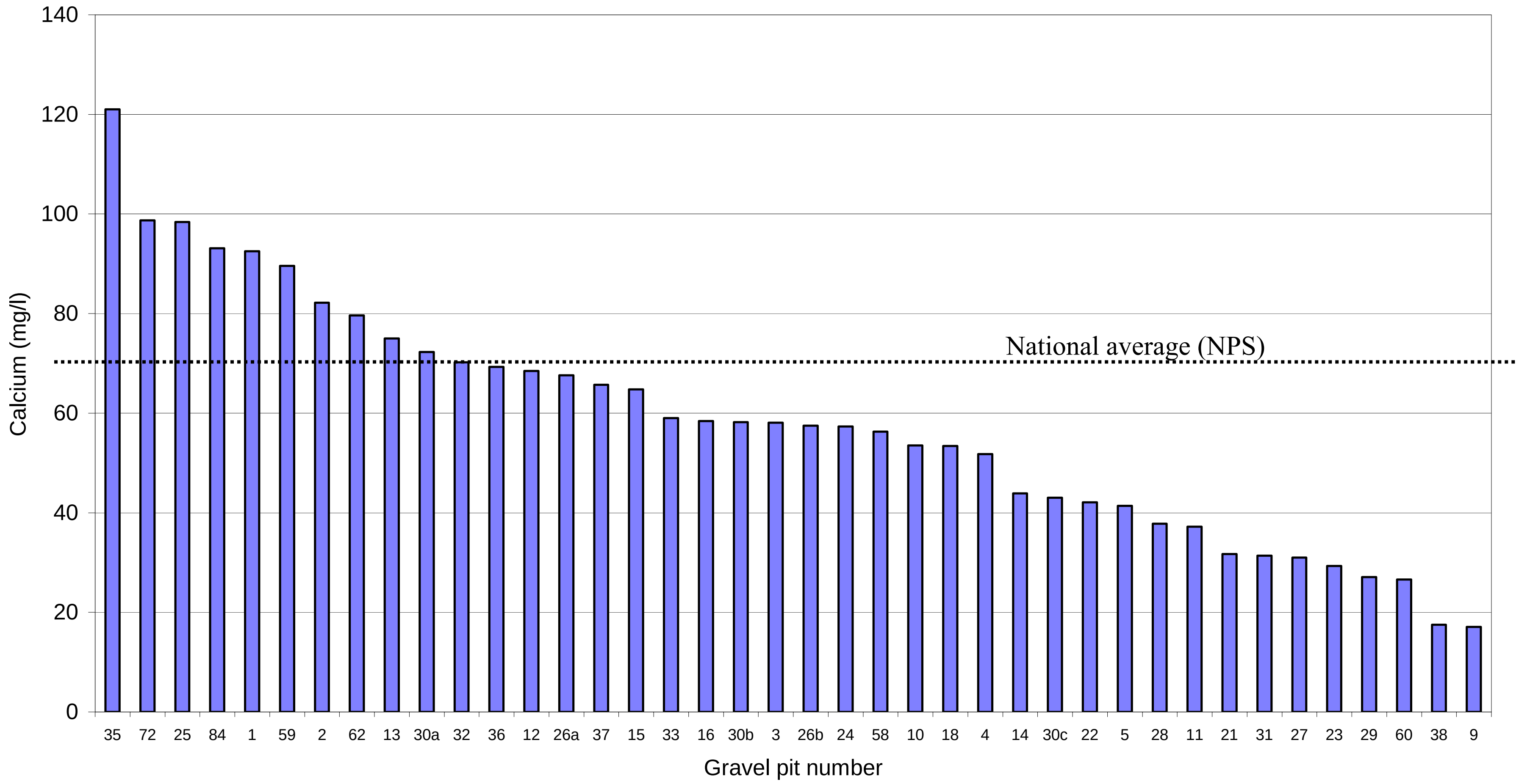


Figure 13 Calcium concentrations for the LWV gravel pits

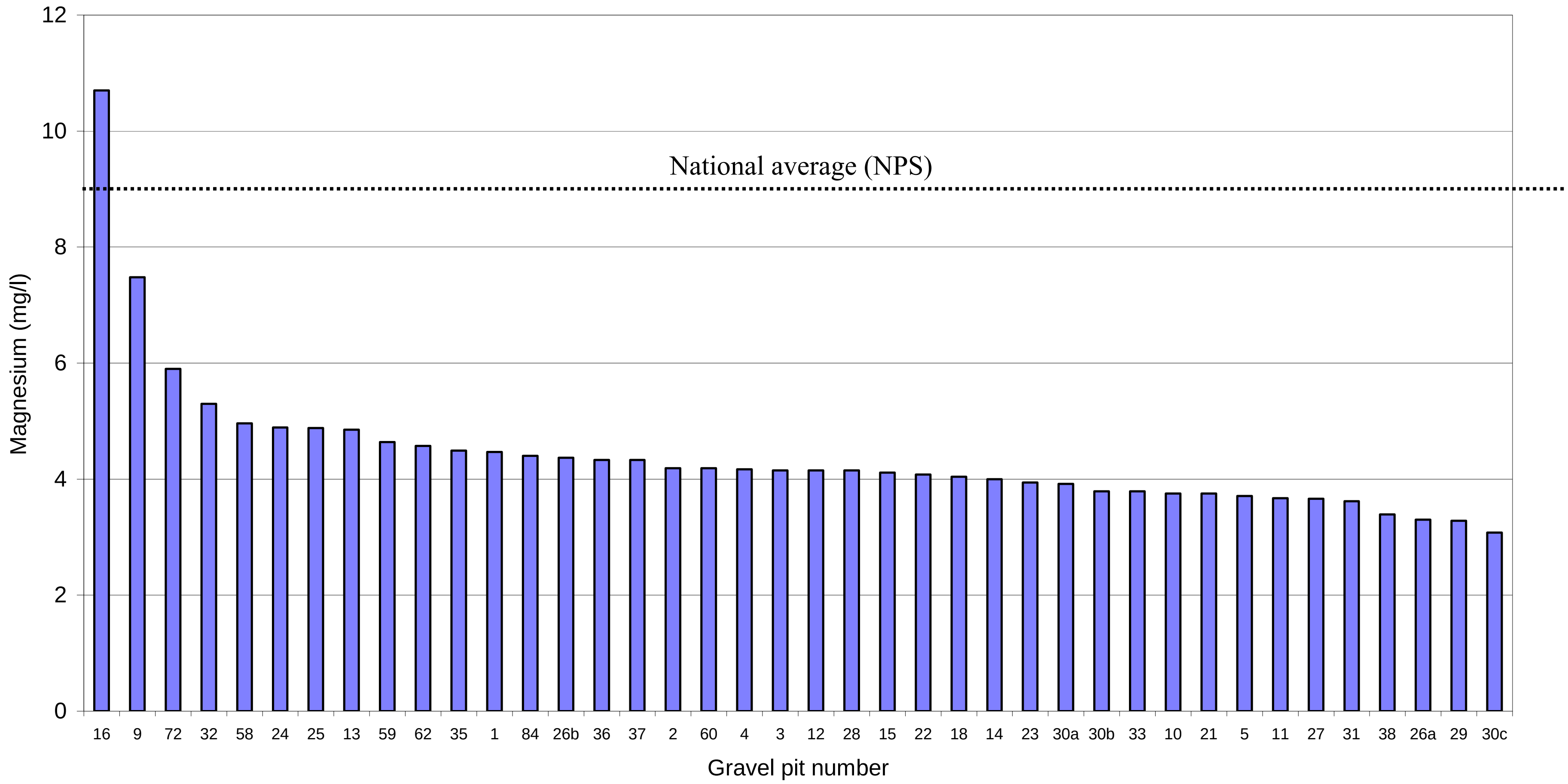


Figure 14 Magnesium concentrations for the LWV gravel pits

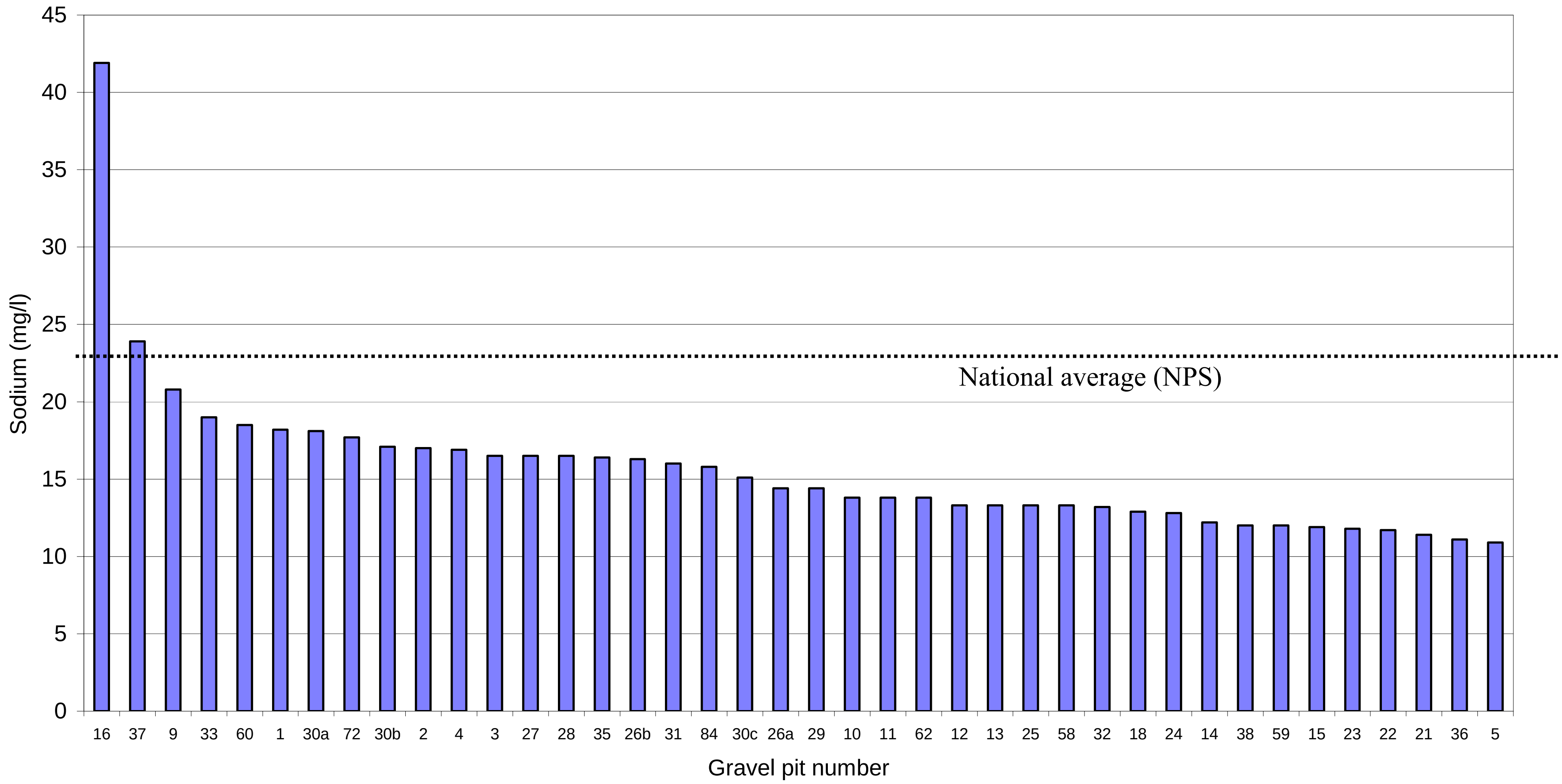


Figure 15 Sodium concentrations for the LWV gravel pits

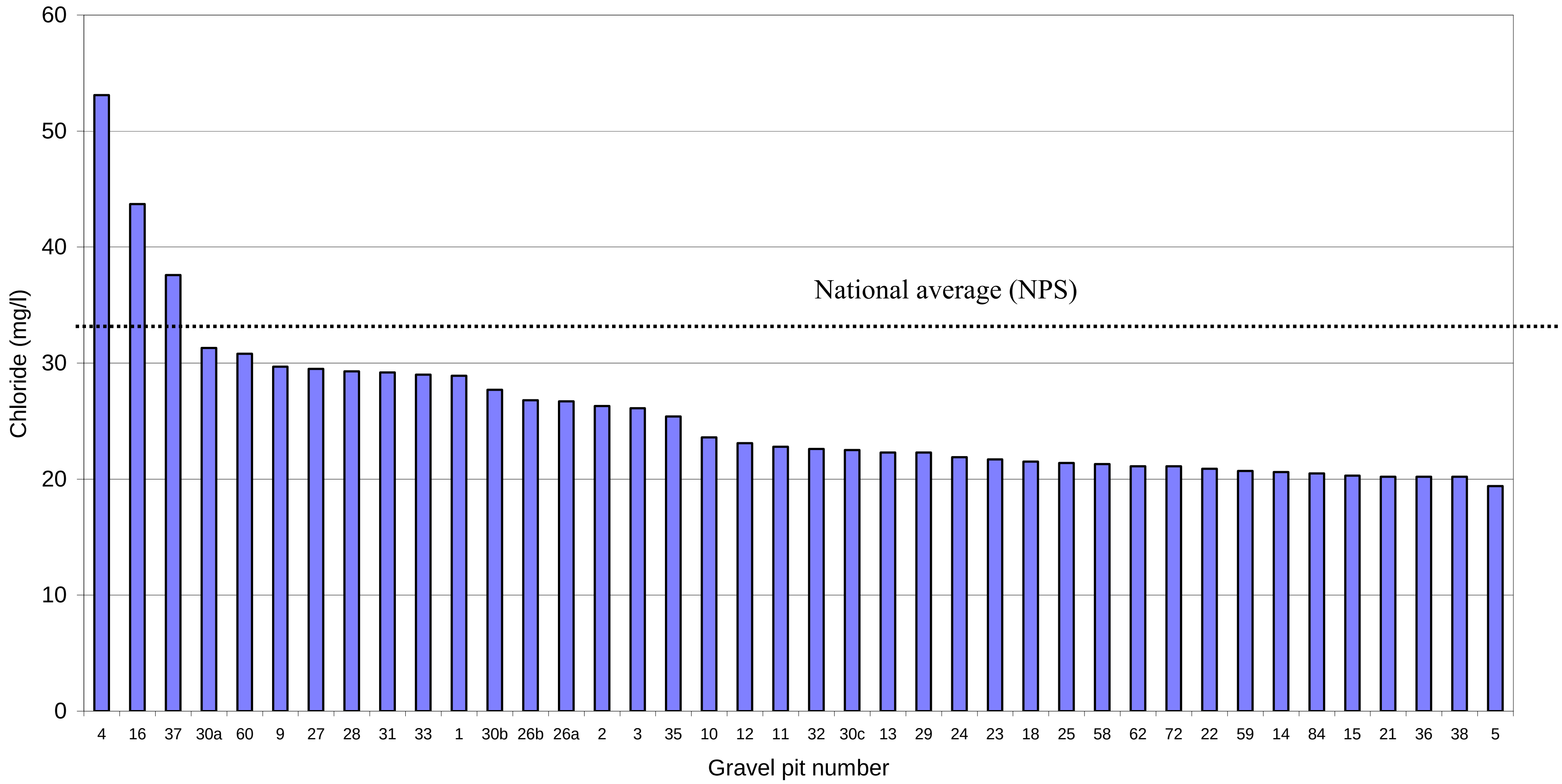


Figure 16 Chloride concentrations for the LWV gravel pits

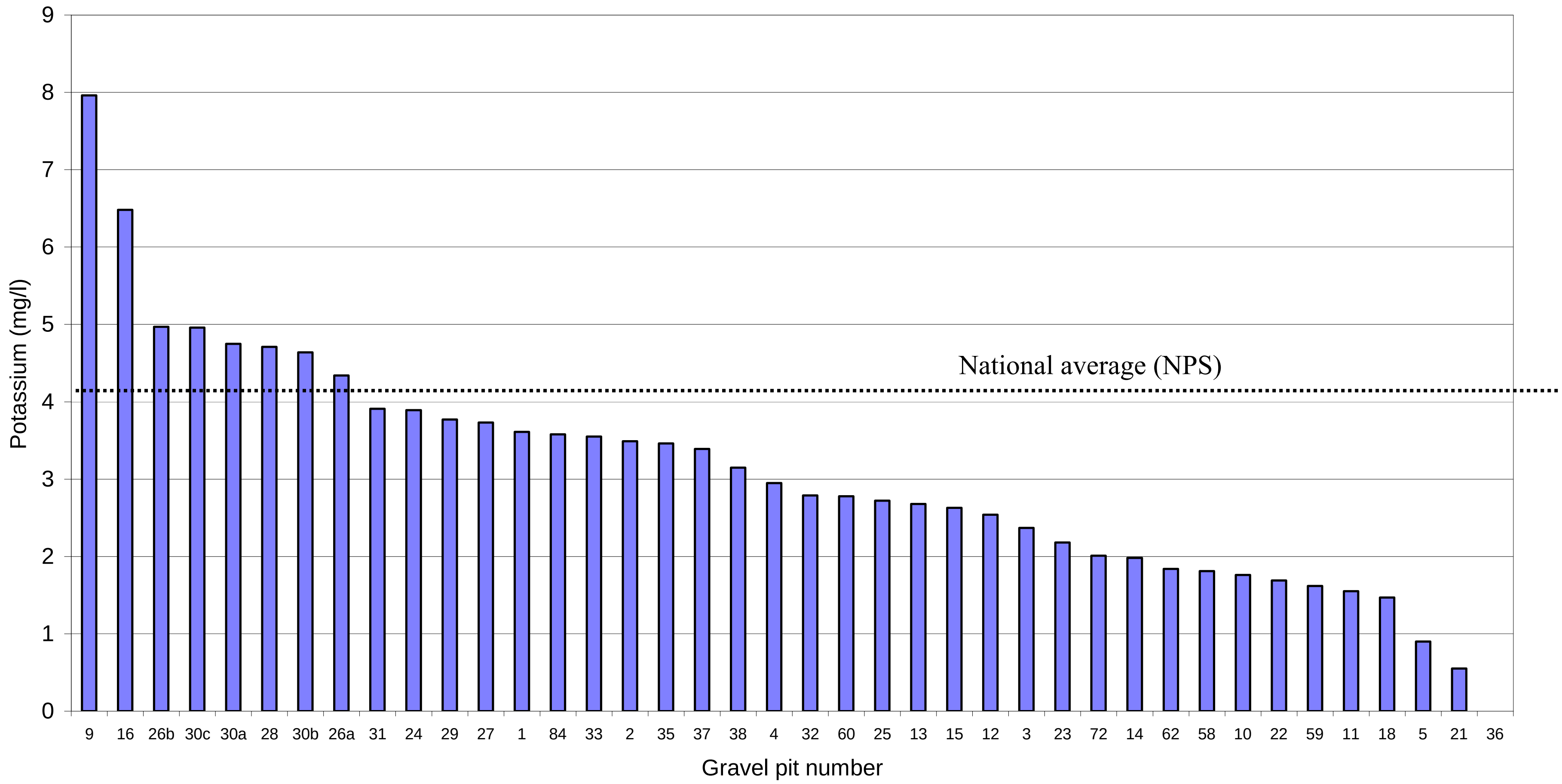


Figure 17 Potassium concentrations for the LWV gravel pits

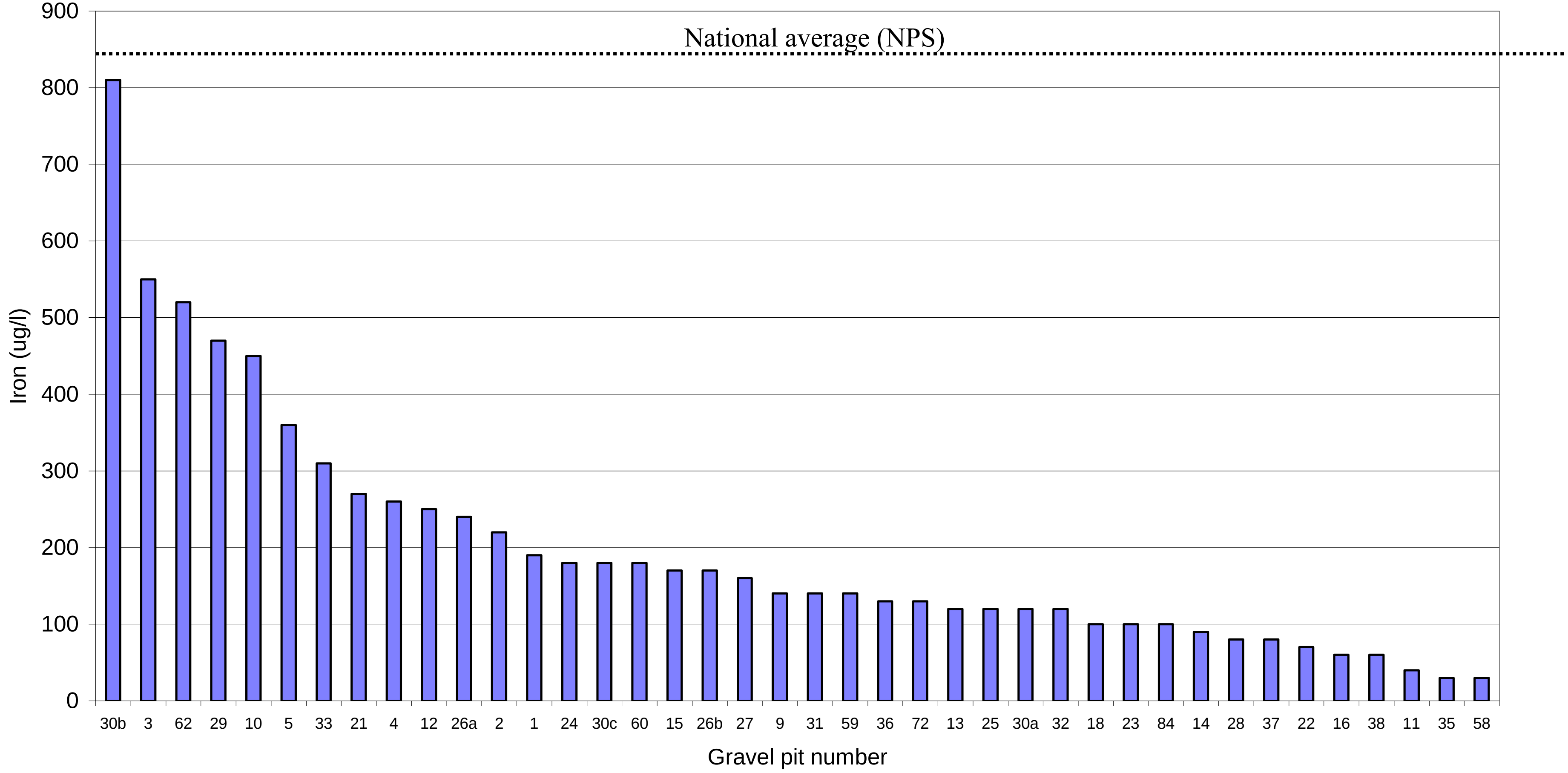


Figure 18 Iron concentrations for the LWV gravel pits

3.2 Wetland plants

3.2.1 National context

The plant assemblages recorded from the gravel pits were classified using the recently revised JNCC classification of British lakes (Duigan *et al*., 2004). It should be noted that this classification is based on the submerged and floating-leaved aquatic plant community alone (i.e. excluding marginal and emergent plants). Using this methodology the LWV lakes were classified as "Group I: widespread, mostly moderately large, base-rich lowland lakes, with *Chara* spp., *Myriophyllum spicatum* and a diversity of *Potamogeton* species". The Cotswold Water Park lakes also fall into this group.

3.2.2 Wetland plant species recorded in the survey

3.2.2.1 All wetland plants

The Lower Windrush Valley gravel pits, as a whole, supported a very diverse plant community (Appendix 2). A total of 122 wetland plant species were recorded in the 40 gravel pits surveyed. This represents approximately 35% of the wetland plant species recorded in Britain.

3.2.2.2 Aquatic plants

Of the 122 wetland plants recorded in the current survey, 33 were aquatic species: nine floating-leaved species and 24 submerged species (Appendix 2). The most common submerged species, which occurred in over 70% of the gravel pits surveyed, were Nuttall's Waterweed (*Elodea nuttallii*), Spike Water-milfoil (*Myriophyllum spicatum*) and Fennel Pondweed (*Potamogeton pectinatus*). Three other submerged species of *Potamogeton* were recorded: Small Pondweed (*Potamogeton berchtoldii*), Curled Pondweed (*Potamogeton crispus*), and Lesser Pondweed (*Potamogeton pusillus*). A total of eight stonewort species were found in the survey. Of these, two species were particularly widespread, occurring in more than half of the gravel pits surveyed: Opposite Stonewort (*Chara contraria*) and Delicate Stonewort (*Chara virgata*). The most common floating-leaved species recorded were Amphibious Bistort (*Persicaria amphibian*) and White Water-lily (*Nymphea alba*). The latter is likely to have been planted at some sites for its ornamental value (see Section 3.2.4.1).

These results are similar to those of a wetland plant survey of 51 lakes in the Cotswold Water Park (CWP), which reported a total of 31 aquatic species, of which eight were stoneworts (Bell, 1995). The main difference between the LWV and the CWP is in the distribution of wetland plant species, with some more widespread in the LWV and others in the Cotswold Water Park. For example, the Nationally Scarce species Lesser Bearded Stonewort (*Chara curta*) occurred in two gravel pits in the LWV but is frequent in the Costwold Water Park (Nick Stewart, pers. com.). In contrast, Rough Stonewort (*Chara aspera*) and Opposite Stonewort (*Chara contraria*), which are quite widespread in the LWV gravel pits, are more uncommon in the Cotswold Water Park (Nick Stewart, pers. com.).

3.2.2.3 Emergent plants

A total of 88 emergent plant species were recorded in the current survey (Appendix 2). The most commonly occurring species were Great Willowherb (*Epilobium hirsutum*), Hard Rush (*Juncus inflexus*), Gipsywort (*Lycopus europeus*), Water Mint (*Mentha aquatica*) and Common Bulrush (*Typha latifolia*) which were each recorded in over 90% of the gravel pits (Appendix 2). Eight species of sedge and eight species of rush were recorded. The most widespread sedges were Hairy Sedge (*Carex hirta*), False Fox-sedge (*C. otrubae*) and Greater Pond-sedge (*C. riparia*). Hard Rush (*Juncus inflexus*), Soft Rush (*J. effusus*) and Articulated Rush (*J. articulatus*) were the most commonly recorded rush species. The emergent plants in the LWV were similar to those of the Cotswold Water Park as reported by Bell (1995). Direct comparison of the emergent plants in the two areas is not possible because the two studies used different plant recording lists as the basis for surveys.

3.2.2.4 Non-native species

In the current survey, eight non-native wetland plant species were recorded in the LWV gravel pits (Table 5). The most widespread of these species was Nuttall's Waterweed (*E. nuttallii*), which was recorded in 85% of the sites surveyed. This submerged aquatic plant has been established in Britain for over 50 years and is now widespread in the wild (Preston *et al*., 2002). Nuttall's Waterweed can form large stands, out-competing native species, and is relatively tolerant of high nutrients status and disturbance. Nuttall's Waterweed is often regarded as a nuisance by fishermen, and there is anecdotal evidence to suggest that herbicides are applied annually or bi-annually in some LWV fishing lakes to control its spread.

Perhaps of greater concern, from a wildlife perspective, was the presence of two other invasive species, both of which are known to form dense stands that can out-compete and exclude other plant species. These were New Zealand Pigmyweed (*Crassula helmsii*) and Indian Balsam (*Impatiens glandulifera*). New Zealand Pigmyweed was recorded in three gravel pits (Pit 5 Darlow Water, Pit 38 Shifford Lake, and Pit 60 Standlake Common Nature Reserve). This species is versatile and can grow in all areas of a water body, from deep water to upper bank areas that dry out in the summer. In addition, New Zealand Pigmyweed is extremely difficult to control and readily spreads from plant fragments, which reduces the potential for mechanical removal. Indian Balsam (*I. glandulifera*) was recorded from one gravel pit (Pit 3 Hardwick Park). This species is the tallest annual plant in Britain (Environment Agency, 2003) and tends to rapidly grow into dense marginal stands, which can shade out native plants. Other non-native species were only recorded in a small number of lakes and currently, at least, are of lesser concern.

Table 5 Non-native wetland plant species in 40 LWV gravel pits

Latin Name	English Name	No. of occurrence
Acorus calamus	Sweet-flag	3
Crassula helmsii	New Zealand Pigmyweed	3
Elodea canadensis	Canadian Waterweed	4
Elodea nuttallii	Nuttall's Waterweed	34
Epilobium ciliatum	American Willowherb	3
Impatiens glandulifera	Indian Balsam	1
Lagarosiphon major	Curly Waterweed	2
Lemna minuta	Least Duckweed	2

3.2.3 Species richness of individual gravel pits

3.2.3.1 All wetland plants

Typically, individual lakes in the LWV complex supported rich wetland plant communities. On average, 35.7 ± 7.7 plant species were recorded per pit, with a range from 20 to 52 species (Figure 19). At a national level, this is towards the upper range of lake species richness. Thus, a review of lake biodiversity in the UK agricultural landscape, derived from data used to develop the JNCC lake classification (Duigan *et al.* 2004), reported averages from 20 to 40 wetland plant species per lake according to landscape type (Figure 20; PCTPR, Cranfield University and ADAS 2003). Regionally, the LWV lakes were slightly richer than those surveyed in the Datchet-Chertsey complex (see Section 2.6), which supported 31.8 species on average, with a range from 14 to 41 species per site (Pond Action, 1991).

In terms of individual gravel pits, the richest lake in the LWV was Pit 37 (Witney Lake), which supported 52 species (Figure 19). Other gravel pits with a particularly high number of species recorded in the current survey were Pit 3 (Hardwick Park), Pit 12 (Oxlease Lake), Pit 5 (Darlow Water), Pit 59 (Gill Mill) and Pit 36 (Brasenose) (Map 4). Generally, lakes which supported a diverse wetland plant community overall were rich in both aquatic and emergent species (correlations coefficients in Appendix 3).

3.2.3.2 Aquatic plants

The LWV lakes aquatic plant community supported an average of 6.4 ± 2.8 species, with the number in individual pits ranging from two to 14 species. Nationally, the average number of aquatic plants in the LWV was lower than that given in the JNCC lake classification for Group I, which was 9.1 ± 4.8 (Duigan *et al*., 2004). However, the mean size of lakes in the JNCC Group 1 was 23.8 ha, compared to 8.7 in the LWV, and the JNCC lakes included sites with surface areas of up to 1400 ha. The largest lake in the LWV is only 35 ha (No 16, Dix Pit). The difference in mean richness is, probably, therefore simply a reflection of the well-known species area effect and not indicative of systematic differences in lake quality.

Compared to other southern gravel pit lake complexes, the LWV gravel pits had similar aquatic plant richness to lakes in (i) the Cotswold Water Park, which supported 5.1 species per site on average (Bell, 1995), and (ii) the Datchet-Chertsey complex, which supported an average species richness of 7.2, and a range of three to 12 species (Pond Action, 1991).

In term of individual lakes, Witney Lake (Pit 37) supported the greatest number of aquatic species (14 species). Other lakes rich in aquatic species included Pit 3 (Hardwick Park), Pit 16 (Dix Pit), Pit 5 (Darlow Water), Pit 12 (Oxlease Lake) and Pit 18 (Stoneacre Lake) (Map 5). These lakes also tended to be rich in stonewort species (Map 6).

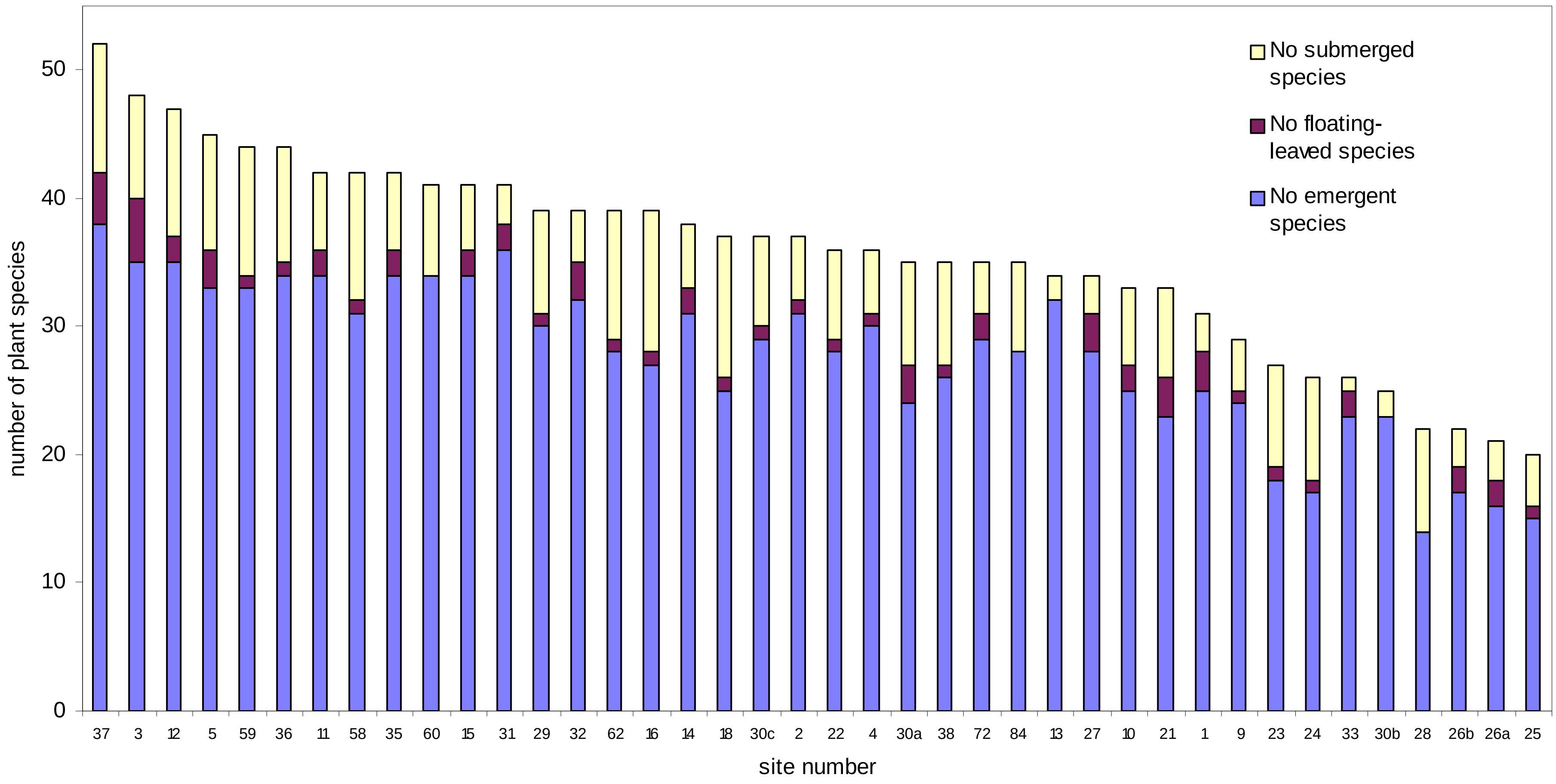
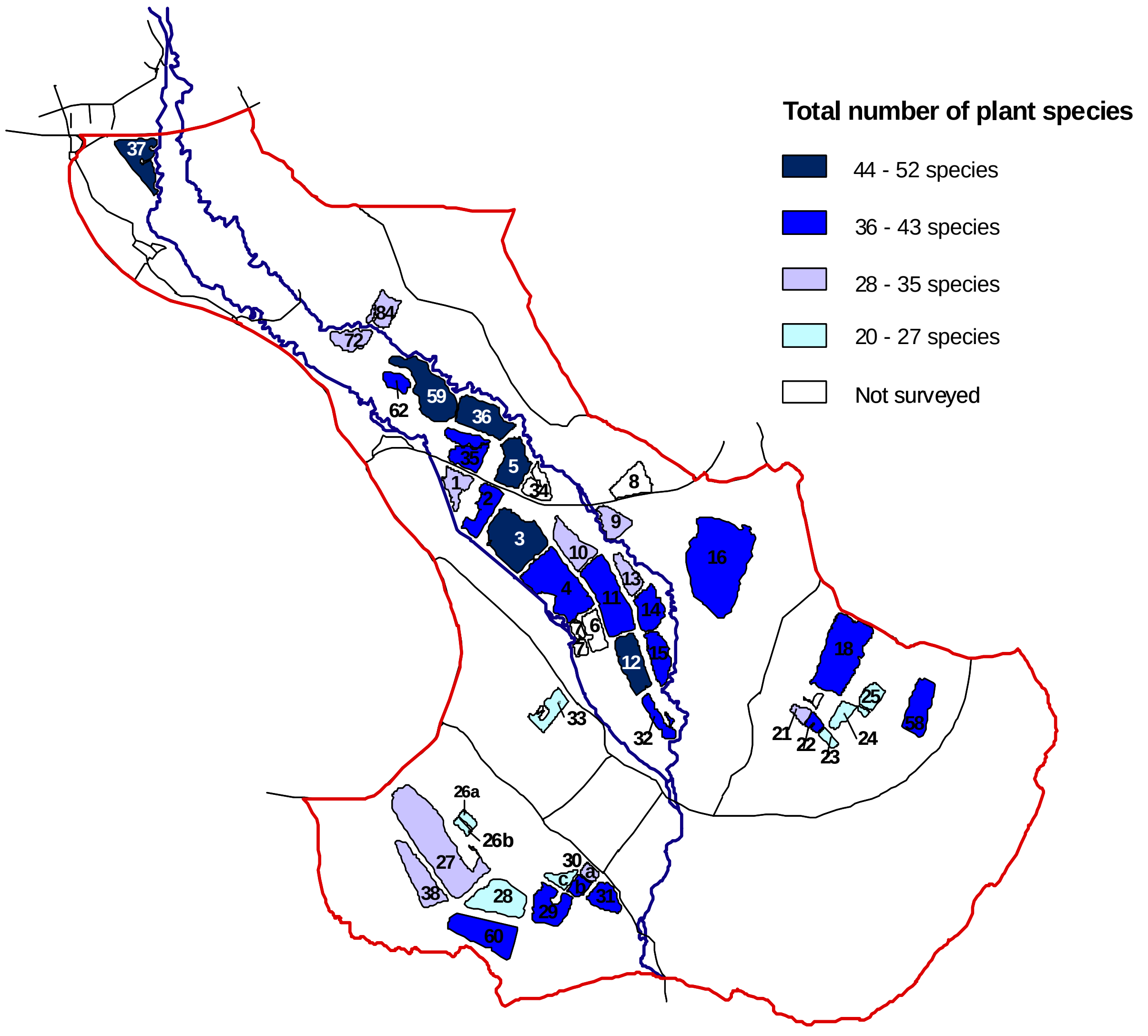


Figure 19 Number of wetland plant species in the LWV gravel pits



Map 4 Wetland plant species diversity in the LWV gravel pits

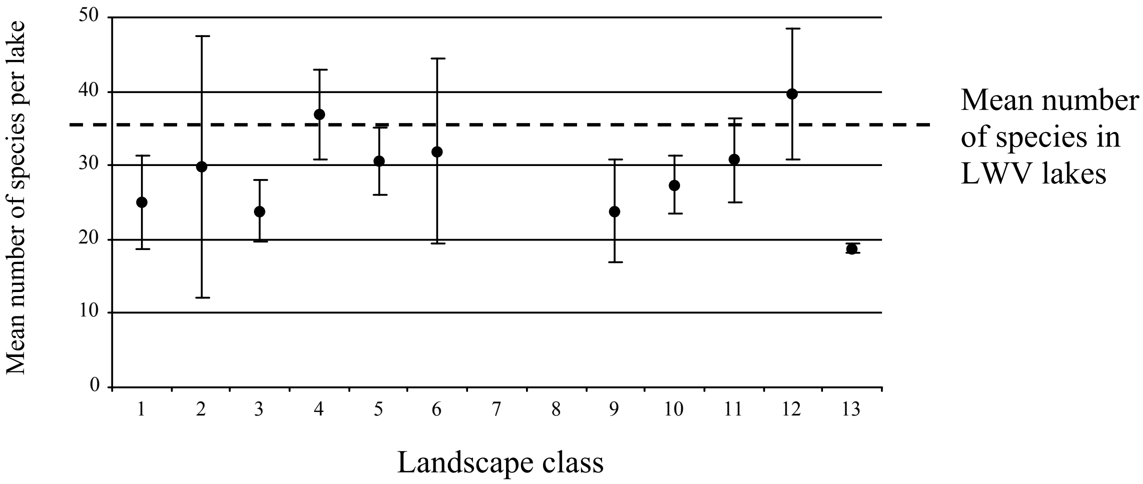
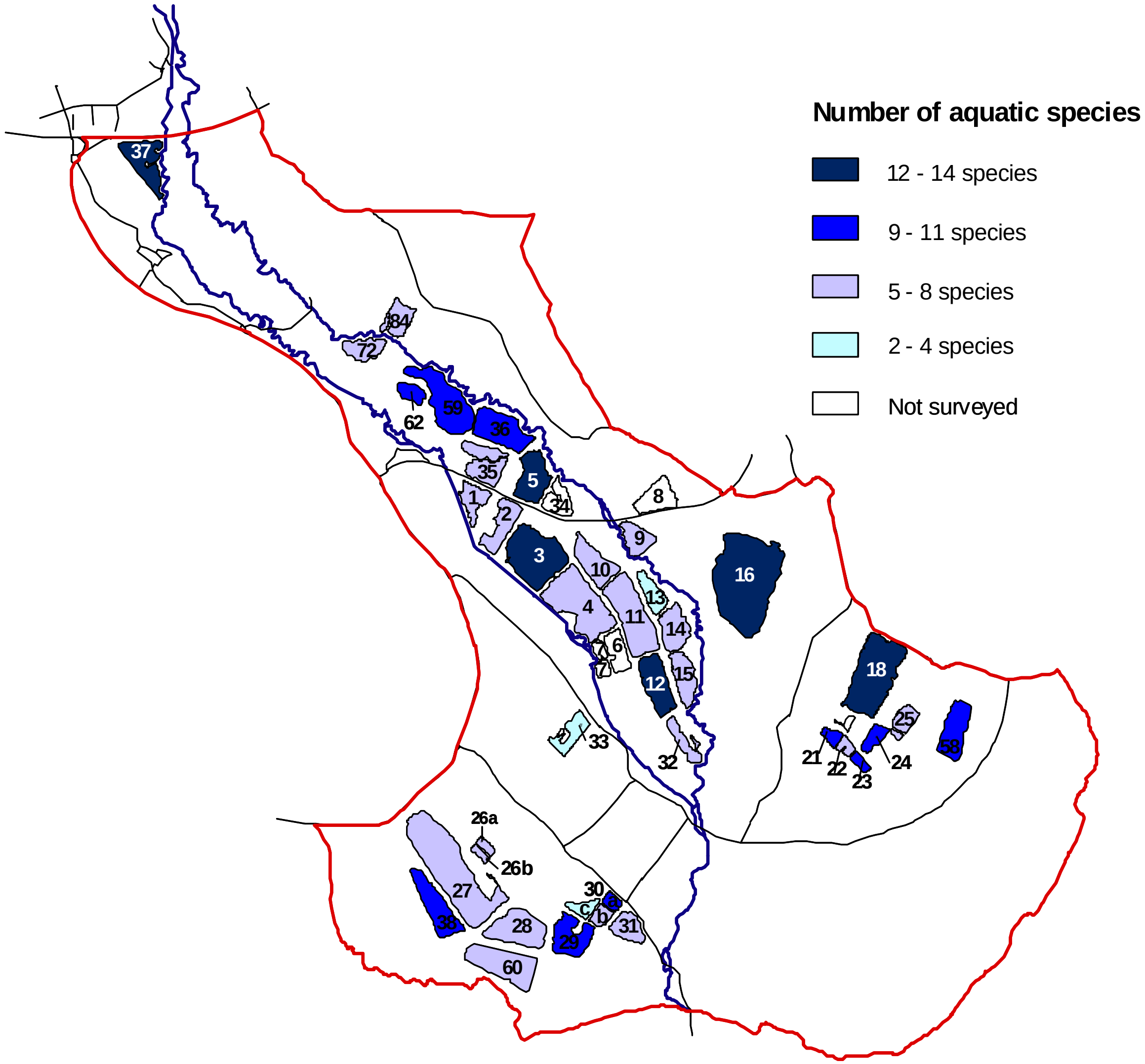
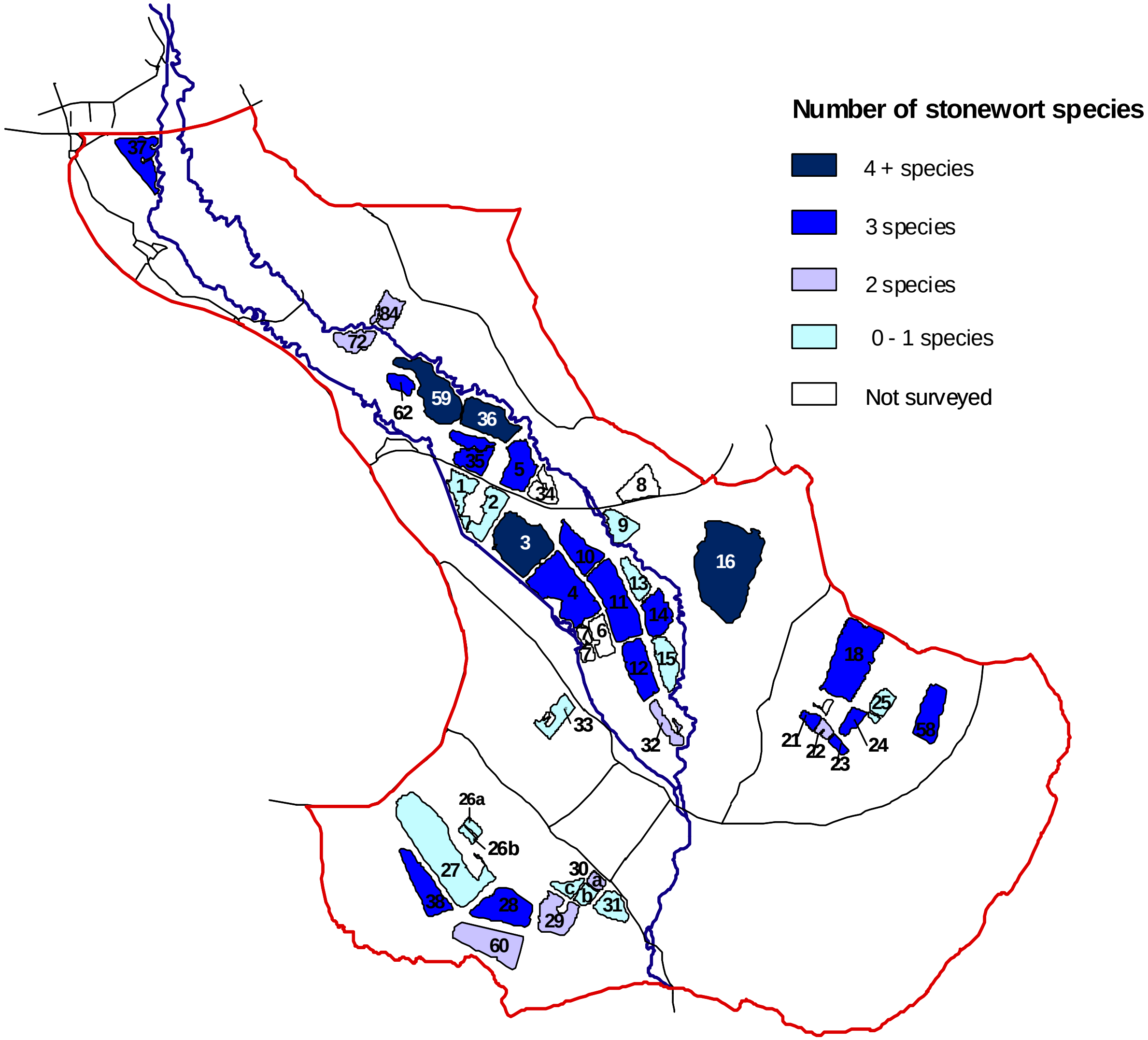


Figure 20 Lake plant species richness in the British landscape

From the Defra Aquatic ecosystems in the UK agricultural landscape project (PCTPR, Cranfield University and ADAS 2003). Landscape classes cover the whole of the British landscape with classes 1-12 being predominantly agricultural areas and class 13 being non-agricultural land (mainly moorland and mountain). The dashed line shows the mean value for the Lower Windrush Valley. Landscape classes: 1 = river floodplains and low terraces, 2 = warplands, fenlands and associated low terraces, 3 = sandlands, 4 = eutrophic tills, 5 = oligotrophic tills, 6 = pre-quaternary clay, 7 = chalk and limestone, 8 = pre-quaternary loam, 9 =mixed, hard, fissured rock and clay, 10 = hard rock, 11 = Scottish fluvioglacial moraine, 12 = Scottish footslopes with loamy drift, 13 = non-agricultural land: mainly mountains and moorland. The analysis was based on data from 840 lakes.



Map 5 Aquatic plant species diversity in the LWV gravel pits



Map 6 Stonewort species diversity in the LWV gravel pits

3.2.3.3 Emergent plants

Emergent plant species richness in the LWV gravel pits was, on average, 27.7 ± 6.3 and ranged from 14 to 38 species. The only comparative data for emergent plants in gravel pits is from the Datchet-Chertsey complex. These lakes supported slightly fewer emergent plants, with 24.6 species on average, and a range from 12 to33 species (Pond Action, 1991). The lake richest in emergent plants was Pit 37 (Witney Lake), following by Pit 31 (Barnes Lake), Pit 3 (Hardwick Park) and Pit 12 (Oxlease Lake) (Map 7).

3.2.4 Species rarity

3.2.4.1 Wetland plant species

A total of 27 uncommon[2] wetland plant species were recorded in the 40 gravel pits surveyed (Table 6), which represent approximately a quarter of the total number of species recorded. Three species had Nationally Scarce status: Lesser Bearded Stonewort (*Chara curta*), Fringed Water-lily (*Nympoides peltata*) and Galingale (*Cyperus longus*). The latter is not native to Oxfordshire and Fringed Water-lily is very rare in the county (Killick *et al*., 1998). Both species are commonly planted for ornamental value, and this is likely to be the case in the LWV. Twenty-two of the wetland plants recorded in the current study had local status[3], seven of which were stoneworts (Table 6). Over 90 percent of the gravel pits surveyed supported at least one uncommon species (Nationally Scarce or local).

Of most interest was the presence of Lesser Bearded Stonewort (*C. curta*), a Biodiversity Action Plan (BAP) species, in two gravel pits (Pit 5 Darlow Water and Pit 14 Unity Lake). It is the first time that this species, and the local species Rough Stonewort (*Chara aspera*), have been recorded in Oxfordshire. Bristly Stonewort (*Chara hispida*) is also very rare in the county (Nick Stewart, pers. com.). Overall, the presence of eight stonewort species in the LWV, and of another Nationally Scarce BAP species in the nearby Pinkhill Meadow pond complex (*Tolypella glomerata*) confirms that the LWV should be regarded as an important stonewort area (Stewart, 2004).

Regionally, a number of species defined as rare or scarce in Oxfordshire were widespread in the LWV (see Appendix 2). Examples include Lesser Pondweed (*Potamogeton pusillus*) and Brooklime (*Samolus valerandi*), which although rare in the county, were recorded in over 35 % of gravel pits in the LWV. Two other species, Horned Pondweed (*Zannichellia palustris*) and Small Pondweed (*Potamogeton berchtoldii*), are scarce in the county and were both recorded in over a quarter of the gravel pits surveyed.

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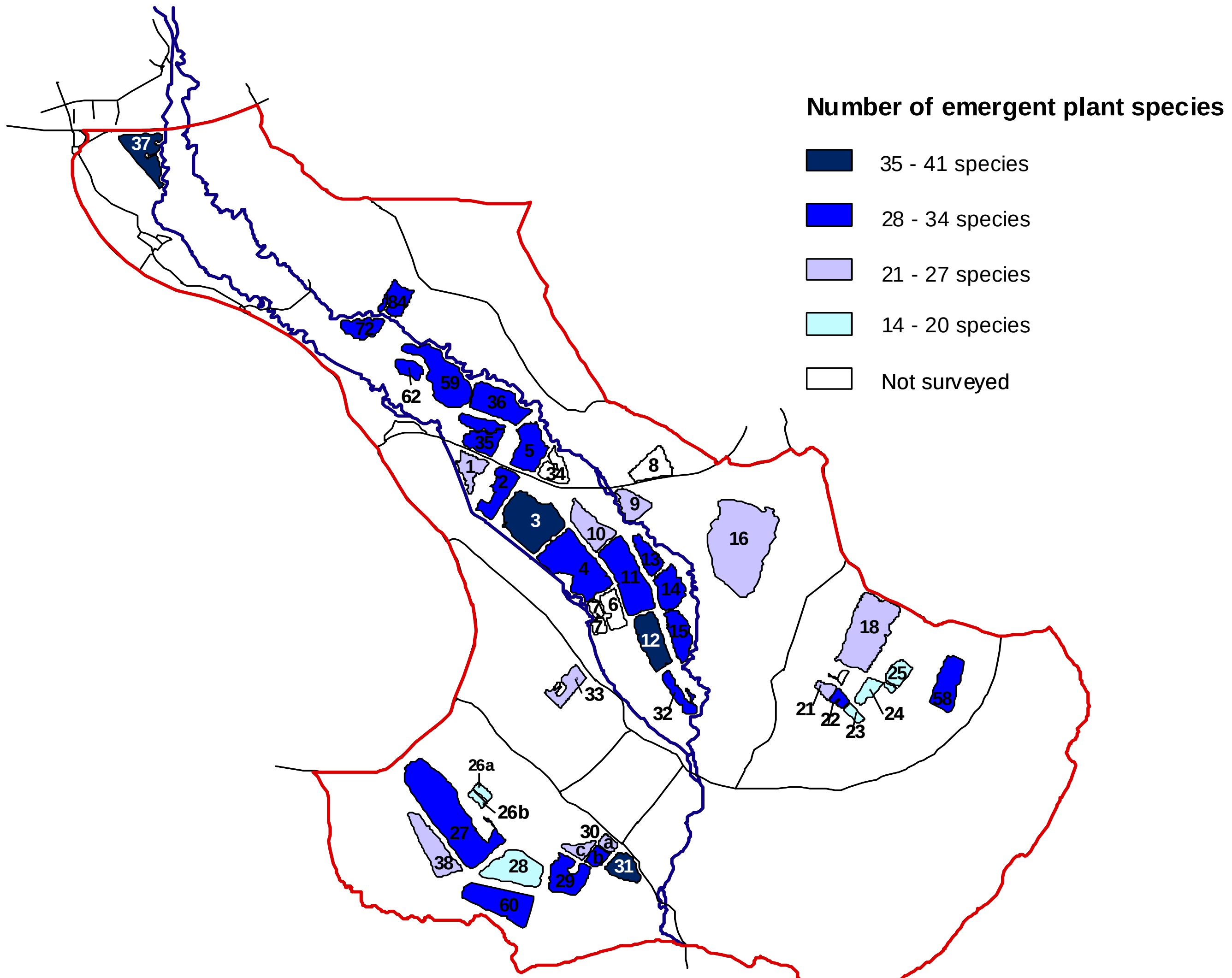
[2] Uncommon includes those which are Nationally Scarce or local in their distribution.
[3] See Section 2.5 for a definition.



Map 7 Emergent plant species diversity in the LWV gravel pits

Table 6 Nationally Scarce and local wetland plant species recorded in the LWV gravel pits

Latin name	Common name	National conservation status	% occurrence
Chara curta	Lesser Bearded Stonewort	Nationally Scarce	5
Cyperus longus	Galingale	Nationally Scarce[a]	5
Nymphoides peltata	Fringed Water-lily	Nationally Scarce[a]	5
Chara aspera	Rough Stonewort	Occasional	25
Chara contraria	Opposite Stonewort	Occasional	68
Chara globularis	Fragile stonewort	Occasional	8
Chara hispida	Bristly Stonewort	Occasional	3
Chara virgata	Delicate stonewort	Frequent	53
Chara vulgaris	Common Stonewort	Frequent	33
Nitella flexilis agg.	Smooth Stonewort	Frequent[b]	20
Bidens cernua	Nodding Bur-marigold	Local	5
Bidens tripartita	Trifid Bur-marigold	Local	10
Butomus umbellatus	Flowering-rush	Local	5
Calamagrostis epigejos	Wood Small-reed	Local	3
Carex acuta	Slender Tufted-sedge	Local	10
Carex pseudocyperus	Cyperus Sedge	Local	3
Groenlandia densa	Opposite-leaved Pondweed	Local	3
Juncus compressus	Round-fruited Rush	Local	13
Juncus subnodulosus	Blunt-flowered Rush	Local	20
Potamogeton pusillus	Lesser Pondweed	Local	38
Ranunculus circinatus	Fan-leaved Water-crowfoot	Local	13
Ranunculus lingua	Greater Spearwort	Local	3
Rorippa amphibia	Great Yellow-cress	Local	3
Sagittaria sagittifolia	Arrowhead	Local	3
Samolus valerandi	Brookweed	Local	35
Typha angustifolia	Lesser Bulrush	Local	3

[a] These species are likely to have been planted.
[b] The lower status in the *Nitella flexilis* group is frequent for *Nitella opaca* (Stewart, 2003).

Notes: national conservation status are derived from Preston et al. (2002) for vascular plants and from Stewart (2003) for stoneworts.

3.2.4.2 Uncommon species richness and the Species Rarity Index (SRI)

The average number of uncommon species per lake recorded in the current survey was 3.8 ± 2.3, with a range from zero to eight species. The Species Rarity Index (SRI), which is a measure of species rarity that takes account of differences in species richness, was 1.10 on average, and ranged from 1.00 to 1.21. The DEFRA aquatic ecosystems of the UK agricultural landscapes study reported lake SRI ranges in the British landscape from 1.10 to 1.24 (PCTPR, Cranfield University and ADAS, 2003). The SRI values for the LWV gravel pits were towards the low end of this range probably because the DEFRA lakes were, on average, larger than those of the LWV.

The lake with the highest SRI was Pit 16 (Dix Pit) (Figure 21), which supported eight uncommon species. Other gravel pits with relatively high SRI included Pit 23 (Linch Hill Complex 5), Pit 28 (Windsurfing Lake), Pit 38 (Shifford Lake), Pit 3 (Hardwick Park), and Pit 58 (Watkins Farm).

3.2.5 Unique species

Lakes which supported unique species, i.e. species which were recorded from only one site in the current survey, make an important contribution to the overall diversity of the LWV. Approximately a quarter of the gravel pits surveyed supported at least one unique species (Table 7). Pit 3 (Hardwick Leisure Park 1) supported four unique species, including the local species Wood Small-reed (*Calamagrostis epigejos*) and Lesser Bulrush (*Typha angustifolia*). Other pits of particular interest were Pit 59 (Gill Mill), which supported the only record for the local submerged species Opposite-leaved Pondweed (*Groenlandia densa*). The only record for Bristly Stonewort (*Chara hispida*), was recorded in Pit 37 (Witney Lake).

Table 7 List of gravel pits which supported a unique wetland plant species

Pit number	Pit name	Number of unique species
3	Hardwick Leisure Park 1	4
59	Gill Mill	2
12	Oxlease Lake	2
37	Witney Lake	2
31	Barnes Lake	1
16	Dix Pit	1
33	Downs Road	1
21	Linch Hill Complex 3	1
26a	Lincoln Lake	1
29	Standlake Common 1	1
13	Yeomans Lake	1

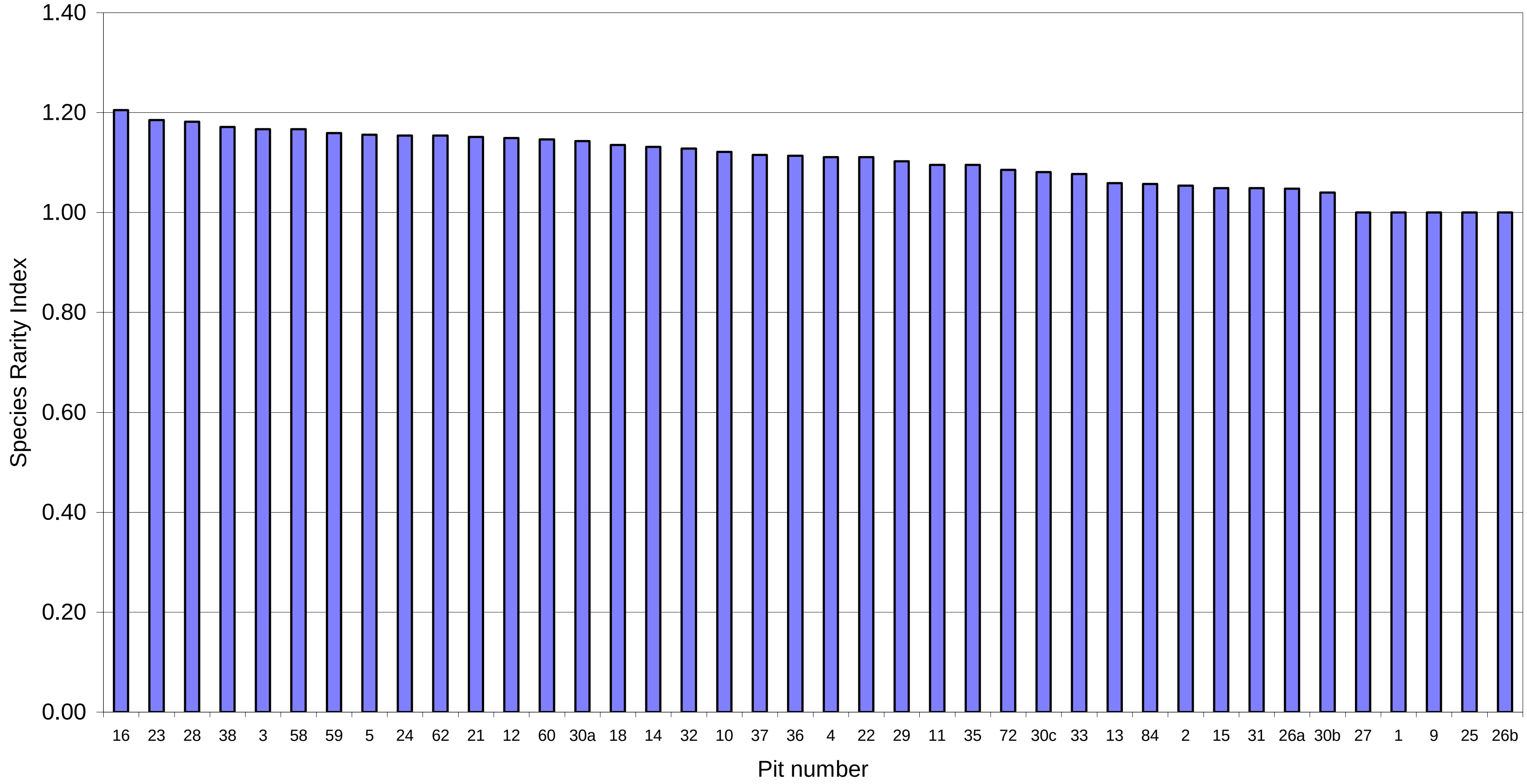


Figure 21 Wetland plant Species Rarity Index (SRI) for the LWV gravel pits

3.2.6 Factors affecting wetland plant diversity

Correlations between the physico-chemical variables and wetland plant species richness showed that a number of factors were correlated with plant diversity in the LWV gravel pits (see Appendix 3 for correlation coefficients). Generally, lakes which supported a greater number of plant species were (i) relatively young, (ii) large, (iii) surrounded by semi-natural landuse, (iv) near a river system, (v) with gently sloping margins, and (vi) with low nutrient concentrations. Trends were similar for all plants combined, and for aquatic and emergent species richness. Each of these factors are discussed briefly below:

1. *Lake age* (years since filling with water): Older pits generally have a tendency towards greater nutrient accumulation, an increase in marginal shade and a reduction in mineral substrates, all of which have the potential to have a negative impact on plant diversity. The link between lake age and plant diversity was also reported in the Cotswold Water Park (Bell, 1995).
2. *Lake surface area*: The relationship between surface area and wetland plant diversity has been demonstrated by a number of studies (e.g. Oertli *et al*., 2002). Generally, larger waterbodies tend not only to have a greater availability of habitat for colonisation, but the potential for greater diversity of habitats, encouraging species richness.
3. *Surrounding landuse*: A waterbody buffered by semi-natural landuse, such as woodland or unimproved grassland is less likely to be exposed to pollutants in surface water run-off from the surroundings. Although LWV gravel pits are, like most gravel pits, mainly fed by groundwater, surface water borne pollutant inputs may also be an important influence on water qaulity, especially as lakes age and initially hydraulically conductive gravels become sealed by sediments.
4. *Profile of margins*: Many wetland plants, and in particular emergent species, establish more easily in shallow water and have specific requirements for shallow water (EN, 1997). A range of species also require a period of drying out before their seeds can germinate. In addition many aquatics, including some stonewort species, thrive in the shallow water. Because of this, lakes with wide, gently sloping margins generally provide more favourable habitats for plants, encouraging both marginal and aquatic plant diversity.
5. *Connectivity*: Proximity to other wetlands facilitates plant dispersal and is generally associated with increased species richness (Williams *et al*., 1999). In addition, lakes near to the River Windrush are more likely to be flooded, which may encourage the movement of plant propagules between sites.
6. *Water quality*: Water quality is well known to be a major influence on plant assemblages in freshwater ecosystems, particularly through the negative effects of eutrophication and acidification. In lowland lakes on base-rich substrates increases in nutrient status, in particular, generally lead to reductions in aquatic plant diversity. Submerged species, and in particular stoneworts, are particularly sensitive to deterioration in water quality (Stewart, 1996). This is clearly reflected in the present survey results.

The results of the correlations between the physico-chemical variables and wetland plant species rarity (uncommon species richness and SRI) were similar to those described above for species richness. This probably reflected the fact that lakes with rich wetland plant assemblages were also more likely to support uncommon species.

There was also evidence that the occurrence of uncommon species was related to (i) the occurrence of low total nitrogen concentrations, (ii) semi-natural landuse around the gravel pits, and (iii) gently sloping margins. In addition, pits with a high intensity of fishing generally had fewer uncommon species and lower SRI values.

3.2.7 Wetland plant assemblages and their relationship with physico-chemical variables

3.2.7.1 Aquatic plants

TWINSPAN classification of aquatic plant species identified five assemblage types in the LWV (Figure 22, Map 8). The eigenvalues, which show the strength of each division were relatively low, with a range from 0.229 to 0.304. This suggested that the species composition of the gravel pits was relatively similar. Indeed, a number of species were widespread in the LWV and occurred in most of the gravel pits. For example Nuttall's Waterweed (*E. nuttallii*), had high constancy values in all TWINSPAN end groups (see Appendix 4).

DCA (Section 2.5) of the aquatic plant data showed that the TWINSPAN end groups were relatively well defined (Figure 23). Axis 1 and Axis 2 accounted for 32% and 25% of the variation in the data, respectively. Correlations between the axis scores and the physico-chemical variables showed that axis 1 was a gradient relating to (i) gravel pit age, (ii) shade, (iii) surrounding landuse, and (iv) water turbidity (Figure 23, see Appendix 3 for correlation coefficients). Statistical analyses of the biotic data showed that Axis 1 was also a species richness and rarity gradient. Axis 2 was correlated with similar variables as Axis 1. It also reflected the surrounding landuse, water chemistry and species richness and rarity. In addition, Axis 2 correlated with the geographical location of the lakes, and with the shoreline index.

Based on TWINSPAN and DCA, the main aquatic plant assemblage types identified in the LWV can broadly be described as follows:

- ***Group 1*** (9 lakes) was characterised by Rigid Hornwort (*Ceratophyllum demersum*) and White Water-lily (*Nymphea alba*). Lakes in this group were relatively species rich in floating-leaved species, but poor in submerged and stonewort species. They tended to be older and more turbid, and had a greater proportion of intensive landuse in their surroundings.

- ***Group 2*** (8 lakes) was characterised by the presence of Rough Stonewort (*Chara aspera*) and White Water-lily (*Nymphea alba*). This group was separated from Groups 2 and 4 along Axis 2 of the DCA, which suggested that sites in this group were relatively diverse in terms of species number and rarity, and with better water quality.

- ***Group 3*** (9 lakes) was characterised by Curled Pondweed (*Potamogeton crispus*) and Fan-leaved Water-crowfoot (*Ranunculus circinatus*). This group was placed in between Group 2 and Group 4 along Axis 2, which suggested intermediate biotic and abiotic conditions compared to those groups.

- ***Group 4*** (8 lakes) was defined by the floating-leaved species Common Duckweed (*Lemna minor*), Amphibious Bistort (*P. amphibia*) and Ivy-leaved Duckweed (*L. trisulca*). Lakes in this group tended to be similar to those of Group 2 and 3, but with poorer water quality, and lower interest in terms of aquatic diversity and rarity.

- ***Group 5*** (6 lakes) was characterised by Horned Pondweed (*Zannichellia palustris*), water-crowfoot species (*Ranunculus* spp., other than *R. circinatus*). This group tended to include younger lakes with high species richness and rarity, particularly for submerged and stonewort species.

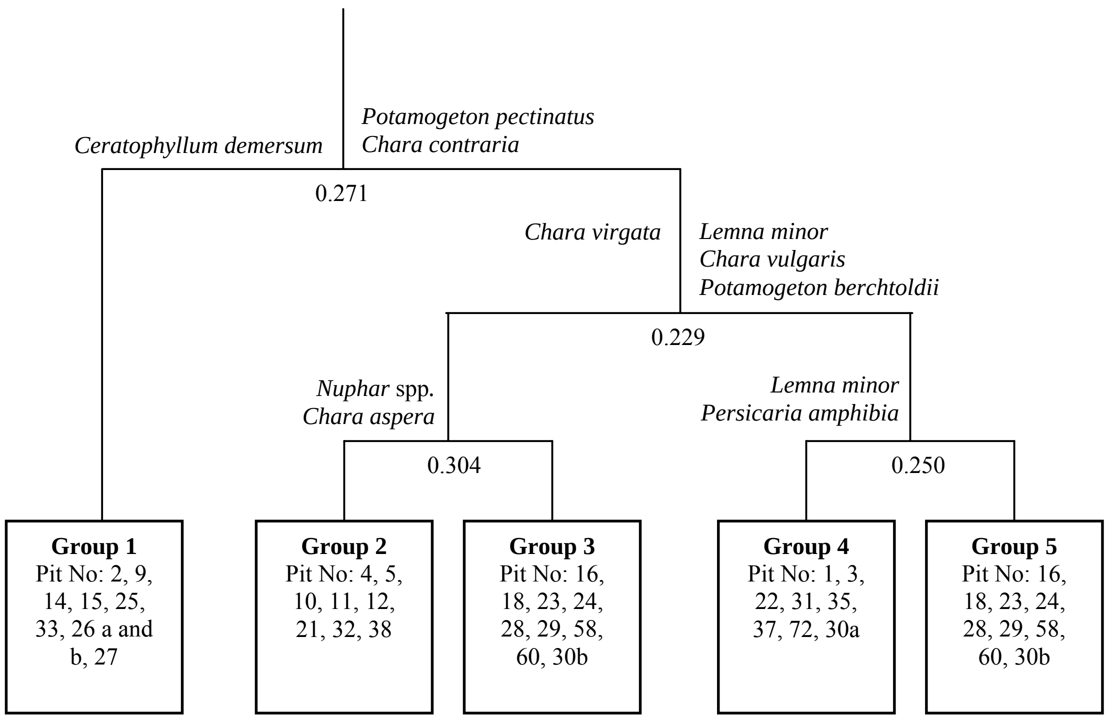
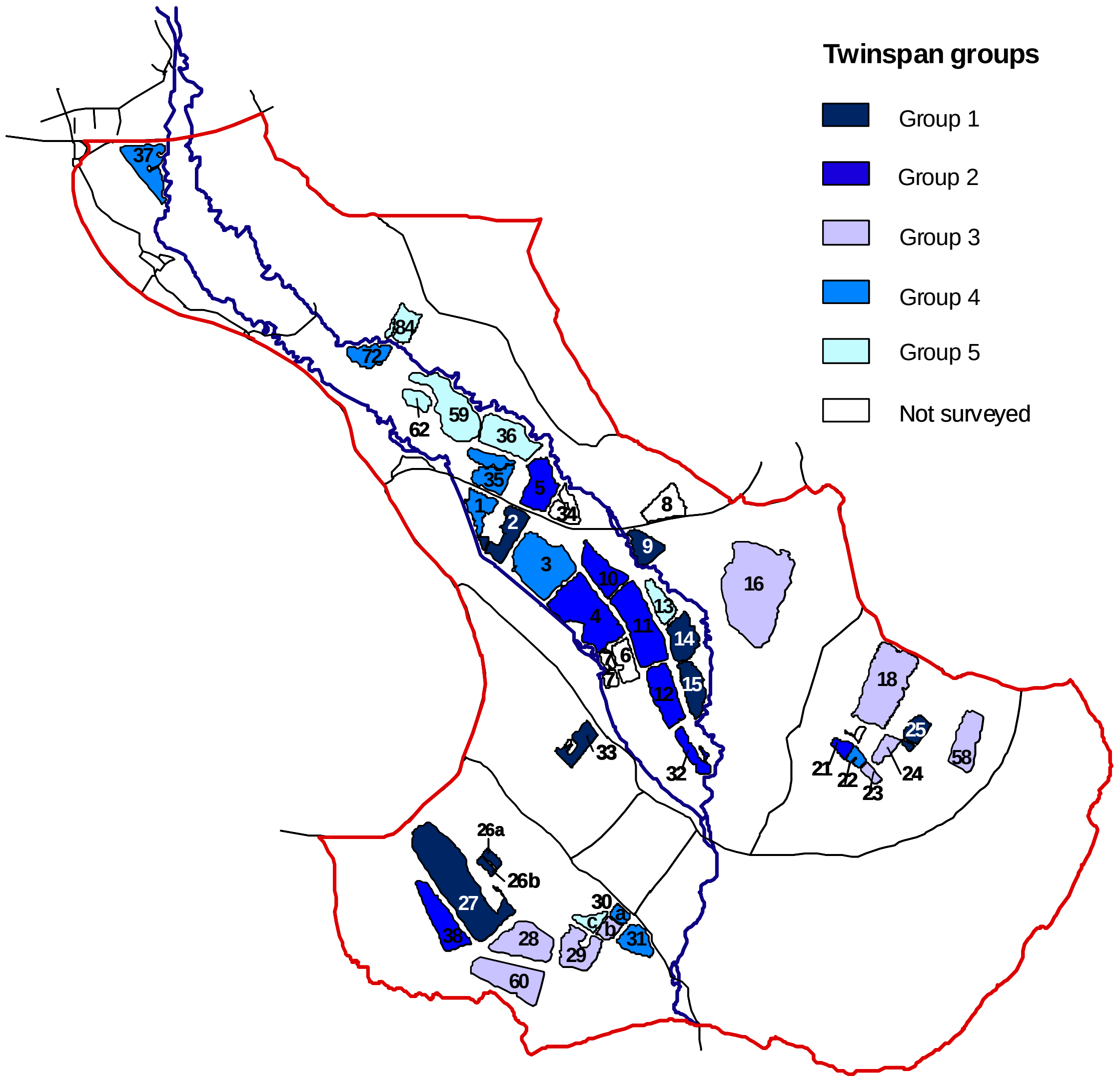


Figure 22 TWINSPAN classification of aquatic plant assemblages in the LWV gravel pits



Map 8 TWINSPAN classification of aquatic plant assemblages in the LWV gravel pits

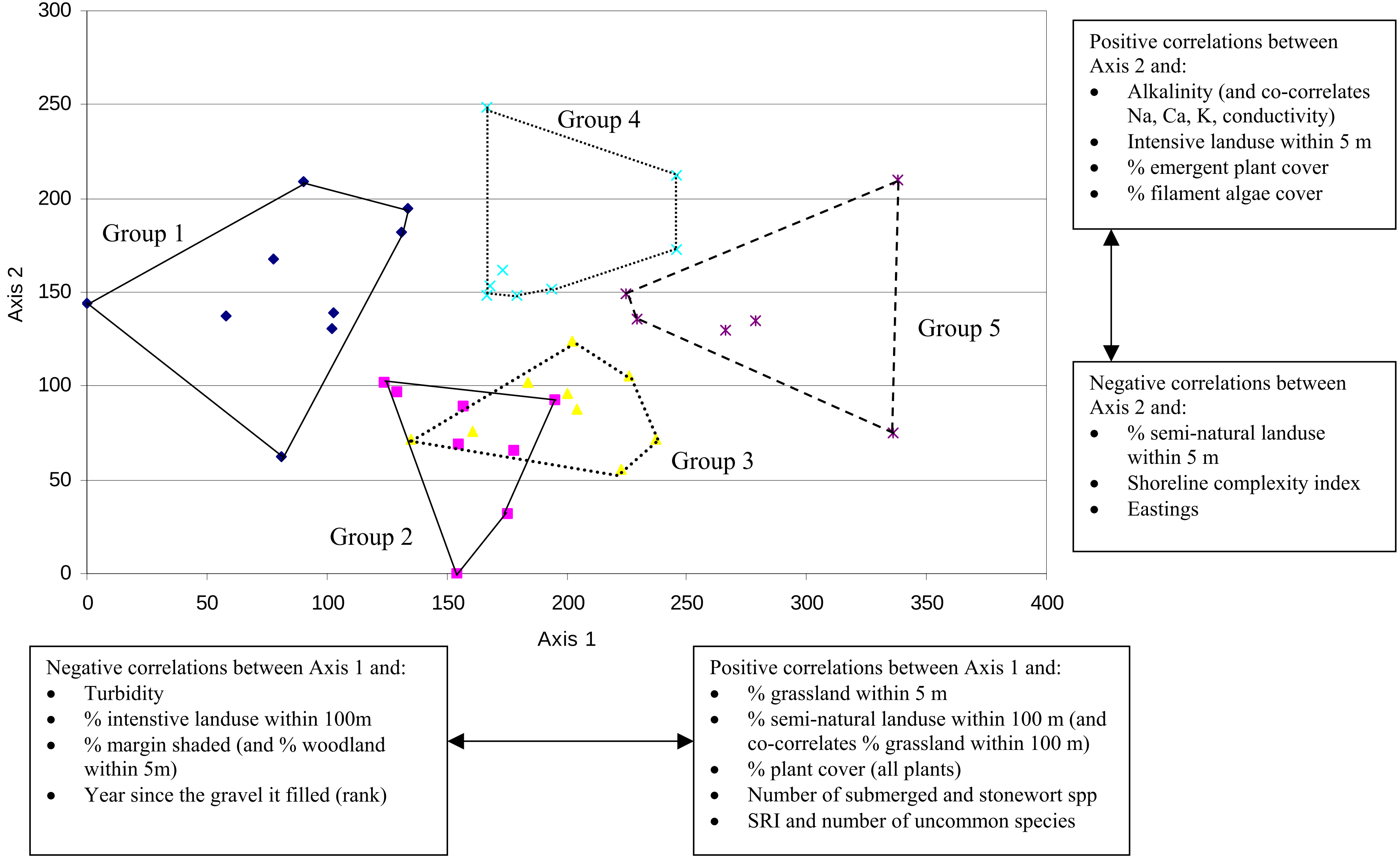


Figure 23 DCA of aquatic plant assemblages in the LWV gravel pits

3.2.7.2 Emergent plants

TWINSPAN classification of emergent plants species defined only three types of communities in the LWV (Figure 24, Map 9). The eigenvalues were even lower than for aquatic plant assemblages, with a range from 0.090 to 0.144. This reflected the relatively homogenous emergent plant community around the gravel pits of the LWV.

The TWINSPAN end groups were relatively well defined on the DCA plot (Figure 25). Axis 1 and Axis 2 accounted for 21% and 13% of the variation in the data, respectively. The results of correlations between the axes and the physico-chemical variables showed that Axis 1 related to conductivity, age (and therefore shade) and the bank profile (Figure 25, see Appendix 3 for correlation coefficients). Axis 2 was associated with, again, shade, but also with the surrounding landuse.

Based on TWINSPAN and DCA, the main aquatic plant assemblage types identified in the LWV can broadly be described as follows:

- ***Group 1*** (6 lakes) was characterised by Blue Water-Speedwell (*Veronica anagallis-aquatica*). Other species with high constancy in this group were Celery-leaved Buttercup (*Ranunculus sceleratus*), and Pink Water-Speedwell (*Veronica catenata*). These species tend to grow in open, often disturbed conditions. Indeed, all the lakes in this group have open, unshaded margins. The gravel pits in this group tended to have relatively high conductivity, to be surrounded by areas of semi-natural landuse and to support relatively high numbers of submerged plant species.

- ***Group 2*** (31 lakes) was the large, and relatively undefined, group, both in terms of emergent plant species composition and physico-chemical characteristics. The indicator species for this group were False Fox-sedge (*Carex otrubae*), Square-stalked St Johns-wort (*Hypericum tetrapterum*), Water Figwort (*Scrophularia auricularia*) and Hairy Sedge (*Carex hirta*).

- ***Group 3*** (3 lakes) had no indicator species and comprised small, relatively shaded gravel pits with margins of low complexity. These pits tended to be particularly species poor, probably because they were amongst the smallest pits in the LWV. They were, however, relatively rich in floating-leaved plant species.

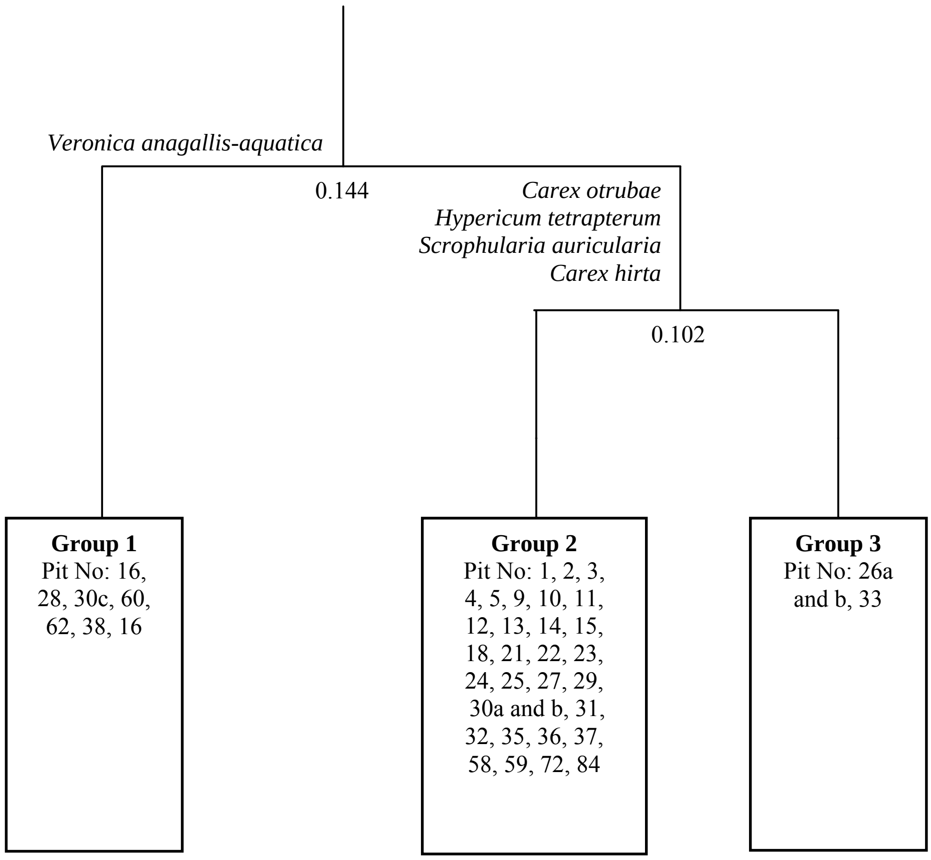
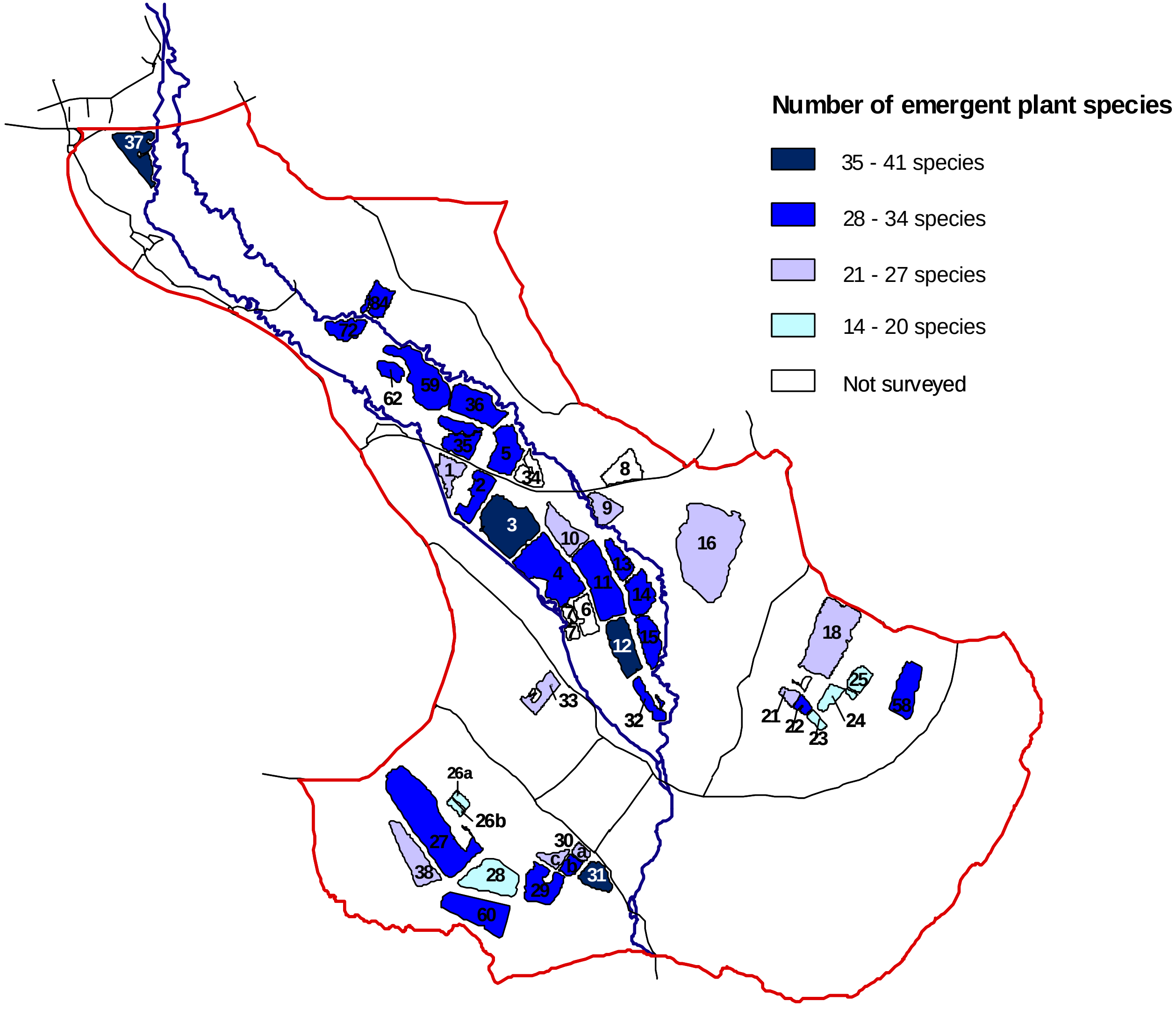


Figure 24 TWINSPAN classification of emergent plant assemblages in the LWV gravel pits



Map 9 TWINSPAN classification of emergent plant assemblages in the LWV gravel pits

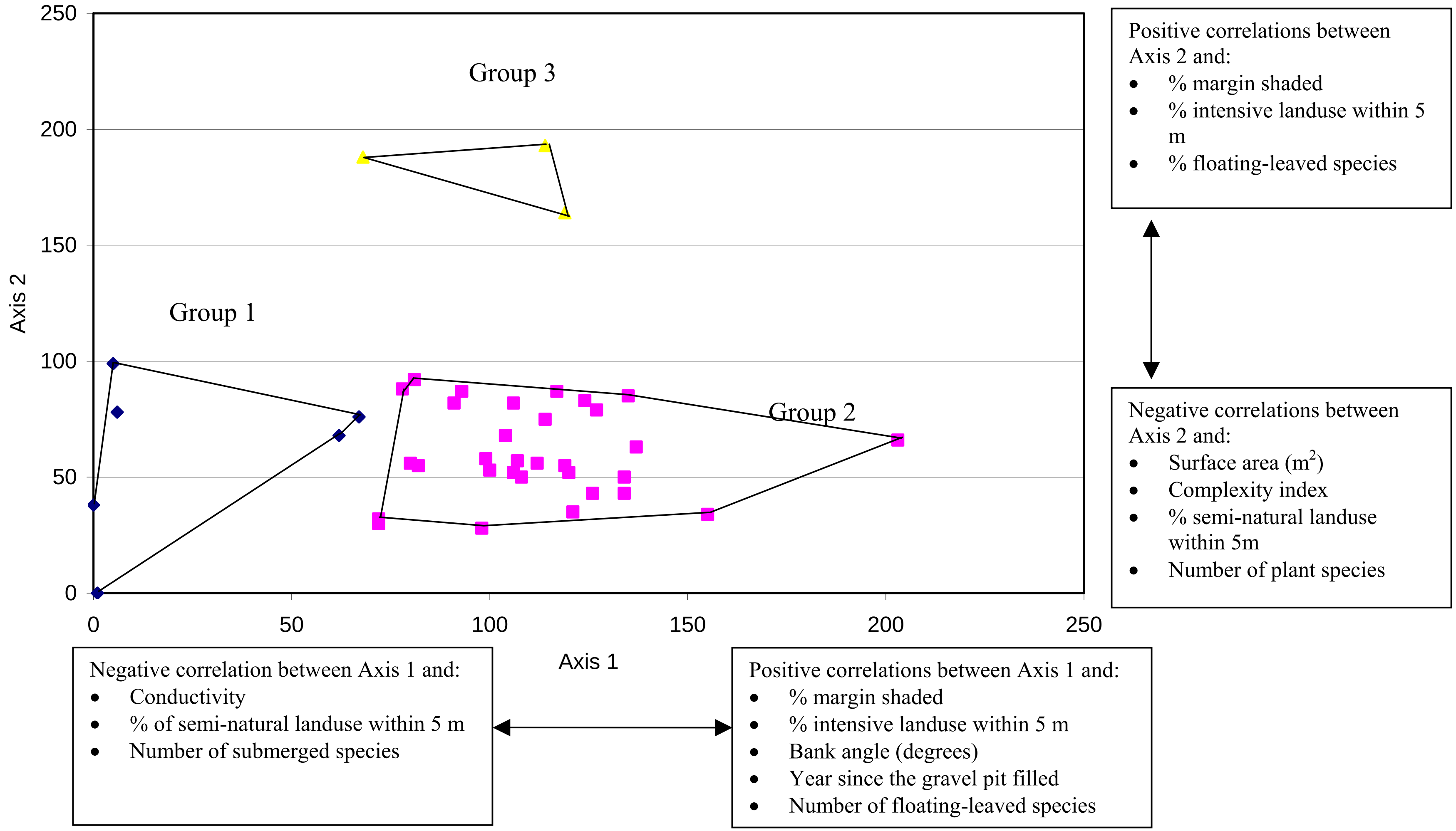


Figure 25 DCA of emergent plant assemblages in the LWV gravel pits

3.3 Summary of wetland plant results

The results of the current survey show that the Lower Windrush Valley gravel pits supported a very diverse plant community, with a total of 122 wetland plant species (c. 35% of the wetland flora in Britain). Nationally, based on their aquatic communities, all the lakes could be classified as "Group I: widespread, mostly moderately large, base-rich lowland lakes, with *Chara* spp., *Myriophyllum spicatum* and a diversity of *Potamogeton* species". Gravel pits species richness was 35.7 ± 7.7 species for all wetland plants, 6.4 ± 2.8 for submerged species and 27.7 ± 6.3 for emergent species. Comparisons with data from the Cotswold Water Park and other gravel pits in southern England confirmed that the LWV gravel pits were of high value for wetland plant biodiversity. A total of 27 uncommon wetland plant species were recorded in the current survey. The stonewort community was of particular interest for its diversity (8 uncommon species). Stonewort species richness and the presence of a Nationally Scarce BAP species, Lesser Bearded Stonewort (*Chara curta*), both confirm the value of the LWV as an "Important Stonewort Area". Species richness and rarity was primarily related to water quality, lake age, surface area and bank characteristics. Intensively stocked angling lakes tended to support fewer species overall. Of concern was also the presence of two invasive species in a small number of sites: New Zealand Pigmyweed (*Crassula helmsii*) and Indian Balsam (*Impatiens glandulifera*).

3.4 Macroinvertebrates

3.4.1 Macroinvertebrate species recorded in the survey

3.4.1.1 All macroinvertebrates

The Lower Windrush Valley gravel pits support a very diverse macroinvertebrate community, with a total of 191 macroinvertebrate species recorded in the present survey (Appendix 2). Overall, this represented approximately 25% of the aquatic macroinvertebrate species occurring in Britain in the groups surveyed. In terms of the composition of the fauna, the community was dominated by water beetles, which accounted for 32 % of the species recorded (Figure 26), followed by water bugs (15%), caddis flies (14%), water snails (12%), and dragonflies (6%). Numerically, the fauna was dominated by water snails (11 of the 20 most numerous taxa were water snails), crustaceans (the water slater, *Asellus aquaticus* and the two freshwater shrimps *Crangonyx pseudogracilis* and *Gammarus pulex*), the Pond Olive and Lake Olive mayflies (respectively, *Cloeon dipterum* and *C. simile*) and the Blue-tailed damselfly (*Ischnura elegans*).

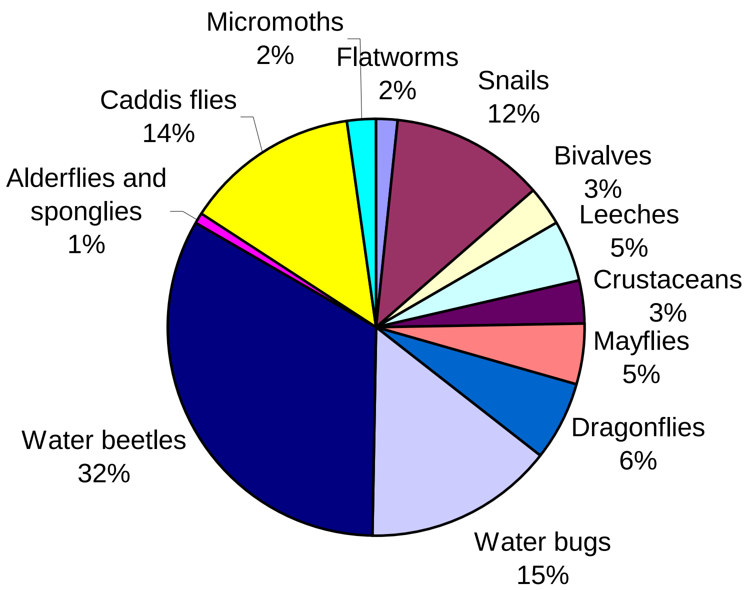


Figure 26 Proportion of the macroinvertebrate groups recorded in the LWV gravel pits

Typically for floodplain lakes in a long-established wetland environment, snail diversity was high, and the gravel pits supported most of the common British taxa (23 species). The fauna included species typical of larger, permanent water bodies and wetlands (e.g. The Bythinia *Bythinia tentaculata*, the Lake Limpet *Acroloxus lacustris* and the Great Pond Snail *Lymnaea stagnalis*) as well as species of smaller, more variable and temporary, habitats (e.g. the Button Ram's-horn *Anisus leucostoma*) (Kerney, 1999). Although no nationally scarce or Red Data Book species were found, two nationally local species were recorded, The Nerite (*Theodoxus fluviatilis*) and the Smooth Ram's-horn (*Gyraulus laevis*). The Nerite is a species characteristic of lime rich, well oxygenated water which, although commonest in running water, also occurs in the wash zone of calcareous lakes (Kerney, 1999). It was recorded in three of the richest pits: Pit 37 Witney Lake, Pit 10 West Oxon Sailing Club 1, and Pit 62 Founders Lake. The Smooth Ram's-horn is a pioneer species associated with new habitats, particularly gravel pit lakes, and is widespread in the complex being present in over half of the lakes (23 sites).

A total of 12 species of Odonata were recorded in the current survey, of which five were damselflies (Zygoptera) and seven were dragonflies (Anisoptera). This is a good but not exceptional total. However, since these records refer entirely to observations of larvae they provide unequivocal evidence of breeding in the LWV. In the Cotswold Water Park (CWP) a total of 13 breeding species were reported by Bell (1995) summarising data from a variety of sources collected over a number of years. This suggests that overall dragonfly richness is similar in the two locations. The CWP also had records of two Nationally Scarce species (Downy Emerald, *Cordulia aenea,* and Scarce Blue-tailed Damselfly, *Ischnura pumilio*), although neither has so far been recorded in the Lower Windrush Valley, both are quite likely to occur. The Downy Emerald is known from a number of sites in Oxfordshire and could well be present on the more wooded lakes of the LWV complex. Likewise the Scarce Blue-tailed Damselfly is known from new temporary water habitats in gravel pit complexes and has been recorded elsewhere in Oxfordshire.

Crawling water beetles of the family Haliplidae were also well-represented. Of the 19 species recorded in Britain, nine were found in the LWV gravel pits. Species in this water beetle family are often associated with base-rich ponds and lakes, and in particular in association with stoneworts (e.g *Haliplus obliquus*) or filamentous algae (e.g *H. laminatus*), which provide the main larval habitat (Brill, 1987). *H. laminatus* is a Nationally Scarce species.

3.4.1.2 Non-native species

In the current survey, two non-native macroinvertebrates were of particular concern, Signal Crayfish (*Pacifastacus leniusculus*) and Zebra Mussel (*Dreissena polymorpha*), which were both recorded from 12 lakes in the LWV. Signal Crayfish (see also Section 3.4.4) was introduced in the UK in the mid-1970s and is one of the main factors responsible for the decline in the native White-clawed Crayfish (*Austropotamobius pallipes*). Signal Crayfish carries the fungal disease commonly known as the crayfish plague (*Aphanomyces astaci*), but also directly competes with White-clawed Crayfish for food and habitat (SAP, 2004).

Zebra Mussel (*Dreissena polymorpha*) was introduced in the UK from the Baltic Sea in the 19^{th} century, probably attached to the hulls of boats. It can easily spread between waterbodies, for example on fishermen's gear. This invasive species has a range of physical and environmental impacts (see EHSNI, 2001). The main concerns for the LWV biodiversity are (i) its ability, through filter feeding, to provide clear water in a nutrient rich environment, which can lead to algae bloom of, for example, toxic blue-green algae, and (ii) its impact on local diversity, particularly the native Swan Mussel (*Anadonta cygnea*).

3.4.2 Species richness of individual pits

Individual pits in the Lower Windrush complex supported rich macroinvertebrate assemblages with 56.2 ± 12.8 species per site on average, with a range from 29 to 87 species per pit (Figure 27). Placing these results in context is currently difficult because there are very few data available describing the invertebrate assemblages of Britain's lakes. However, results from the present study can be compared with those of two projects undertaken by PCTPR (see Section 2.6): (i) an investigation of the invertebrate assemblages of 15 unimpaired small lakes in England and Wales which ranged in size from 1 to 10 ha and (ii) a study of 33 gravel pit lakes in the Caversham area (Reading) and the Datchet-Chertsey complex, south-west of London (9 to 93 ha.).

Average species richness in the LWV gravel pits was greater than that in small, minimally impaired lakes, and similar to that in other Thames Valley gravel pits survyed by PCTPR. Mean species richness in the unimpaired small lakes was 44.9 species per site, and in the gravel pit lake studies 55.5 species per site. All studies used the National Pond Survey methodology applied in the present project. These data indicate that the Windrush pits are at least as rich as other lakes in the Thames Valley, including gravel pits in the Wraysbury and Hythe End Gravel Pits SSSI, which were in part designated for their aquatic invertebrate and plant assemblages.

In term of individual lakes, Pit 59 (Gill Mill) was the richest lake in the LWV. It supported 87 macroinvertebrate species overall (Figure 27, Map 10). This pit was particularly rich in water beetle and dragonfly species (Map 11 and 12). Two other lakes were particularly rich in macroinvertebrate species: Pit 72 (Graham Water) supported a particularly diverse water bug and water beetle community (Map 11 and 13) and Pit 37 (Witney Lake) was rich in snails, bivalves and caddis flies (Map 14 and 15). The main reason these gravel pits were so diverse is likely to be linked to habitat diversity. For example, Gill Mill and Graham Water both included significant areas of shallow marginal habitats, which are particularly favoured by water beetles. Similarly, Witney Lake included habitats rarely seen elsewhere in the LWV including unmanaged and overgrown margins, and narrow channels, which maintained suitable conditions for pioneer species.

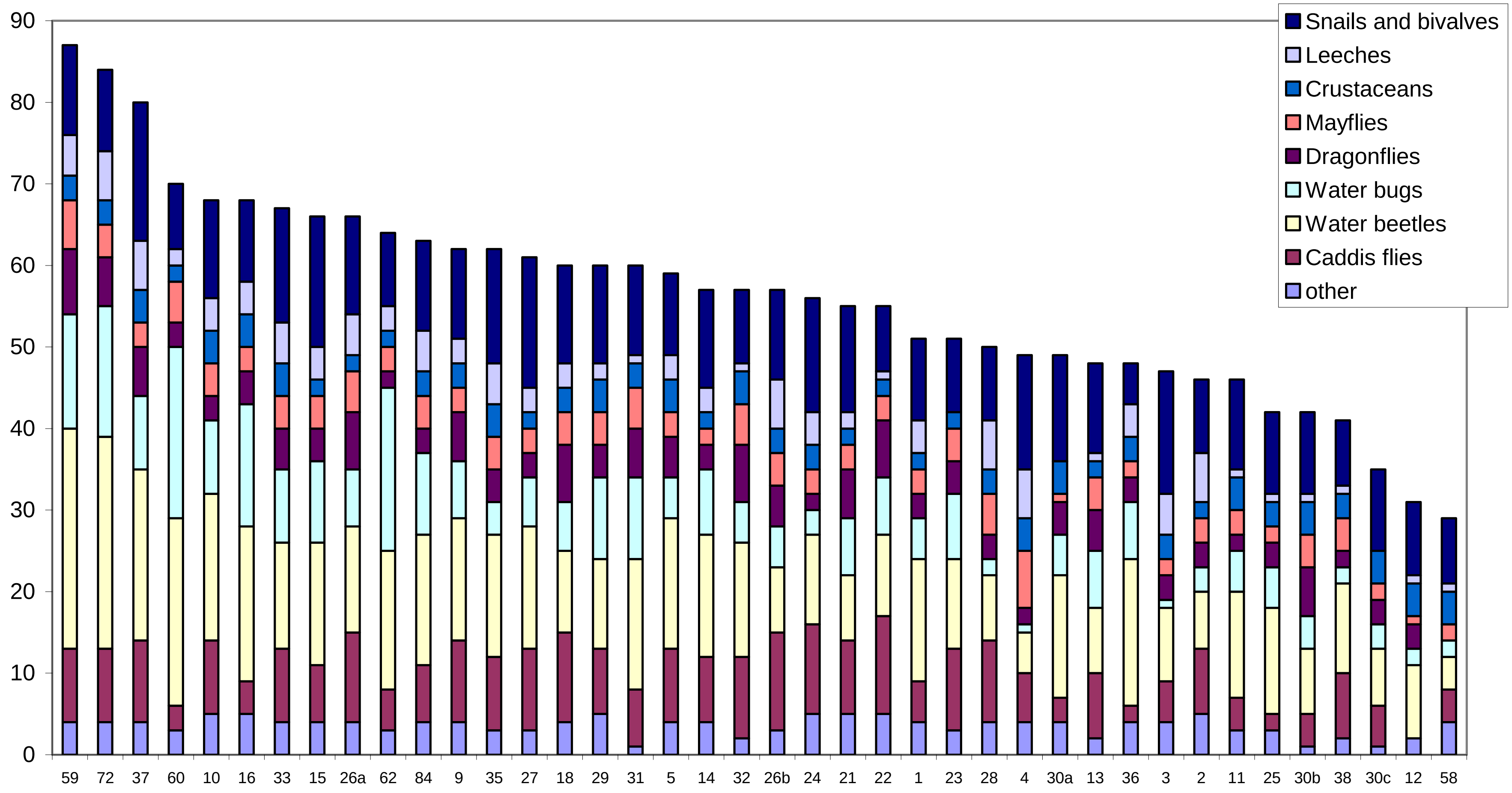
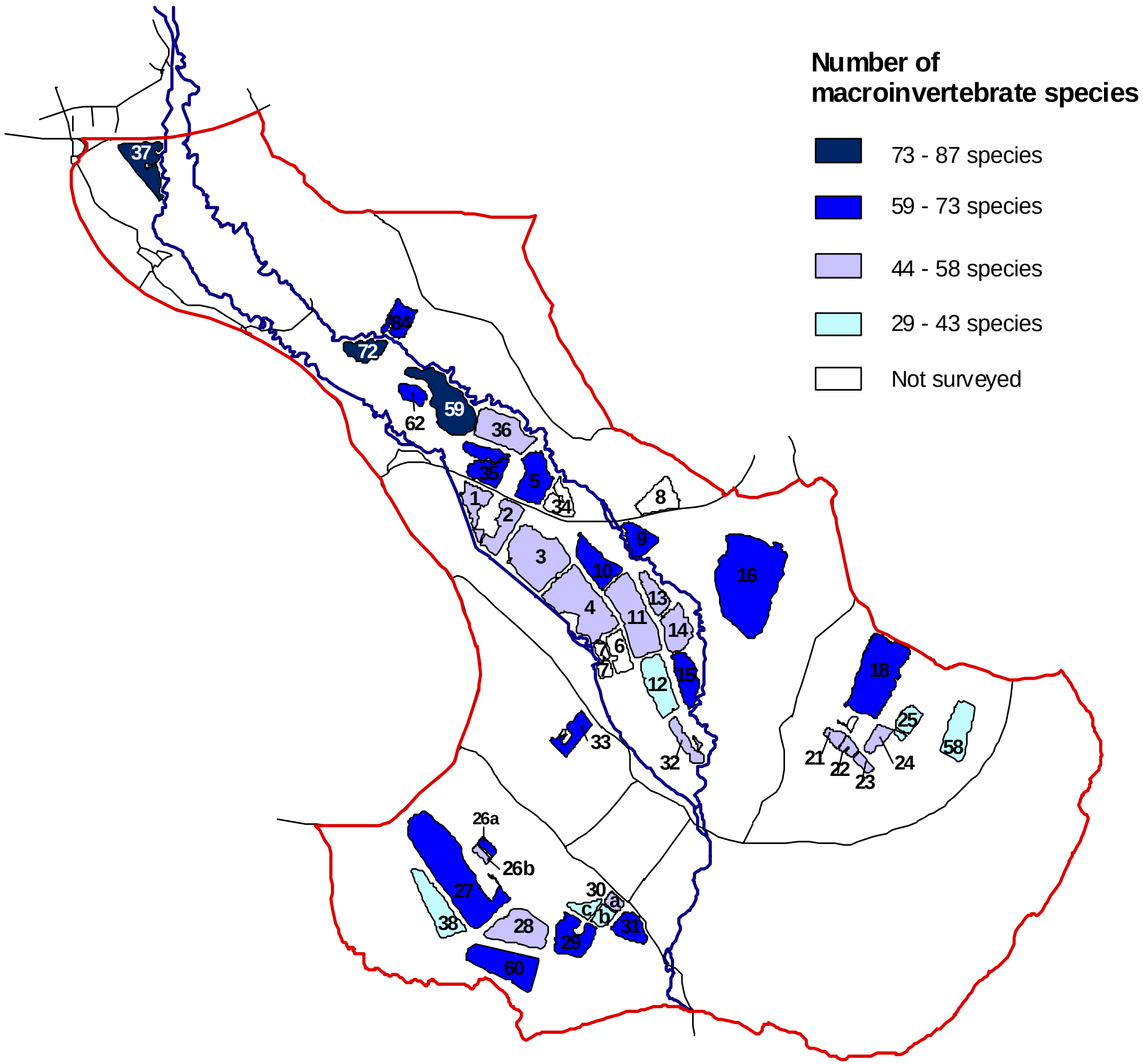
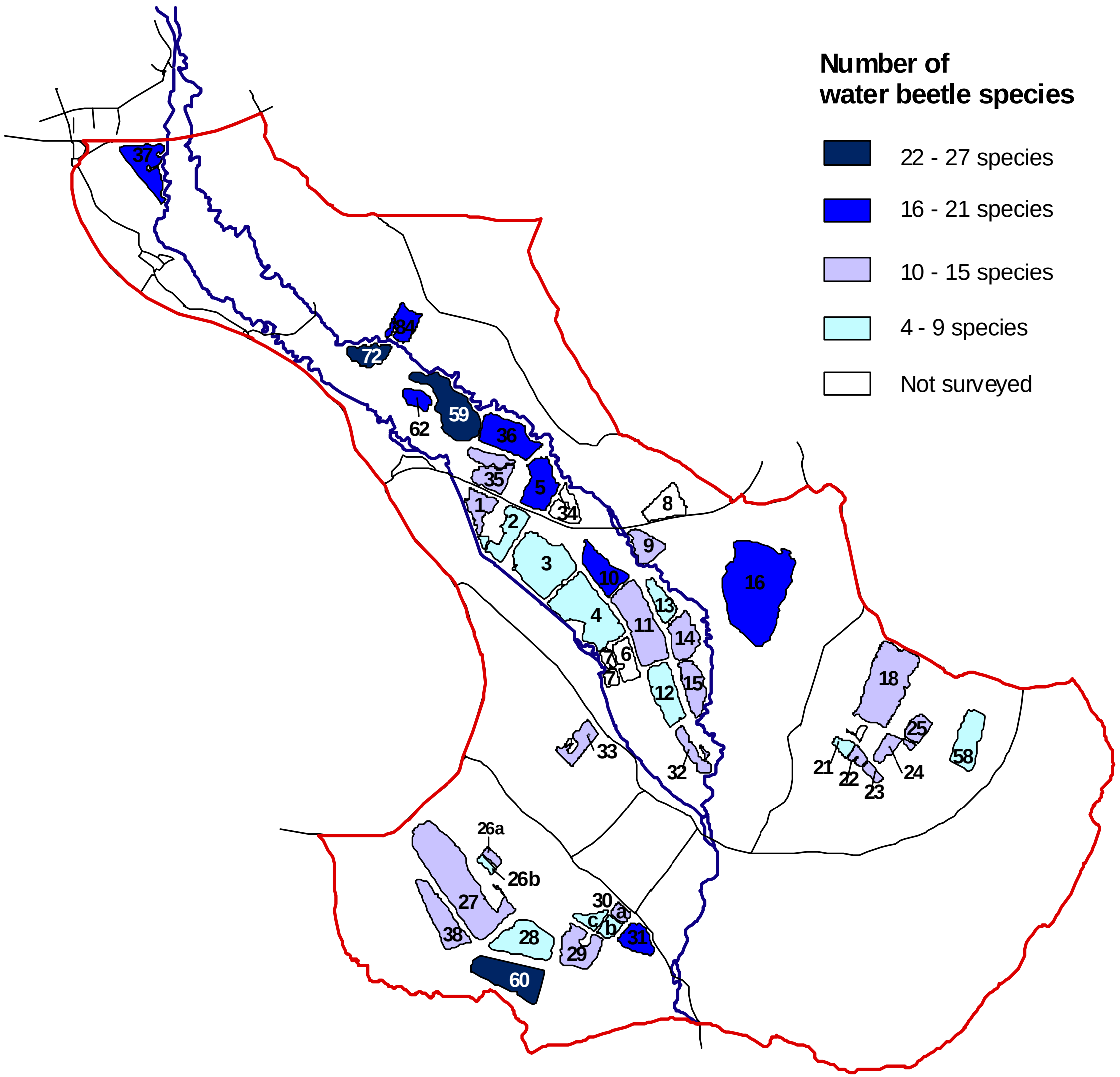


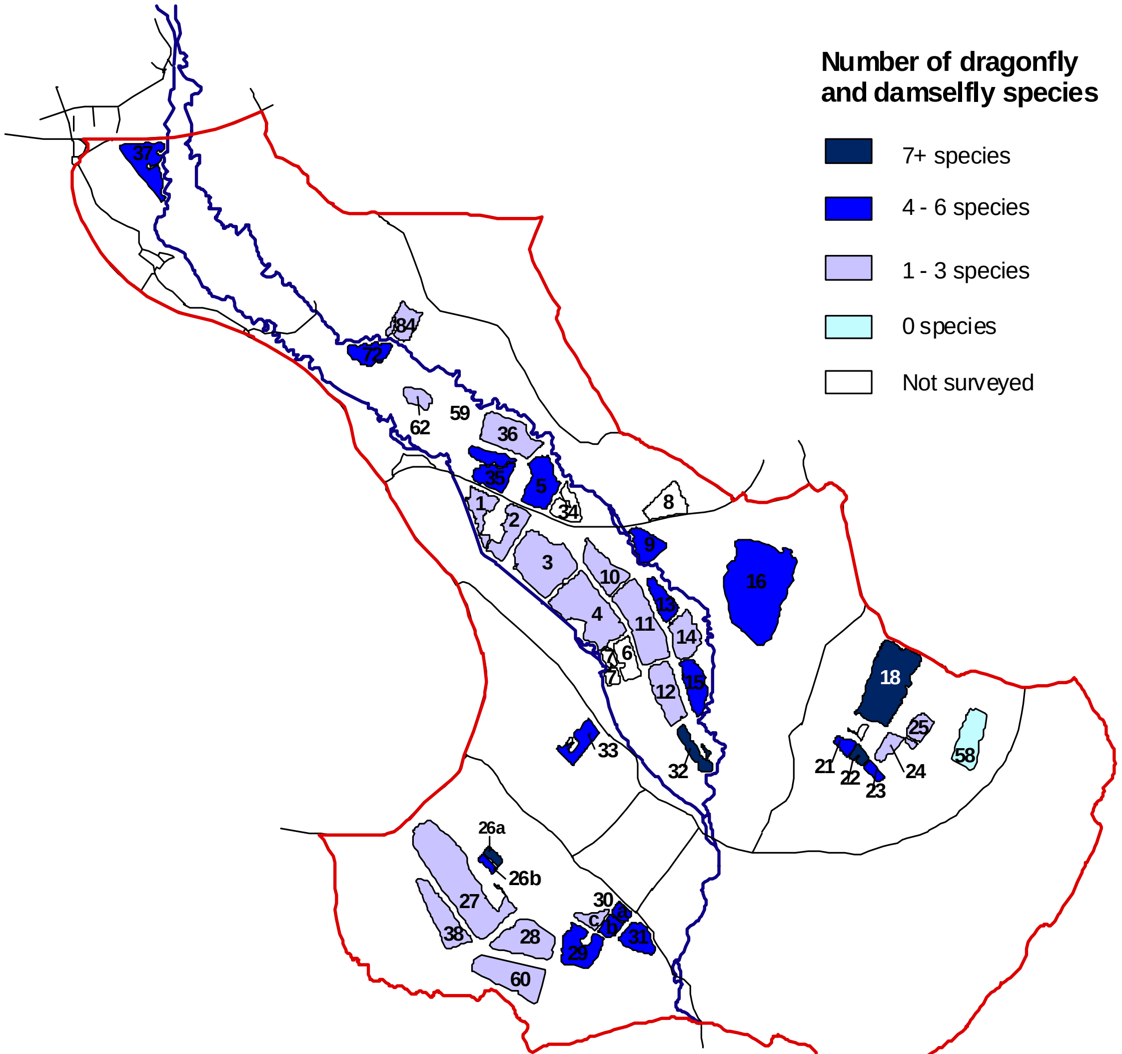
Figure 27 Number of macroinvertebrate species in each gravel pit (LWV)



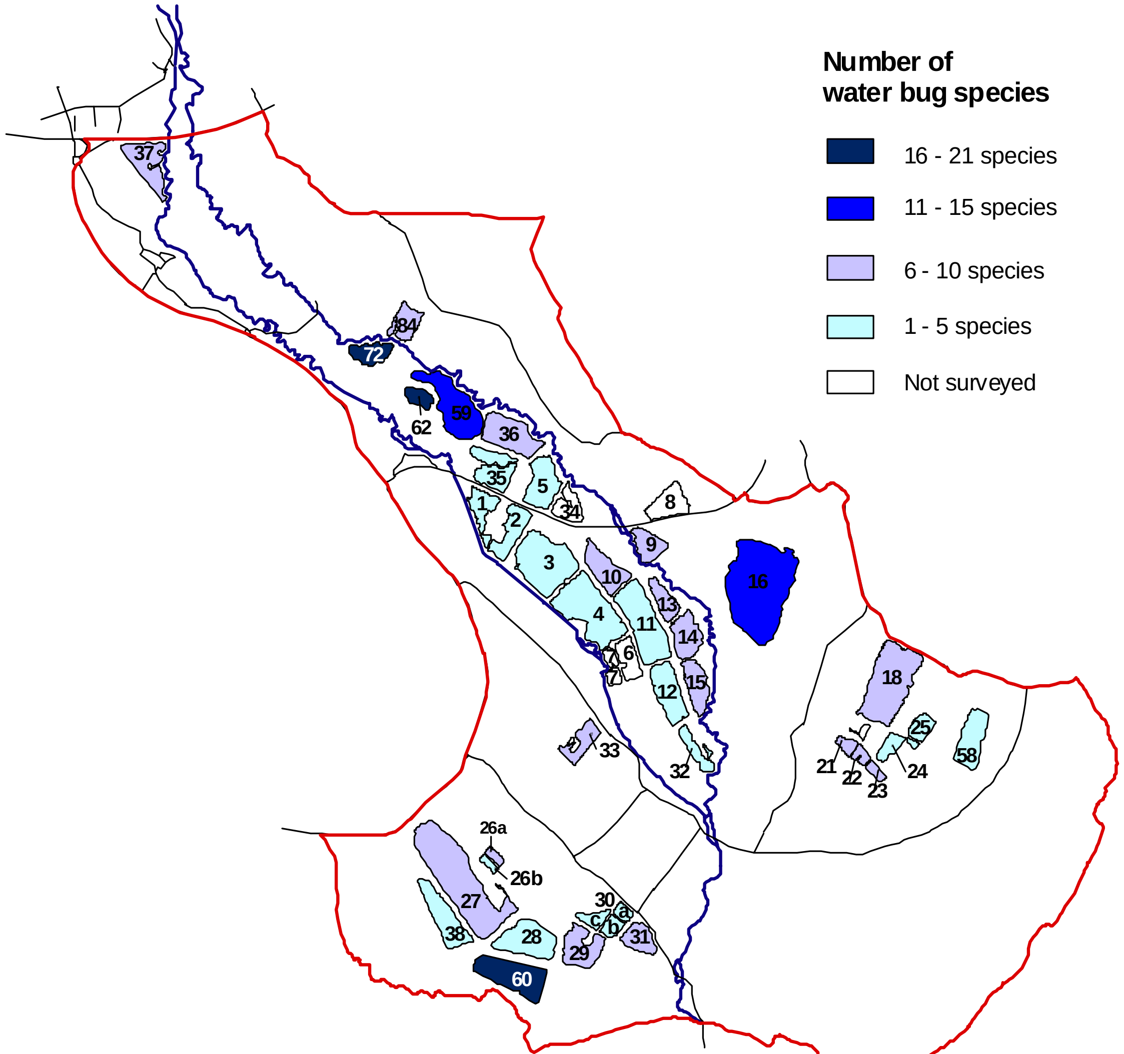
Map 10 Macroinvertebrate species diversity in the LWV gravel pits



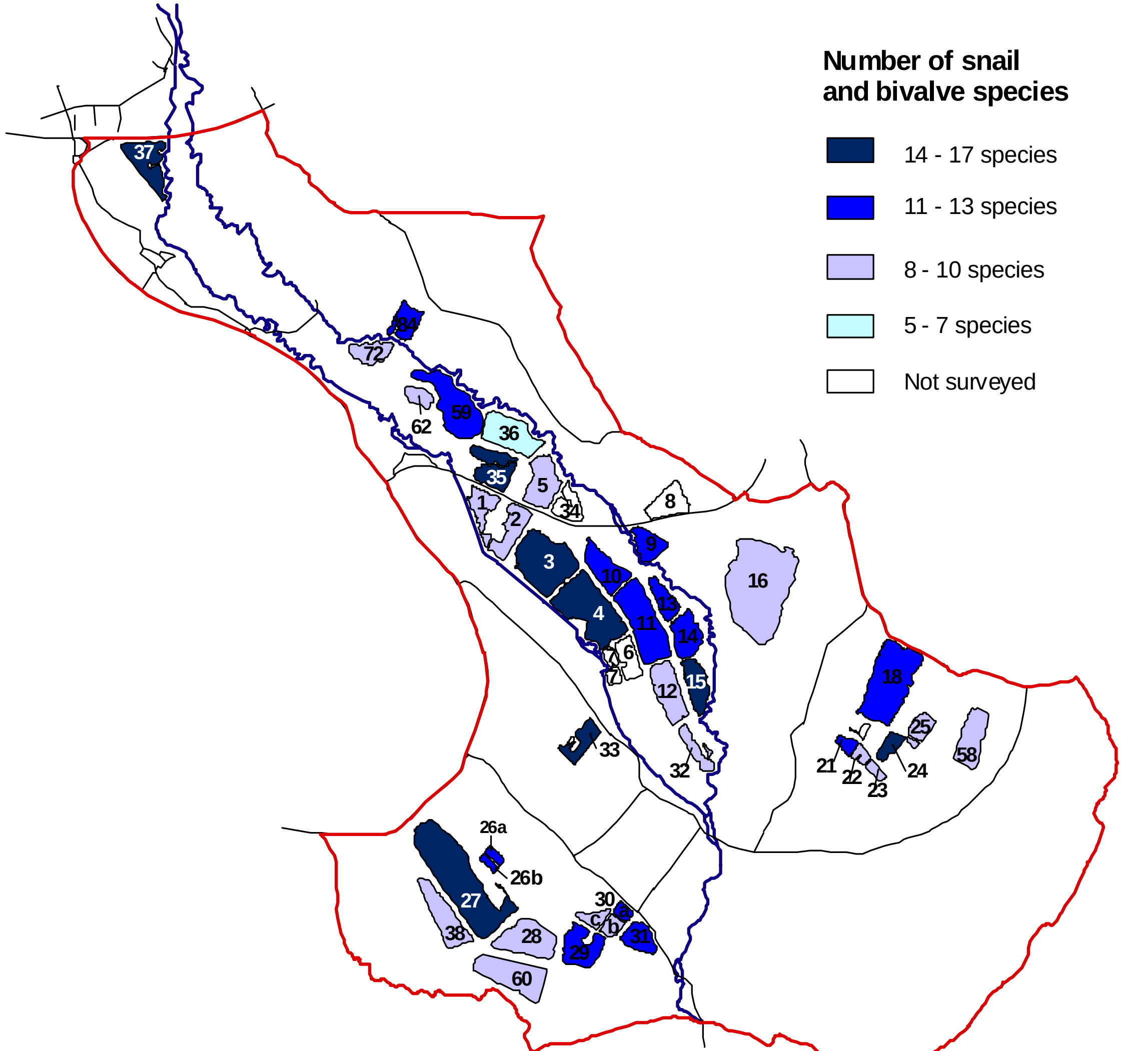
Map 11 Water beetle species diversity in the LWV gravel pits



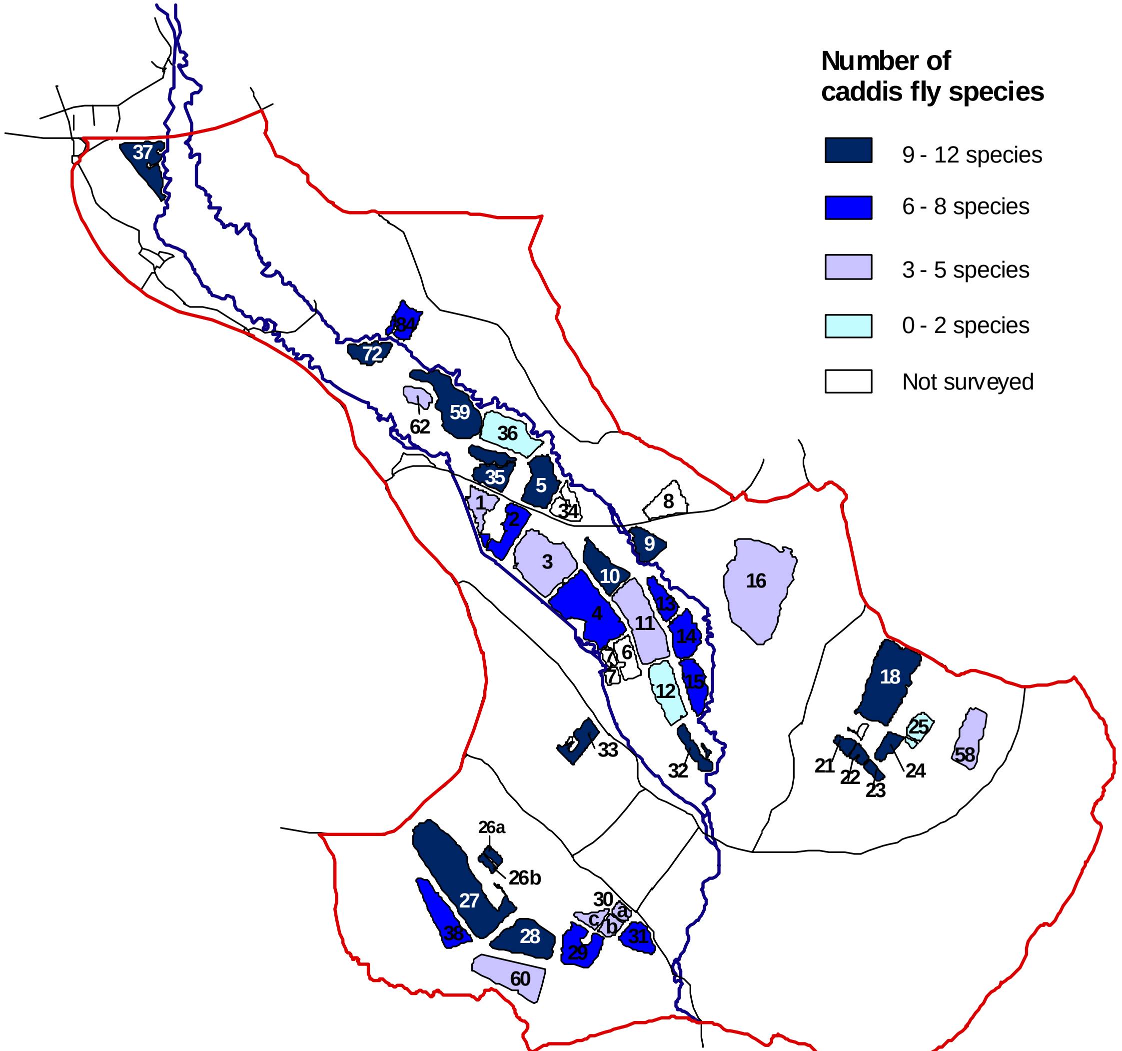
Map 12 Dragonfly species diversity in the LWV gravel pits



Map 13 Water bug species diversity in the LWV gravel pits



Map 14 Snail and bivalve species diversity in the LWV gravel pits



Map 15 Caddis fly species diversity in the LWV gravel pits

3.4.3 Species Rarity

3.4.3.1 Macroinvertebrate species

A total of 29 uncommon invertebrate species were recorded in the 40 LWV gravel pits (Table 8), which represent 15 % of the total number of species found in the current survey. Eleven species had Nationally Scarce status, all water beetles, and 18 species had local status. Of particular interest was the record for the White-clawed Crayfish (*Austropotamobius pallipes*), a BAP species (see Section 3.4.4).

The diving beetle *Ilybius fenestratus* was the most commonly recorded Nationally Scarce species occurring in 70% of the pits (Table 8). *I. fenestratus* is one of relatively few larger diving beetles predominantly confined to permanent ponds and lakes, probably because it is adapted to tolerate fish predation (Foster, 2000).

Several of the Nationally Scarce species that were recorded are characteristic of new or disturbed habitats. These included the rather uncommon Nationally Scarce 'A' diving beetle *Hygrotus nigrolineatus,* the scavenger beetle *Enochrus melanocephalus* and the diving beetle *Hydroglyphus geminus. H. nigrolineatus* was first recorded in the UK in Kent in 1983 and is a pioneer species which, in Britain, seems to be particularly associated with habitats created by gravel extraction (Foster, 2000). *Enochrus melanocephalus* is frequently found in newly created habitats and the tiny (2 mm) diving beetle *Hydroglyphus geminus* is associated with a variety of pioneer habitats.

Four Nationally Scarce water beetle species were recorded which are associated with fens or well-developed marginal vegetation: *Anacaena bipustulata, Cercyon sternalis, Berosus affinis* and *Hydraena testacea* (Foster, 2000). The small scavenger beetle *Limnebius nitidus* is characteristic of another distinctive habitat, moist clay or silt beds at the edges of either standing or running water bodies (Foster, 2000). This species was found in two sites, Site 37 (Witney Lake) and Site 26a (Lincoln Lake).

The structural diversity of some pits allowed some unexpected species to occur. Thus the Nationally Scarce scavenger beetle *Helophorus granularis* is more typical of temporary waters than of gravel pits. In Oxfordshire, it is known to occur in shallow temporary ponds on Pixey Mead, a traditionally managed flood meadow. In the Windrush complex *H. granularis* was recorded in very shallow grassy pools at the edge of Pit 72 (Graham Water) which, although connected to the main waterbody in the winter, probably dry up in the summer. This highlights the importance, for macroinvertebrate diversity, of maintaining a range of aquatic habitats as part of the restoration process.

Local species were recorded in a range of groups including snails, leeches, crustaceans, damselflies, water bugs, water beetles and caddis flies (Table 8). Local species particularly associated with gravel pits include the Smooth Ram's-horn (*Gyraulus laevis*), the water bug *Micronecta scholtzi* and The Nerite (*Theodoxus lacustris*).

Table 8 Nationally Scarce and local macroinvertebrate species recorded in the LWV gravel pits

Latin Name	Common name	National Status	% occurrence
Hygrotus nigrolineatus	A diving beetle	LRnsA	5
Haliplus laminatus	A crawling water beetle	LRNnsB	8
Hydroglyphus pusillus	A diving beetle	LRNnsB	3
Ilybius fenestratus	A diving beetle	LRNnsB	70
Anacaena bipustulata	A scavenger beetle	LRNnsB	53
Enochrus melanocephalus	A scavenger beetle	LRNnsB	15
Berosus affinis	A scavenger beetle	LRNnsB	10
Cercyon sternalis	A scavenger beetle	LRNnsB	3
Helophorus granularis	A scavenger beetle	LRNnsB	3
Hydraena testacea	A scavenger beetle	LRNnsB	5
Limnebius nitidus	A scavenger beetle	LRNnsB	5
Theodoxus fluviatilis	The Nerite	Local	8
Gyraulus laevis	Smooth Ram's-horn	Local	58
Hemiclepsis marginata	A leech	Local	30
Glossiphonia heteroclita	A leech	Local	13
Austropotamobius pallipes	Altantic Stream Crayfish	Local	3
Erythromma najas	Red-eyed Damselfly	Local	45
Mesovelia furcata	A water bug	Local	45
Gerris argentatus	A pond skater	Local	15
Ranatra linearis	Water Stick Insect	Local	45
Micronecta scholtzi	A lesser water boatman	Local	33
Cymatia bonsdorffi	A lesser water boatman	Local	8
Cymatia coleoptrata	A lesser water boatman	Local	35
Corixa panzeri	A lesser water boatman	Local	15
Sigara concinna	A lesser water boatman	Local	10
Hygrotus versicolor	A diving beetle	Local	10
Cercyon marinus	A scavenger beetle	Local	3
Ecnomus tenellus	A caddis fly	Local	15
Mystacides nigra	A caddis fly	Local	63

Notes: see Section 2.5 for sources from which national conservation status were derived.

3.4.3.2 Uncommon species richness and the Species Rarity Index (SRI)

All 40 LWV gravel pits surveyed supported at least one local macroinvertebrate species and Nationally Scarce species occurred in 35 lakes (c. 90%). Overall, the average number of uncommon macroinvertebrate species recorded per pit was 6.3 ± 3.2.

The Species Rarity Index (SRI, see Section 2.5) was 1.17 on average, and ranged from 1.00 to 1.30. The lake with the highest SRI was Pit 60 (Standlake Common Nature Reserve), which supported 13 uncommon species, including four Nationally Scarce water beetles (Map 16). This gravel pit was restored for nature conservation purposes and includes a range of aquatic habitats, including small, shallow pools around its margins, which make an important contribution to macroinvertebrate diversity at the site. Other lakes in the LWV with relatively high SRIs included Pit 31 (Barnes Lake), Pit 14 (Unity Lake), Pit 26a (Lincoln Lake), and Pit 59 (Gill Mill).

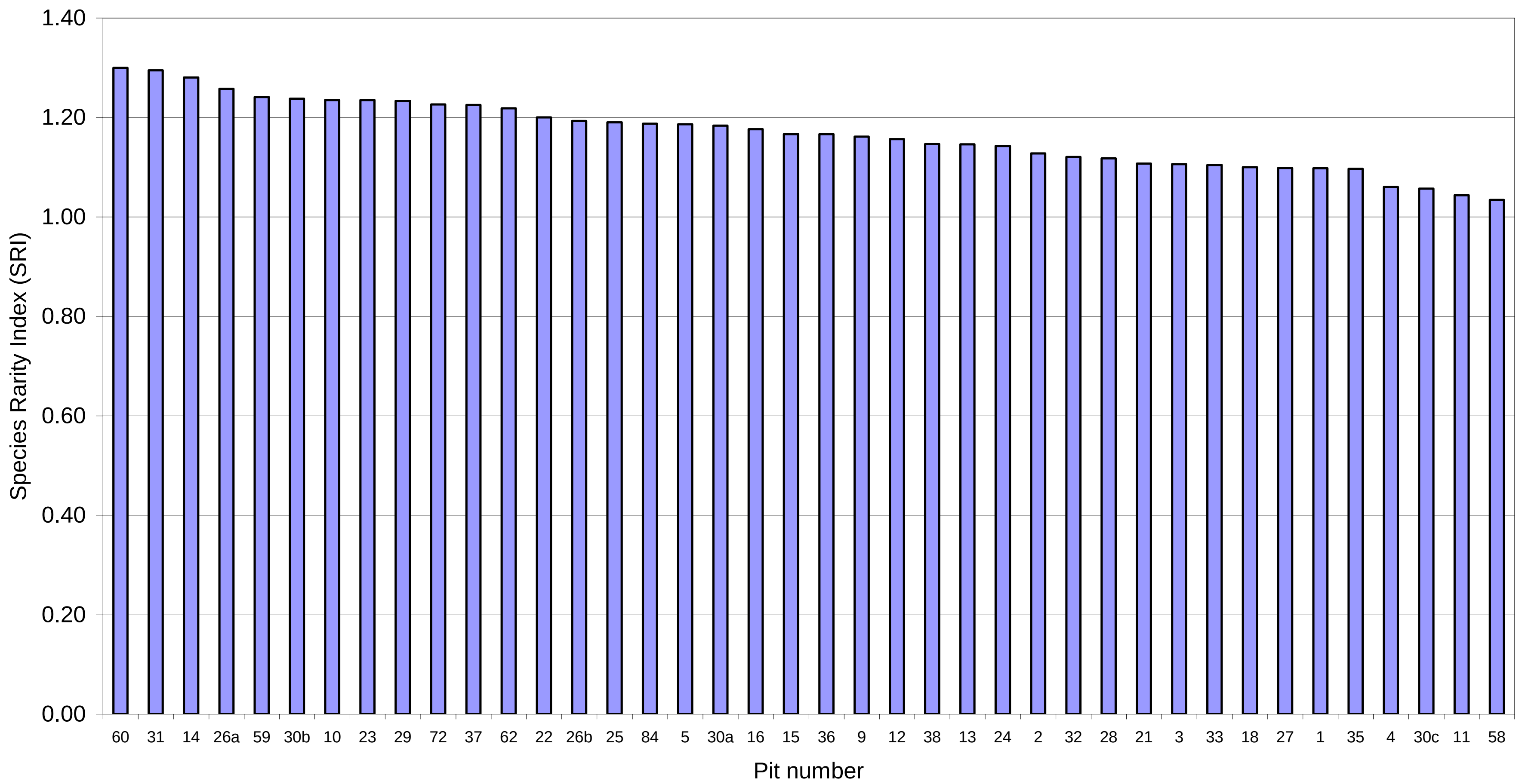
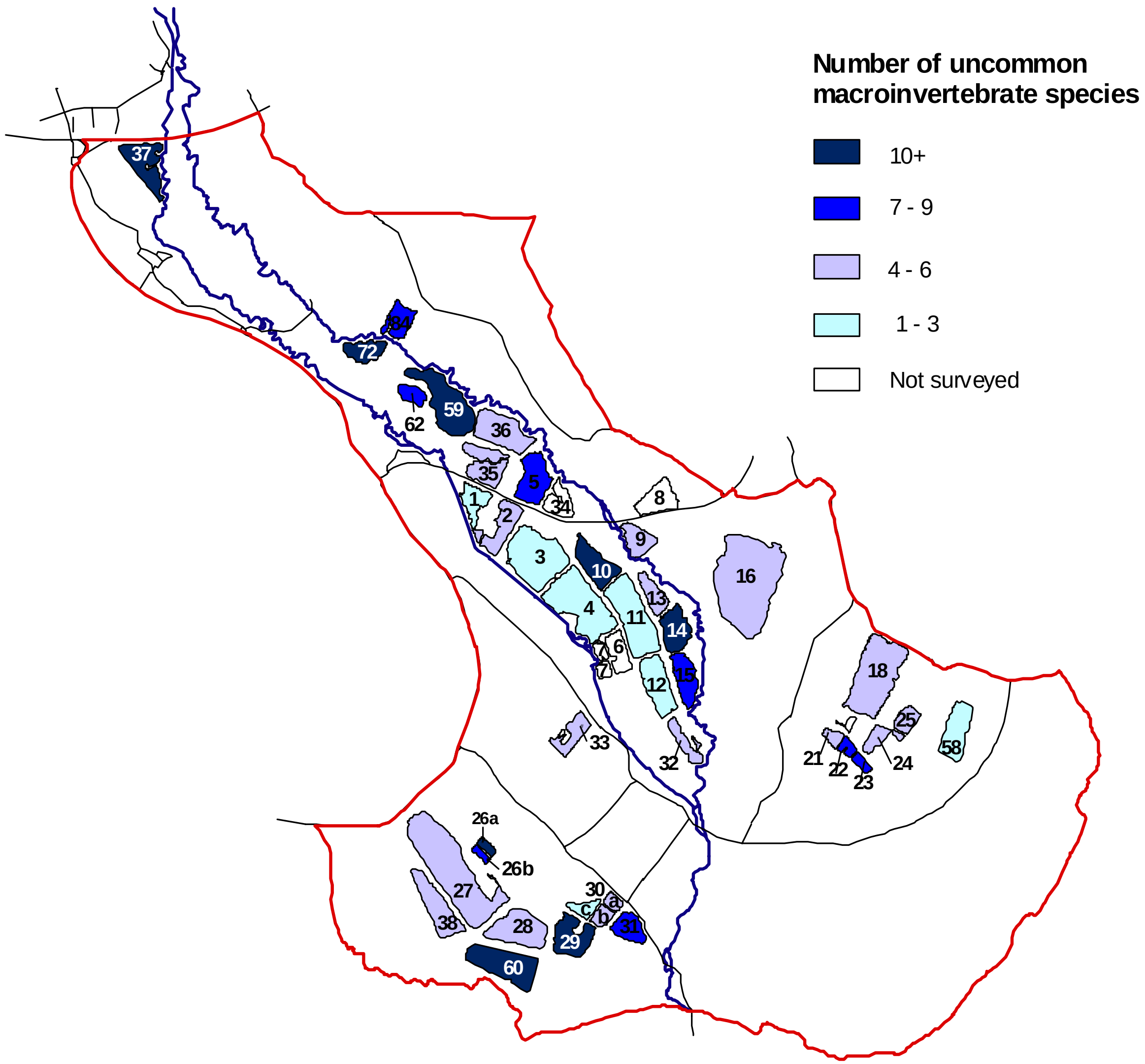


Figure 28 Macroinvertebrate Species Rarity Index (SRI) for the LWV gravel pits



Map 16 Uncommon macroinvertebrate species richness in the LWV gravel pits

3.4.4 Crayfish

The presence of crayfish was confirmed in 14 gravel pits in the Lower Windrush Valley (Map 17). Records were predominantly of the Signal Crayfish (*Pacifastacus leniusculus*) but the native White-Clawed Crayfish (*Austropotamobius pallipes*) was recorded in Pit 33 (Downs Road). The occurrence of White-clawed Crayfish was not previously known at this site, making this a new record for Oxfordshire. White-clawed Crayfish are now rarely recorded in the upper Thames and were thought to be all but extinct in the River Windrush.

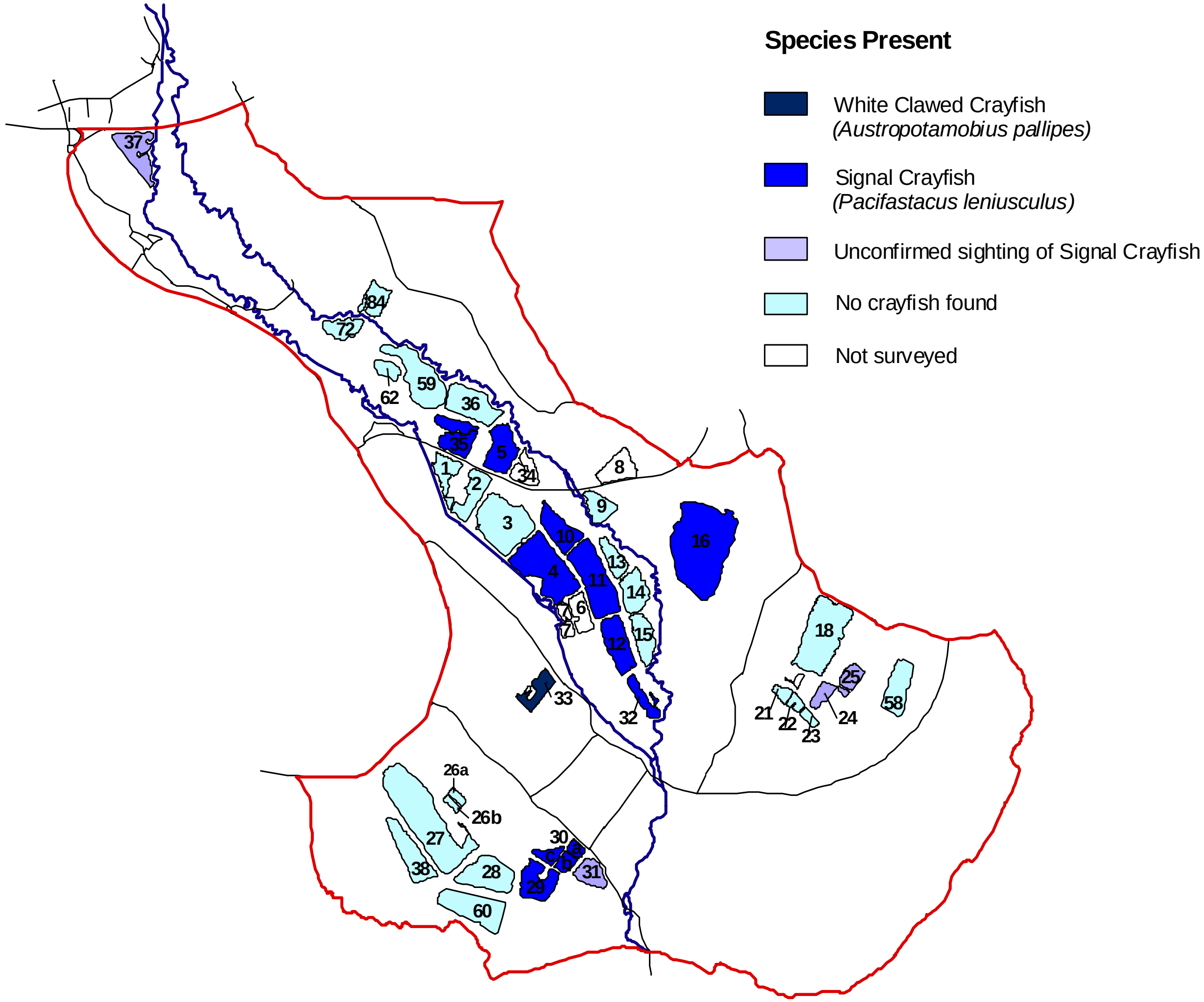
Signal Crayfish were recorded in 12 of the gravel pits. There is anecdotal evidence that this species was also present at another five sites (Map 17) where it has been seen by fishermen or landowners. It is also very likely that Signal Crayfish are present in Pit 3 (Hardwick Leisure Park 1). This pit has a direct connection with Pit 4, which is known to support the species. From discussions with landowners, the occurrence of Signal Crayfish in the lakes seems to be mainly the result of deliberate introductions by landowners or fishermen, rather than by natural dispersal from the River Windrush, where they are known to occur in abundance.

3.4.5 Unique species

Lakes which supported unique species, i.e. species which were recorded from one site only in the current survey, made an important contribution to the overall diversity of the lake complex, with unique species representing approximately 15% of the total species pool. Almost half the gravel pits surveyed in the LWV supported unique species (Table 9) with the greatest number being recorded in Pit 72 (Graham Water) with five unique species, including a Nationally Scarce water beetle (*H. granularis*, see Section 3.4.3.1).

Table 9 List of gravel pits which supported a unique macroinvertebrate species

Pit number	Pit name	Number of unique species
72	Graham Water	5
33	Downs Road	3
60	Standlake Common Nature Reserve	3
9	Vauxhall Lake	2
27	Three T's Lake	2
62	Founders Lake	2
4	Hardwick Leisure Park 2	1
14	Unity Lake	1
16	Dix Pit	1
18	Stoneacres Lake	1
21	Linch Hill Complex 3	1
24	Willow Pool	1
26a	Lincoln Lake	1
31	Barnes Lake	1
32	Hunts Corner	1
38	Shifford Lake	1
84	Claire Lake	1



Map 17 Occurrence of White-clawed Crayfish (*A. pallipes*) and Signal Crayfish (*P. leniusculus*) in the LWV gravel pits

3.4.6 Factors influencing macroinvertebrate richness and rarity

Correlations between physico-chemical variables and species richness and rarity showed that macroinvertebrate diversity in the LWV pits was probably related to: (i) marginal complexity, (ii) lake age, or more specifically the amount of time since the gravel pits filled with water, and (iii) after-use (see Appendix 3 for correlation coefficients). These three factors are briefly discussed below.

- *Lake age* (years since filling with water). Correlation analysis indicated that older pits generally had fewer invertebrate species, although there was no evidence that numbers of uncommon species declined with lake age. The decline in overall species richness with age was probably related to changes in habitat suitability for different invertebrate groups as pits aged. Older lakes were generally more nutrient rich and more shaded than younger lakes, both factors which tended to reduce the availability of habitats generally. In addition, older pits also tended to be preferred by molluscs (snails and bivalves) and caddisflies which, compared to the beetles, were a relatively species poor group. In contrast, younger pits were more likely to provide good habitat structure for water beetles and, since water beetles are a species rich group generally, this led to higher overall species richness.
- *Marginal complexity*. High marginal complexity was generally associated with increased habitat diversity, which in turn led to increased macroinvertebrate species richness. This trend was particularly apparent for water beetles.
- *Afteruse*: Lakes managed for conservation and those with low intensity fishing tended to have richer invertebrate assemblages than those which were intensively fished or were used for watersports. This was probably the result of both direct and indirect impacts on invertebrate assemblages. Thus in stocked lakes with high fish biomasses, predation pressure on invertebrates would almost certainly be greater than in lakes with more natural fish populations. In addition, such waters commonly have high densities of bottom feeding species, such as carp, which tend to reduce the abundance of submerged vegetation and, therefore, the availability of invertebrate habitat. Water sports also have a pronounced impact on lake invertebrate assemblages, creating open, wave-washed margins with little vegetation or other suitable habitat for macroinvertebrates.

3.4.7 Macroinvertebrate assemblages and their relationship with physico-chemical variables

TWINSPAN classification of macroinvertebrate species data identified five assemblage types in the LWV (Figure 29, Map 18). The eigenvalues, which show the strength of each division, were relatively low, with a range from 0.096 to 0.151. This suggested that the macroinvertebrate species composition of the gravel pit assemblages was relatively similar between sites. A constancy table, which shows the occurrence of species in the TWINSPAN groups is given in Appendix 4 and the five groups are briefly described below.

DCA of the aquatic plant data showed that the TWINSPAN end groups were relatively well defined (Figure 30). Axis 1 and Axis 2 accounted for 23% and 11% of the variation in the data, respectively. Correlations between the axes scores and the physico-chemical variables showed that axis 1 was a gradient relating to (i) water quality, (ii) the surrounding landuse, (iii) lake surface area, (iv) age and shade (Figure 30, see Appendix 3 for correlation coefficients). Statistical analyses of the biotic data showed that Axis 1 was also a richness and rarity gradient, particularly in terms of the number of water beetles and water bugs. Axis 2 was correlated with (i) the fishing intensity and (ii) marginal complexity. Axis 2 was also a richness and rarity gradient.

Based on TWINSPAN and DCA, the main macroinvertebrate assemblage types identified in the LWV can broadly be described as follows:

- ***Group 1*** (3 lakes) was characterised by the occurrence of the water bug *Arctocorisa germani*. Gravel pits in this group tended to be relatively large, with a high proportion of semi-natural landuse in their surrounds, and with relatively high conductivity. The water beetle and water bug communities were relatively rich, including a high number of Nationally Scarce species.

- ***Group 2*** (7 lakes) was characterised by the presence of the caddis fly *Molanna augustata* and the water bug *Plea leachi*. Gravel pits in this group were intermediate between Group 1 and Groups 4/5 in terms of their biotic and abiotic characteristics. This group generally supported a diverse water beetle and water bug assemblage.

- ***Group 3*** (8 lakes) had three indicator species: the caddis fly *Arthripsodes aterrimus*, the leech *Hemiclepsis marginata*, and the aquatic moth *Elophila nympheata*. The physico-chemical characteristics of the gravel pits in this group were intermediate between group 4 and 5.

- ***Group 4*** (14 lakes) was defined by the occurrence of the Red-eyed Damselfly (*Erythromma najas*), a species particularly associated with floating-leaved species, which it needs as perches during the breeding season and as egg-laying sites (Brooks, 1997). Gravel pits in this group tended to be more intensively fished, and with relatively high concentrations of phosphorus. They also had relatively low species richness and rarity.

- ***Group 5*** (8 lakes) was characterised by the occurrence of the Common Water Measurer (*Hydrometra stagnorum*), the Nationally Scarce water beetle *Anaceana bipustulata*, the Common Darter dragonfly (*Sympetrum striolatum*) and the lesser water boatman *Micronecta scholtzi*. Lakes in this group tended to be older and smaller, with relatively high total phosphorus concentrations. They supported a diverse macroinvertebrate community, including uncommon species.

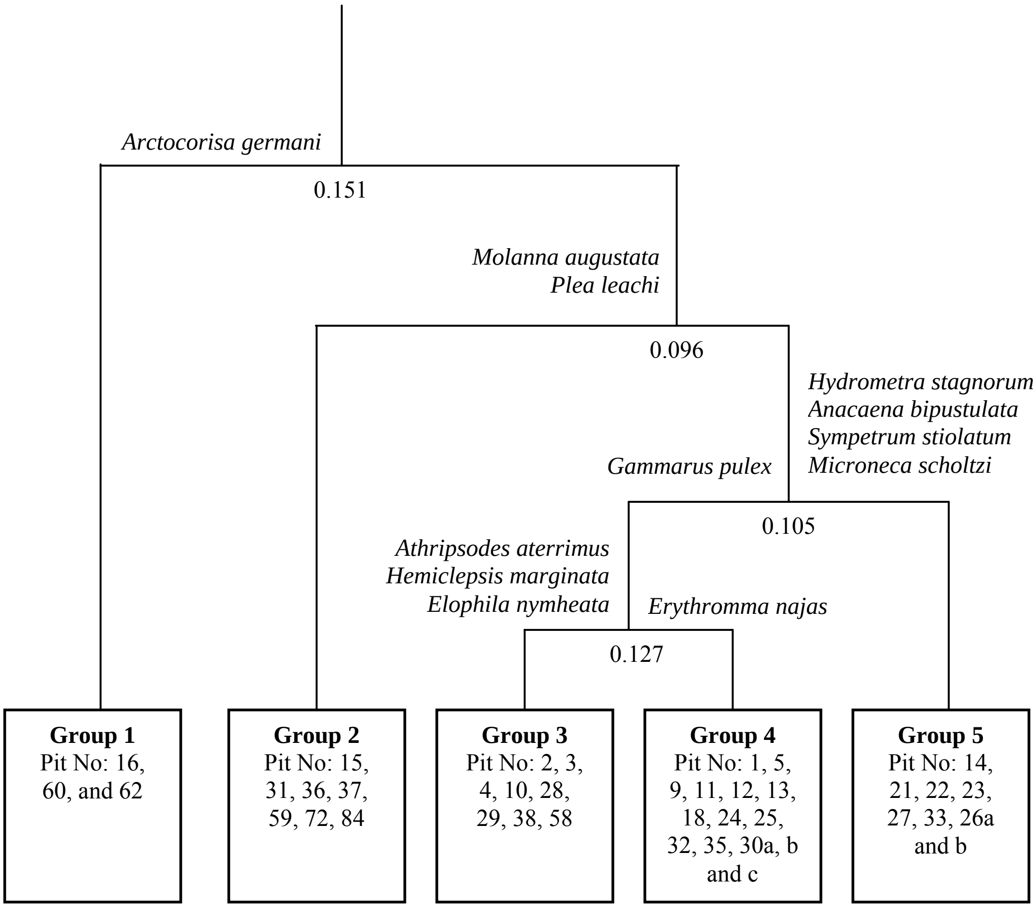
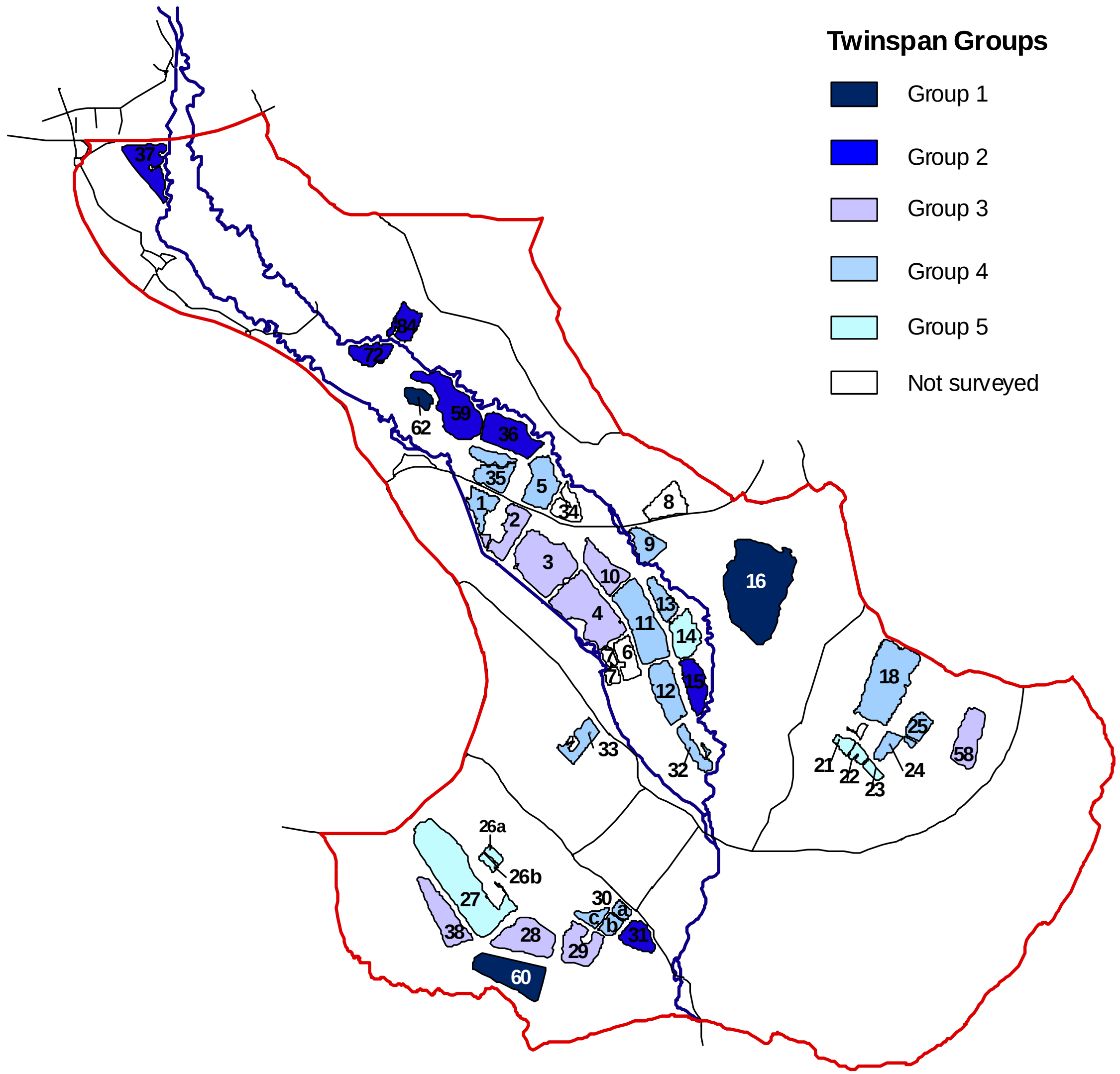


Figure 29 TWINSPAN classification of macroinvertebrate assemblages in the LWV gravel pits



Map 18 TWINSPAN classification of macroinvertebrate assemblages in the LWV gravel pits

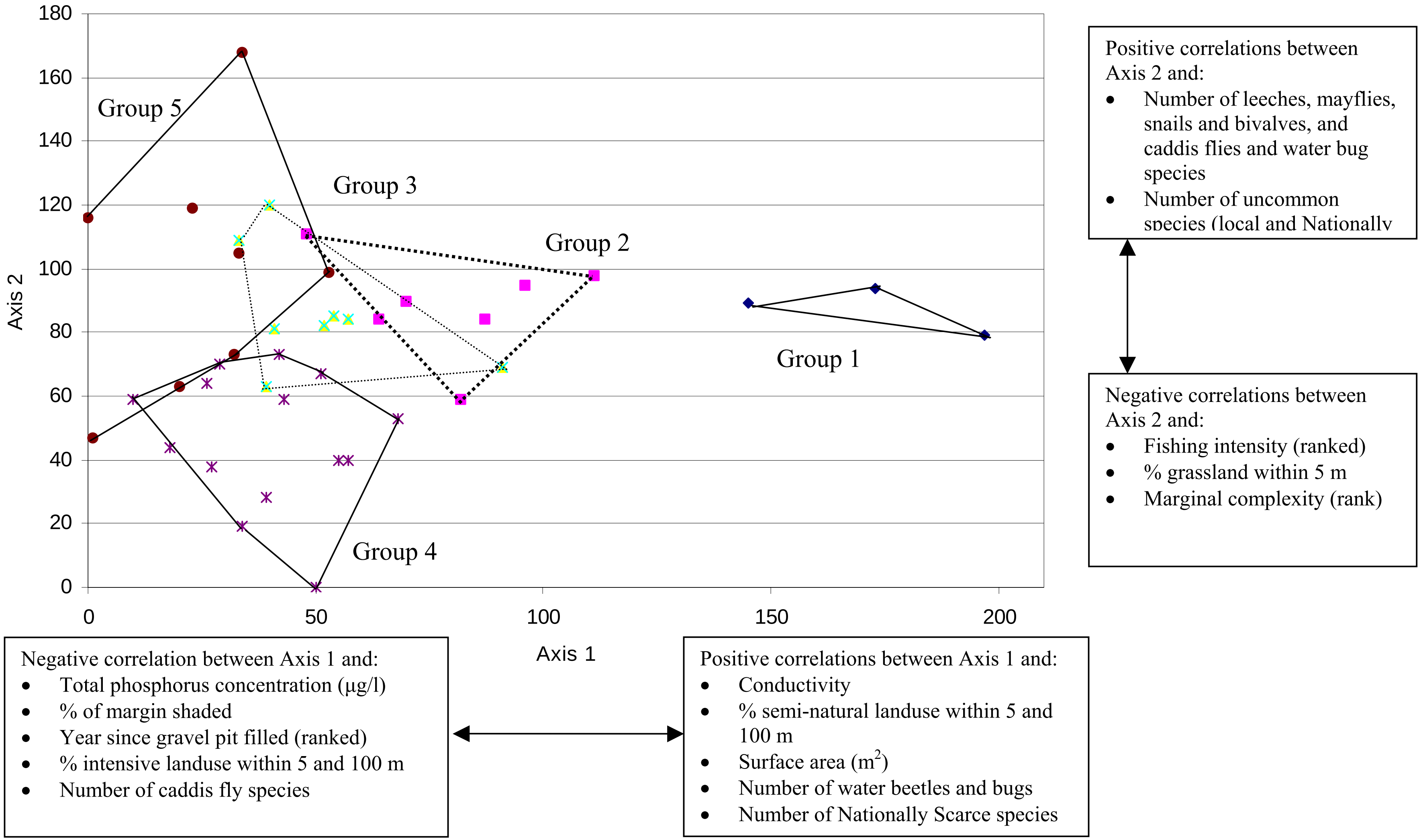


Figure 30 DCA of macroinvertebrate assemblages in the LWV gravel pits

3.5 Summary of macroinvertebrate results

The result of the current survey show that the Lower Windrush Valley gravel pits supported a very diverse macroinvertebrate community. In total, 191 macroinvertebrate species were recorded, which represents c. 25% of aquatic species in Britain, in the groups surveyed. Diversity was particularly high for water snails (23 species), crawling water beetles (Haliplidae, nine species), and 12 breeding species of dragonflies were recorded, which is comparable with data from the Cotswold Water Park. On average, lake species richness was 56.2 ± 12.8. Comparison with data from undegraded lakes and high quality gravel pits confirmed the value of the LWV for macroinvertebrate diversity. A total of eleven Nationally Scarce species were recorded, all water beetles. Local species were recorded in a range of taxonomic groups. Of particular interest was a new record for White-clawed Crayfish (*Austropotamobius pallipes*) in the oldest gravel pit in the LWV. All 40 gravel pits supported at least one uncommon species, and c. 90% a Nationally Scarce species. Species richness and rarity were primarily related to lake age, the degree of marginal complexity and the amenity use of the lakes. Generally, heavily used pits were less diverse. Of particular concern was the presence of two invasive macroinvertebrate species, which were recorded in over a quarter of the lakes: Signal Crayfish (*Pacifastacus leniusculus*) and Zebra Mussel (*Dreissena polymorpha*).

4. The importance of the Lower Windrush Valley for birds

4.1 Introduction

Prior to this Baseline Ecological Assessment being undertaken there was relatively little reliable information available on the habitats and species associated with the lakes in the Lower Windrush Valley. Of the existing records, it is only the surveys of wintering wildfowl undertaken by the Oxford Ornithological Society (OOS) that offer a comprehensive data set and so, at present, it is this particular group of species that traditionally, tends to have the highest profile when restoration plans are designed and management plans are prepared with nature conservation as the main objective. The information in this particular section was supplied by the OOS and is included in order to help make an initial assessment as to whether there are any clear relationships between the lakes that are of highest value for birds and those that are important for plants or invertebrates. It should be noted that this section only covers wintering wildfowl and does include breeding birds, gulls or other bird species commonly associated with lakes and adjacent habitats.

4.2 The Wetland Bird Survey (WeBS)

Gravel pits in the Lower Windrush Valley (LWV) have been included in the Wetland Bird Survey (WeBS), organized nationally by the BTO, WWT, RSPB and JNCC, for several years. Surveys are carried out by local volunteer birdwatchers. At two critical times of year (November and February) Oxford Ornithological Society (OOS) has been conducting a co-ordinated count to estimate the wintering population over a three-hour period. Survey results are submitted to the organizers of WeBS, who publish an annual report. This report, covering important lakes, gravel pits, and estuaries over the whole of Great Britain, enables the data from the Lower Windrush Valley to be seen in a national context.

In this wider context, although the Lower Windrush Valley covers a relatively small area, it has been shown to be of national importance for certain species. The criterion for a site being defined as “of national importance” (according to the EC Directive on the Conservation of Wild Birds) for a bird species is that it regularly holds 1% or more of the estimated national population. Thus the LWV has been designated as being of national importance for Gadwall, Pochard, Tufted Duck, Coot, and Lesser Black-backed Gull.

In addition to these species, large numbers of other waterfowl frequent the gravel pits, these include Mallard, Wigeon, and feral Geese, as well as good numbers of Great Crested Grebe, Goldeneye, Shoveler, Teal, Mute Swan and Cormorant. Comparative rarities such as Little Egret, Water Rail, Mandarin, and Smew also occur more irregularly.

4.3 Importance of individual pits

Ranking the importance of individual pits for waterfowl over time is difficult because birds have the ability to move between lakes daily or hourly, for example according to weather conditions or disturbance.

For the purpose of this analysis, counts in February and November 2003 and 2004 are analysed. There were large, not untypical, variations in the total numbers of birds counted on these occasions:

- Feb 2003 3,270
- Nov 2003 5,755
- Feb 2004 4,231
- Nov 2004 4,974

Overall, between six and nine of the pits accounted for some two-thirds of the total wildfowl wintering in the area (Table 10). Pit 16 (Dix Pit) has fairly consistently had the highest number of birds, and if one were to include gulls (mainly Lesser Black Backed and Black-headed) this position would be strengthened.

Gulls are not wildfowl and so are not included in this data set but it is worth noting that the landfill sites adjacent to Dix Pit attract significant populations of gull species which feed amongst the rubbish and so this somewhat unusual habitat does contribute to both bird numbers and diversity at this particular site.

Table 10 Gravel pits in the Lower Windrush Valley supporting 5% or more of the total count of birds in February and November 2003/4

Pit number	2003		2004	
	Feb (%)	Nov (%)	Feb (%)	Nov (%)
16	17	35	13	20
38	9	5	14	16
27	Ж	11	Ж	10
28	7	7	5	8
11	7	5	5	7
58	6	Ж	7	5
18	8	6	5	5
3	6	Ж	5	Ж
60	6	Ж	12	Ж
4	5	Ж	Ж	Ж
Total >5%	71	69	66	71

Ж = less than 5%.
Figures exclude gulls, which are not always fully included in the counts.

4.4 Number of species per gravel pit

The mean number of waterfowl species per gravel pit, taking account of all sites, was just under six. The top five pits supported between seven and 16 species. In general, the pits with the highest total number of birds also supported the greatest number of species.

Table 11 Numbers of waterfowl species recorded in the most species-rich pits in the Lower Windrush Valley

Pit number	2003 Feb	2003 Nov	2004 Feb	2004 Nov
16	16	16	14	15
38	12	15	9	17
28	6	7	10	7
11	9	7	8	10
18	16	9	10	11
Average of above	12	11	10	12
Average of all pits	5	6	6	6

4.5 Rare species

For the purpose of this analysis, "rare" species are taken to mean those which have been recorded in numbers under four on any one of the counts conducted in the period 2003 and 2004. Nine species, some of which are feral, fall into this category:

- Greylag Goose — Pit 10
- Snow Goose — Pit 60
- Shelduck — Pit 3
- Mandarin — Pit 27
- Pintail — Pit 16
- Red-crested Pochard — Pit 10 (twice) & Pit 58
- Smew — Pits 18 & 28
- Goosander — Pits 18 & 38
- Ruddy Duck — Pits 16, 27, & 38

It will be seen that with the exception of the Greylag on Pit 10 (WOSC), all of the pits listed above are those showing the greatest number of birds. In other words, a pit that is good for numbers is also more likely to harbour the rarities.

4.6 Factors affecting waterfowl diversity

It is difficult to review the characteristics of the individual pits to determine why each is good or less good for birds: however the pits listed in the above paragraphs that attract the greatest waterfowl numbers and diversity do have certain qualities.

Size - The pits which are best for birds are generally amongst the largest. This is logical, as birds come here not only for feeding, but also for refuge, and the larger pits provide more security for them to move about in.

Tree cover - For the same reason, the better pits are not hemmed in by trees. Too many trees make flight access more difficult, and provide cover for predators. Open surroundings are much preferred by waterfowl.

Islands - An additional advantage of several of these pits is the presence of islands. Islands provide places for birds to roost where there are few land predators, and for the same reason are favoured as nesting sites (e.g. the Cormorant and Grey Heron colonies at Dix Pit).

Extensive margins and shallows - A pit that deserves special mention is Pit 60 (Standlake Common Nature Reserve), which has been designed as a bird reserve. Pit 60 has been carefully planned to have different areas of depth, and with shallows suitable for wading birds.

By comparison the pits which support fewer birds tend to experience a greater degree of disturbance whether this be in the form of boating, shooting, ease of access for dog-walkers, or in some cases fishing.

Results of the winter counts show that the whole of the Lower Windrush is important for birds and while other interests must be catered for, some of the key pits need maximum protection for bird conservation.

5. Ecological assessment

5.1 Importance of the Lower Windrush Valley gravel pit complex

Based on the current evaluation, it is clear that the Lower Windrush Valley (LWV) gravel pits provide an important resource for aquatic biodiversity at a local, regional and, probably, although there is little comparable data, national level.

The LWV gravel pits, as a whole, supported a very diverse biota, which included, approximately 35% of the aquatic macroinvertebrate, and 25% of the wetland plant species found in Britain. The LWV waterbodies also compare well with other high quality gravel pit complexes in southern England, such as those of the Cotswold Water Park, and the Datchet-Chertsey complex (which includes the Wraysbury-Hythe End Gravel Pits SSSI).

Lakes in the LWV fell into Group 1 of the JNCC lake classification. Although the mean number of submerged and floating-leaved species in the Windrush complex was lower than the mean for JNCC Group 1 sites, this may simply have been a reflection of the fact that the JNCC Group 1 lakes were, on average, three times bigger than those of the Lower Windrush. A number of features were of particular interest in the LWV gravel pits:

- *Stonewort diversity*. The LWV supported eight species of stonewort, including the Nationally Scarce and BAP species Lesser Bearded Stonewort (*Chara curta*). The gravel pits in the Stanton Harcourt area have recently been designated as a nationally 'Important Stonewort Area' (Stewart, 2004). The results of this survey confirm the LWV gravel pit complex as exceptionally valuable for its stonewort assemblage.
- *BAP species*. Two BAP species were recorded in the LWV gravel pits: Lesser Bearded Stonewort (noted above) was recorded from three sites, and White-clawed Crayfish (now increasingly uncommon in the Upper Thames catchment), was recorded at one site.
- *Regionally scarce and rare wetland plant species*. A number of wetland plant species, both aquatic and emergent, which are considered rare in Oxfordshire were found to be widespread in the LWV (e.g. Lesser Pondweed, *Potamogeton pusillus*).
- *Macroinvertebrate diversity*. Although few comparative data are available, the results of the current survey indicate that LWV sites are about equal in terms of species richness to high quality lakes of similar size (e.g. Hatchet Pond in the New Forest, Holme Fen lake in Cambridgeshire, Upton Broad in the Norfolk Broads). The LWV lakes also support a range of locally uncommon and Nationally Scarce invertebrate species.
- *Wildfowl diversity*. Recent counts of wildfowl in the WeBS scheme indicates that the Lower Windrush Valley supports nationally important populations (1% of the total) of Gadwall, Pochard, Tufted Duck, Coot, and Lesser Black-backed Gull. Dix Pit (the largest waterbody in the complex) supports the largest numbers of waterfowl with up to 35% of the total number of birds in the complex.

- *Water quality.* Overall, from the single set of chemical data currently available, it appears that the lakes generally have very good water quality, with virtually all sites either mesotrophic or eutrophic/mesotrophic in nutrient status. Mesotrophic and eutrophic lakes are both UK Biodiversity Action Plan priority habitats, so the majority of lakes within the LWV complex are likely to fall under the remit of these Habitat Action Plans (HAPs).

5.2 Value of individual pits in the local context

The majority of lakes within the Lower Windrush complex, regardless of their physico-chemical characteristics or amenity uses, contributed to the overall biological diversity of the study area. This is shown in Table 12, which summarises the value of each gravel pit in terms of different macrophytes and macroinvertebrate groups.

Lakes of high value for wetland plants were not necessarily rich or important for macroinvertebrates, and vice versa. Thus, Pit 12 (Oxlease Lake) had high value for most wetland plant richness and rarity attributes, but had only low or moderate value for macroinvertebrates. Conversely, Pit 26a (Lincoln Lake) supported rich dragonfly and caddis fly assemblages, as well as good numbers of uncommon macroinvertebrate species, but its wetland plant community was of moderate to low value. A number of lakes not particularly rich in either wetland plants or macroinvertebrate species (e.g. Pit 13 Yeoman's Lake), contributed to the diversity of the complex as a whole by supporting unique species not recorded from other pits surveyed.

Within the survey, however, three lakes did stand out as particularly rich for both wetland plants and macroinvertebrates: Pit 37 Witney Lake, Pit 59 Gill Mill and Pit 60 Standlake Nature Reserve. In addition to good water quality, the key factor explaining the value of these sites appeared to be habitat diversity, including extensive areas of shallow water with varied microtopography or well developed low-growing emergent vegetation. The habitat characteristics of each of these lakes are briefly described below.

Pit 37 Witney Lake

Witney Lake is located in a country park and is one of the few gravel pits in the LWV open to the public. Although this lake is subjected to relatively heavy public pressure, and is open to angling in its northern half, it was exceptionally rich in both wetland plants and macroinvertebrates. Four main areas of the lake could be defined, each contributing to the overall structural diversity of the site:

- Fishing bays and areas trampled by the public, which maintain open habitat on the shoreline interspersed with stands of sedges and rushes in its northern half.
- A non-intervention area in its southern half which provides a complex of dense bank and well-vegetated shallow water habitats.
- A promontory (closed to the public) which has areas of shallows with extensive stands of stonewort and short emergent vegetation.
- Narrow channels, which have been created on the eastern side of the lake, and which provide habitat for pioneer plant and invertebrate species.

Overall, the characteristics of this lake demonstrate the value of zoning access to site areas, and of creating a range of contrasting aquatic habitats in order to maximise biological diversity.

Pit 59 Gill Mill
Gill Mill is only a few years old, and is soon to be opened to anglers. This was the richest lake in the valley for macroinvertebrates, and diversity was also very high for wetland plants, in particular stoneworts. In its current state, the main features of the lake were:

- Good water quality, as shown by the water chemistry results, and by the submerged plant species richness.
- Complex marginal vegetation, ranging from extensive stands of tall emergent plants to short grassy and rushy edges.
- Extensive areas of shallow water with a varied structure, including stonewort and pondweed stands.

The high biological value of this site demonstrates the importance of good water quality, and of shallow, well-vegetated habitats. The high diversity recorded at this site may also, in part, reflect its relatively young successional stage, and the current lack of disturbance from amenity uses.

Pit 60 Standlake Common Nature Reserve
Standlake Common Nature Reserve was designed as a bird-focused nature reserve and has no public access except for two hides. It was very rich in macroinvertebrates, and the water bugs and water beetles were particularly diverse. The following design features are likely to be particularly important for invertebrate diversity:

- Extensive areas of drawdown, with a varied microtopography, including small, shallow, temporary pools which tend to support distinct species from large permanent waterbodies.
- Extensive areas of shallow water.

The value of this gravel pit lake for wildlife demonstrates the importance of low angled banks and a topographically complex design.

Table 12 Matrix analysis: richness and rarity attributes of individual pits

Pit No	**1**	**2**	**3**	**4**	**5**	**9**	**10**	**11**	**12**	**13**	**14**
Site Name	**Manor Farm Lake**	**St John's Lake**	**Hardwick Park 1**	**Hardwick Park 2**	**Darlow Water**	**Vauxhall Lake**	**WOSC North**	**WOSC South**	**Oxlease Lake**	**Yeoman's Lake**	**Unity Lake**
WETLAND PLANTS											
Total No. of spp.	M	H	**VH**	H	**VH**	M	M	H	**VH**	M	H
No. of aquatic spp.	M	M	**VH**	M	**VH**	M	M	M	**VH**	L	M
No. of stonewort spp.	L	M	**VH**	H	H	L	H	H	H	L	H
No. of emergent spp.	M	H	**VH**	H	H	M	M	H	**VH**	H	H
No. of uncommon spp	L	M	**VH**	H	H	L	H	H	**VH**	M	M
MACROINVERTEBRATES											
Total No. of spp.	M	M	M	M	H	H	H	M	L	M	M
No. of water beetles spp.	M	L	L	L	H	M	H	M	L	L	M
No. of water bugs spp.	L	L	L	L	L	M	M	L	L	M	M
No. of caddis flies spp.	M	H	M	H	**VH**	**VH**	**VH**	M	L	H	H
No. of dragonflies spp.	M	M	M	M	H	H	M	M	M	H	M
No. of molluscs spp.	M	M	**VH**	**VH**	M	H	H	H	M	H	H
No. of uncommon spp.	L	M	L	L	H	M	**VH**	L	L	M	**VH**
No. of local spp.	L	M	L	M	H	M	**VH**	L	L	M	**VH**
No of Nationally Scarce spp.	M	M	M	L	M	M	H	L	M	M	H
Unique species			Y	Y		Y			Y	Y	Y

Conservation value: VH: very high, H: high, M: moderate, L: low

Table 12 (continued) Matrix analysis: richness and rarity attributes of individual pits

Pit No	**15**	**16**	**18**	**21**	**22**	**23**	**24**	**25**	**26a**	**26b**	**27**
Site Name	**Gaunt Lake**	**Dix Pit**	**Stoneacres Lake**	**Linch Hill**	**Linch Hill**	**Linch Hill**	**Willow Pond**	**Christchurch Lake**	**Lincoln Lake**	**Lincoln Lake**	**3Ts**
WETLAND PLANTS											
Total No. of spp.	H	H	H	M	H	L	L	L	L	L	M
No. of aquatic spp.	M	**VH**	**VH**	H	M	H	H	M	M	M	M
No. of stonewort spp.	L	**VH**	H	H	M	H	H	L	L	L	L
No. of emergent spp.	H	M	M	M	H	L	L	L	L	L	H
No. of uncommon spp	M	**VH**	H	H	H	H	H	L	L	L	L
MACROINVERTEBRATES											
Total No. of spp.	H	H	H	M	M	M	M	L	H	M	H
No. of water beetles spp.	M	H	M	L	M	M	M	M	M	L	M
No. of water bugs spp.	M	H	M	M	M	M	L	L	M	L	M
No. of caddis flies spp.	H	M	**VH**	**VH**	**VH**	**VH**	**VH**	L	**VH**	**VH**	**VH**
No. of dragonflies spp.	H	H	**VH**	H	**VH**	H	M	M	**VH**	H	M
No. of molluscs spp.	**VH**	M	H	H	M	M	**VH**	M	H	H	**VH**
No. of uncommon spp.	H	M	M	M	H	H	M	M	**VH**	H	M
No. of local spp.	H	M	M	H	H	H	H	L	**VH**	H	M
No of Nationally Scarce spp.	M	H	M	L	M	M	M	M	H	M	M
Unique species		Y	Y	Y			Y		Y		Y

Conservation value: VH: very high, H: high, M: moderate, L: low

Table 12 (continued) Matrix analysis: richness and rarity attributes of individual pits

Pit No	28	29	30a	30b	30c	31	32	33	35	36	37
Site Name	Windsurfing Lake	Standlake Common	Standlake Common	Standlake Common	Standlake Common	Barnes Lake	Hunts Corner	Standlake Trout Lake	Smiths Pool/Hardwick Lake	Brasenose Lake	Witney Lake
WETLAND PLANTS											
Total No. of spp.	L	H	M	L	H	H	H	L	H	**VH**	**VH**
No. of aquatic spp.	M	H	H	L	M	M	M	L	M	H	**VH**
No. of stonewort spp.	H	M	M	L	L	L	M	L	H	**VH**	H
No. of emergent spp.	L	H	M	M	H	**VH**	H	M	H	H	**VH**
No. of uncommon spp	H	H	H	L	M	M	H	M	M	M	**VH**
MACROINVERTEBRATES											
Total No. of spp.	M	H	M	L	L	H	M	H	H	M	**VH**
No. of water beetles spp.	L	M	M	L	L	H	M	M	M	H	H
No. of water bugs spp.	L	M	L	L	L	M	L	M	L	M	M
No. of caddis flies spp.	**VH**	H	M	M	M	H	**VH**	**VH**	**VH**	L	**VH**
No. of dragonflies spp.	M	H	H	H	M	H	**VH**	H	H	M	H
No. of molluscs spp.	M	H	H	M	M	H	M	**VH**	**VH**	L	**VH**
No. of uncommon spp.	M	**VH**	M	M	L	H	M	M	M	M	H
No. of local spp.	M	**VH**	M	M	L	M	M	M	M	L	**VH**
No of Nationally Scarce spp.	M	M	M	M	L	**VH**	M	M	M	M	H
Unique species		Y				Y	Y	Y			Y

Conservation value: VH: very high, H: high, M: moderate, L: low

Table 12 (continued) Matrix analysis: richness and rarity attributes of individual pits

Pit No	**38**	**58**	**59**	**60**	**62**	**72**	**84**
Site Name	**Shifford Lake**	**Watkins Farm Lake**	**Gill Mill Lake**	**Standlake Common Nature Reserve**	**Founder's Lake**	**Graham Water**	**Claire Lake**
WETLAND PLANTS							
Total No. of spp.	M	H	**VH**	H	H	M	M
No. of aquatic spp.	H	H	H	M	H	M	M
No. of stonewort spp.	H	H	**VH**	M	H	M	M
No. of emergent spp.	M	H	H	H	H	H	H
No. of uncommon spp	**VH**	**VH**	**VH**	**VH**	**VH**	M	M
MACROINVERTEBRTATES							
Total No. of spp.	L	L	**VH**	H	H	**VH**	H
No. of water beetles spp.	M	L	**VH**	**VH**	H	**VH**	H
No. of water bugs spp.	L	L	H	**VH**	**VH**	**VH**	M
No. of caddis flies spp.	H	M	**VH**	M	M	**VH**	H
No. of dragonflies spp.	M	L	**VH**	M	M	H	M
No. of molluscs spp.	M	M	H	M	M	M	H
No. of uncommon spp.	M	L	**VH**	**VH**	H	**VH**	H
No. of local spp.	M	L	**VH**	**VH**	H	**VH**	H
No of Nationally Scarce spp.	M	L	H	H	H	H	M
Unique species	Y		Y	Y	Y	Y	Y

Conservation value: VH: very high, H: high, M: moderate, L: low

5.3 Important issues to consider

5.3.1 Water quality

One of the most important characteristics of the Lower Windrush Valley lakes is their generally high water quality. Clean and relatively unpolluted lakes are a rare habitat in southern Britain and every effort should be made to both maintain and extend this valuable resource. Good water quality underpins both the biological value of the lakes and their amenity use so maintaining high water quality is central to the future management of the lakes.

Although water quality is generally good there is evidence of local water quality deterioration in some of the pits, caused by both point and diffuse pollution sources. For example, in Pit 18 (Stoneacre Lake) there was evidence of an organic effluent, possibly sewage, entering the lake via an inlet in the north-eastern corner, which locally excluded growth of stoneworts from that part of the pit. Several lakes (e.g. Pit 1 Manor Farm and Pit 2 St John's Lake) appeared to be considerably impacted by stocking with bottom feeding fish giving turbid water and relatively poor invertebrate assemblages.

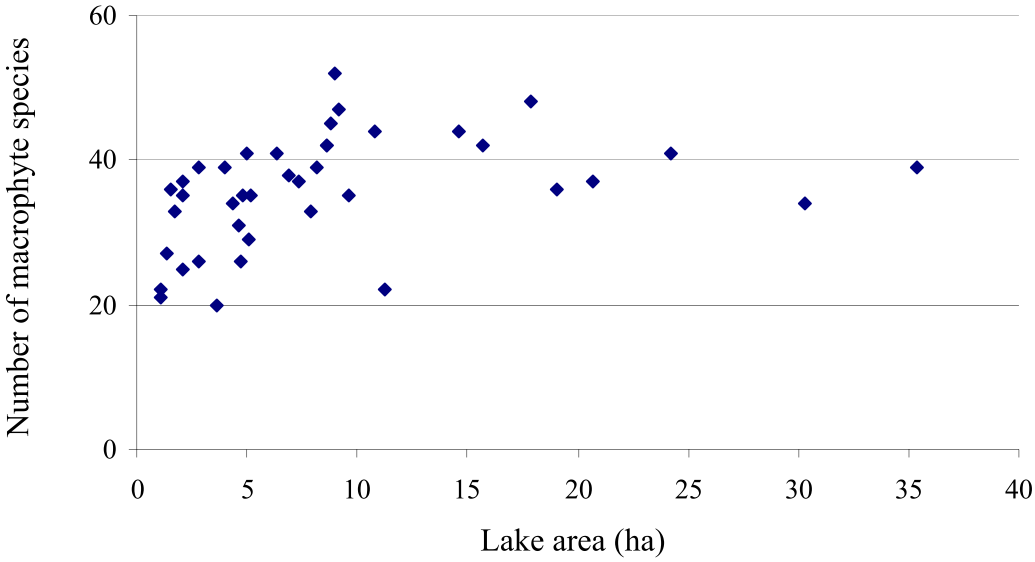
The biological impact of other pollutants known or believed to be relevant to the gravel pits is more speculative on evidence from the current survey but includes:

- Herbicides, which are reported by local anglers to be applied annually in spring to fishing lakes to control aquatic vegetation such as *Elodea* spp. These may change the plant assemblage composition and biomass of the lakes unfavourably.
- On lakes with intensive marginal development, particularly from mobile homes, there is a whole range of potential impacts including the leaching of pesticides and fertilisers from lawn and soil treatments, sewage-storage accidents and runoff from adjacent roads. These may potentially affect the long-term quality of the pits through the build up of the pollutant burdens in bottom sediments.
- Inflows of water with high sediment loads from adjacent working pits (e.g. Pit 18, Stoneacre Lake) which can locally increase water turbidity, giving at least short term impacts on the pit biota.
- Nutrients, and possibly pesticides, derived from adjacent farmland, entering the pits either via runoff or groundwater, potentially affecting the long term quality of the lakes via pollutant build up in bottom sediments.

5.3.2 Lake size

Although large lakes generally supported more plant species than small lakes, most of the richest lakes for plants were relatively small, with two of the three richest sites less than 10 ha in area. For invertebrates there was no relationship between lake area and richness and the three richest lakes were all less than 15 ha (the second richest site, Graham Water, was only 5 ha) (Figure 31).

(a) Macrophytes



(b) Macroinvertebrates

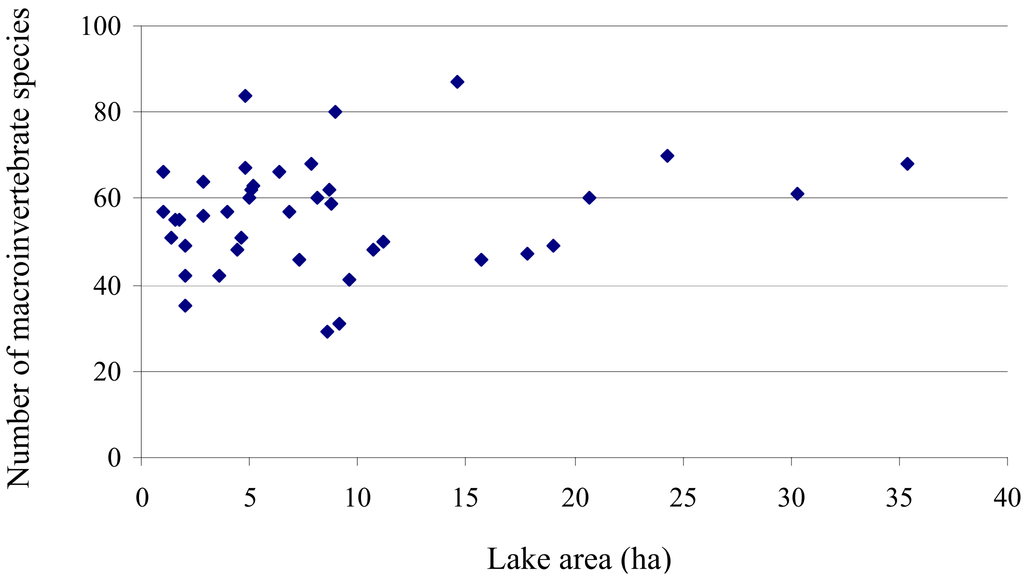


Figure 31 The relationship between lake area and species richness: (a) macrophytes and (b) macroinvertebrates

5.3.3 Lake age

Early succession lakes were particularly rich in the Lower Windrush complex. However it should also be noted that all stages of the succession, including lakes with extensively wooded margins, made a contribution to the overall diversity of the complex. Thus relatively species-poor lakes such as Site 38 (Shifford Lake) and Site 4 (Hardwick Leisure Park 2) and lakes with extensively shaded margins, such as Site 32 (Hunts Corner), all supported unique macroinvertebrate species not found in other sites.

5.3.4 Design and restoration of lake margins and adjacent habitats

Lake margins are critical areas for biodiversity: they potentially provide areas where extensive and diverse stands of marginal and aquatic vegetation thrive, and these stands, in turn, provide a critical habitat for a wide range of aquatic macro invertebrates. High quality gravel-pits are likely to have a range of bank angles, but with a predominance of very low-angled banks and extensive drawdown zones, often with pools or shallow undulations within them. On lakes designated for nature conservation, where modern design and restoration techniques have been directly applied (e.g. Pit 60 Standlake Common Nature Reserve), the creation of low-angled margins with high physical heterogeneity, ensures that these lakes will provide good wildlife habitat in the long term.

In the majority of lakes, however, particularly pits where nature conservation is not the primary use, bank angles *above spring water-levels* are typically steep, giving little opportunity for the development of marginal fen or wet woodland assemblages. On the few occasions where such vegetation has been allowed to develop (e.g. the northern boundary of Pit 3 Hardwick Leisure Park 1), the value of such areas is exceptional, and significantly enhances the value of the pit. Similarly, bank lines tend to be straight, rather than embayed, and there are very few sites where marginal pools have been created or allowed to develop. At or below water-level, too, many pits drop rapidly into relatively deep water (30cm+), with little area given over to the very shallow water (0-20 cm) where many emergents and shallow water aquatic plants, and associated invertebrates thrive.

5.3.5 Management and disturbance of lake margins and adjacent habitats

The intensity of the management of the shoreline and its immediate surroundings can, depending on circumstances, have either a negative or positive impact on biodiversity. For example around fishing lakes, the impact of mowing or cutting of margins or fishing bays can be favourable, both by (i) maintaining some older pits relatively unshaded, thus preventing succession of all pit margins to woodland, and (ii) promoting within-pit diversity from locally disturbed and less shaded fishing-bays in otherwise tree-bordered pits.

However, if this management is too intense it ceases to be beneficial and starts to become a negative influence. Observations made during this study revealed that at some pits, (e.g. Pit 25 Christchurch Lake) intensive use clearly leads to compaction of the soil around the margins of the lake. It was also noted that management of marginal vegetation was particularly intensive around fly fishing lakes (e.g. Pit 5 Darlow

Water), thereby reducing the extent of available marginal habitat for plants and animals.

Lakes with mobile homes experience similar problems (e.g. Pit 3 Hardwick Leisure Park 1), with residents either extending their gardens to the water's edge or bordering gardens with platforms. Apart from the general loss of potential for development of native vegetation in these areas, there are also risks associated with planting of non-native aquatics. On a small scale, such practices probably have limited impact but when a significant proportion of the lake margin is managed in this way, and the effects extend over a number of lakes, there will inevitably be loss of biodiversity potential.

Watersports clearly also affect the development of marginal vegetation in some lakes in the LWV complex. On Pit 27 (3Ts) and Pit 28 (Windsurfing lake), for example, use of motor boats clearly had an impact on the marginal vegetation: wave-wash created marginal cliffs at the waters edge inhibiting growth of marginal vegetation stands. Wash also created locally turbid water in the shallows, as loose bottom sediments were continually re-suspended in the water column, reducing the abundance of shallow-growing submerged plant species. Where zoning was employed on pits used for motorised watersports, (e.g. Pit 4 Hardwick Park 2, where some areas are roped off) this locally created more favourable conditions, particularly for the growth of shallow-water stonewort species.

5.3.6 Afteruse

The LWV lakes include a wide range of afteruse, angling being the most common. As noted in the previous section, amenity after-uses (e.g. angling, mobile home gardens, informal public recreation), can either reduce the nature conservation of lakes, or help maintain heterogeneity of habitat within and between lakes, depending on the intensity of the activities taking place. For example, intensively stocked angling lakes and those used for watersports tended to support fewer plant and animal species overall, probably by reducing habitat availability and water quality. On the other hand, low intensity management and disturbance of the margins by mowing or cutting can help to maintain habitat diversity by keeping areas of the lake margins open and restricting colonisation by woody vegetation.

As mineral extraction continues to take place and further waterbodies are created, it would also be desirable, if possible, to increase the number of lakes within the LWV complex which are dedicated to nature conservation. So far, two gravel pits have been restored specifically for nature conservation purposes: Standlake Common Nature Reserve (Pit 60), which was included in the current study, and Rushy Common Nature Reserve, which is currently in the process of being restored. As new planning applications for gravel extraction are submitted a balance of different afteruses needs to be maintained within the LWV. However, opportunities for the establishment and long-term management of new nature reserves should be actively encouraged.

5.3.7 Water levels

Natural fluctuations in water levels, particularly associated with the gradual lowering of water tables over the summer and early autumn, are generally beneficial for aquatic biodiversity (Williams *et al*. 1999). Many aquatic organisms have life-histories which are adapted to the predictable changes associated with seasonal drawdown, and the drawdown zones of lakes and ponds are amongst the richest parts of these waterbodies. In contrast, rapid changes in water level at inappropriate times of year are likely to stress aquatic ecosystems and reduce biodiversity.

Working gravel pit complexes may also be affected by dewatering of adjacent working pits. In the LWV there was some evidence, based on field observations, of rapid fluctuation in water levels as a result of the pumping of active gravel quarries near-by (e.g. Pit 18, Stoneacre Lake). These activities are regulated by the Environment Agency, and the impacts of such water level fluctuations are unknown. However, it does seems likely that impacts could be detrimental, at least in the short term, and where pits support biologically significant species (e.g. Lesser Bearded Stonewort *Chara curta*) such pumping-down should be carefully considered before being undertaken.

5.3.8 Invasive species

Invasive alien species are a permanent threat to the integrity of freshwater ecosystems in Britain. In the Lower Windrush Valley the four main species of concern are New Zealand Pygmyweed (*Crassula helmsii*), Indian Balsam (*Impatiens glandulifera*), Signal Crayfish (*Pacifastacus leniusculus*) and the Zebra Mussel (*Dreissena polymorpha*). The occurrence of these species in the LWV should be monitored and where possible, controlled.

5.4 Ecological assessment: conclusions

The results of this study indicate the major factors influencing the nature conservation value of the lakes are related to water quality, marginal structure and after-use (probably through its effects on water quality and habitat availability). Size and age had a relatively small impact on wetland plant and macroinvertebrate diversity. These factors are, however, important for wildfowl diversity, which tend to require large waterbodies and open conditions (Section 4). Overall, these results indicate that management for maintenance of overall lake biodiversity should focus on protecting water quality, improving lake margin structure and minimising the impact of amenity uses.

6. Recommendations

6.1 Management objectives for the Lower Windrush Valley

6.1.1 Overall objectives

Based on the current evaluation, the overall management objectives for the Lower Windrush Valley gravel pit complex should be to:

- Maintain, and where possible, improve water quality.
- Maintain and enhance habitat diversity for both aquatic species, and the terrestrial wildlife associated with the gravel pits.

More specifically, these objectives can be achieved by:

- Encouraging wildlife sympathetic management on existing lakes where management for biodiversity is not the primary objective.
- Maximizing the potential for nature conservation in the design of new restoration plans within the constraints of the proposed after use.

6.1.2 Biodiversity Action Plans

The results of the current evaluation showed that much can be achieved to contribute to the standing water HAP. Available water quality data suggests that most of the lakes in the Lower Windrush Valley are either mesotrophic or borderline eutrophic/ mesotrophic. Thus most sites within the complex fall within the remit of the Mesotrophic lakes or Eutrophic Standing Waters Habitat Action Plans. Given the limited extent of such habitats in southern Britain, particularly of Mesotrophic lakes, protection of the LWV lakes could make a significant contribution to the objectives of these plans. There is also potential for actions to promote the conservation of other priority HAP habitats such as floodplain grazing marsh, reed beds, fens and wet woodland, particularly in any new wetland creation schemes associated with future restorations of worked-out gravel pits.

In terms of individual BAP species, the Lower Windrush lake complex has the potential to make a considerable contribution to the conservation of a number of wetland and aquatic species, including both those recorded for the first time in the Windrush complex in the present study, and those already known from the area more generally. In particular, with new lake and wetland restoration projects there is potential to target measures for the conservation of a range of BAP species including:

- Otter
- Water vole
- Pipistrelle
- White-clawed Crayfish
- Great Crested Newt
- Lesser Bearded Stonewort

If large-scale wetland creation becomes feasible, then other species could be considered as targets for the area (e.g. Bittern).

6.1.3 Maintain and improve water quality

Maintaining lake water quality should be a key objective in the LWV complex. There are two components to this process: general maintenance of groundwater quality and local actions to control pollution in individual lakes. In both cases this work is likely to be most effectively undertaken by maintaining and developing good local relationships with the Environment Agency and ensuring that Agency staff are aware of the importance of the LWV complex. Locally there may also be scope to work with agri-environment advisers to promote the adoption of low intensity land management practices in the valley.

We also recommend that every effort is made to involve the Environment Agency in the monitoring of lake quality. The Agency is currently beginning its programme of work on lakes required for the implementation of the Water Framework Directive (WFD). Given the importance of the LWV lakes it would be reasonable to expect some key sites to be included in the monitoring programme for the WFD.

If insufficient resources are available within the Environment Agency to establish monitoring programmes a possible alternative would be to include some sites in the LWV under the auspices of the National Pond Monitoring Network, which is likely also to include a range of small lakes. This project, which is jointly sponsored by The Ponds Conservation Trust, English Nature, the Environment Agency and other organisations, is currently developing a national list of high quality water bodies, which should be monitored under the auspices of the Water Framework Directive.

6.2 Recommendations for gravel pit management and restoration

6.2.1 Habitat creation for nature conservation

The LWV gravel pit complex currently supports a rich and diverse freshwater plant and invertebrate assemblage. There is, however, considerable potential to further enhance the value of the area for nature conservation by careful habitat management and creation. This study has revealed the importance of size, age, marginal structure, after use and water levels, as key factors influencing the biodiversity of the lakes and these should be taken into account in any future schemes.

For convenience, potential habitat creation projects in the Lower Windrush complex can be divided into three broad categories:

- Small scale modifications of existing gravel pits, both on-pit (e.g. reshaping margins) and off-pit (e.g. pond complex creation) which require relatively modest resources.
- Restoration of individual gravel pits for nature conservation.
- Larger scale wetland creation schemes associated with gravel pit restoration.

6.2.1.1 Small-scale on-pit and off-pit habitat creation and enhancement

The present study has shown that lakes with good marginal structure are generally amongst the richest in terms of biodiversity. This clearly indicates that it would be valuable to enhance those pits lacking good marginal structure and we recommend that a strategic approach is taken to identify those part of existing pits which have the greatest potential for on-pit and off-pit enhancement. This would include:

- Re-profiling banks to increase the area of shallow water and reduce marginal slopes.
- Digging marginal mosaics of shallow pools, depressions in the drawdown zone to increase marginal heterogeneity.
- Increasing margin length by adding embayments and shallow spits.

Where off-pit enhancements are possible, these should focus particularly on the creation of complexes of permanent, semi-permanent and seasonal ponds, building on the experience which has been gained at Pinkhill Meadow. At this site, adjacent to Farmoor Reservoir, a small complex of ponds and pools with a combined area of only 2.5 ha was colonised within 6 years by 20% of the wetland plant and invertebrate species that can be seen in Britain. The site was also used as a breeding site by three species of waders (Williams *et al*., 1999). Such pond complexes are a particularly valuable addition to gravel pit systems because they provide habitat, which is largely absent from lakes, such as shallow water, including sites which are seasonally dry and free from fish predation pressure, which is the preferred habitat of a large proportion of freshwater plants and animals.

6.2.1.2 Design of new gravel pit restoration schemes

Combining the results of the present study with existing knowledge of the biodiversity function of smaller water bodies, it is possible to outline a number of key design features, which should be included in high quality gravel pit restorations. Although the benefits of some of these are understood and have been applied in the LWV, they have never to date been either applied together or, if they have, monitored rigorously to determine their effectiveness. Monitoring is particularly important to continue to improve on current best practice, as part of an iterative process. Examples of the type of design features that could be linked include:

- *Maximising successional diversity*. Early stage lakes are valuable habitats (e.g. for stoneworts); late stages may support fewer species but provide unique habitats. It is not necessary to add topsoil to such lakes, or plant them up, as this reduces the duration of this valuable, but relatively transient, stage.

- *Creating very low bank angles*. A key feature of high quality natural waterbodies is low bank angles, often with extensive drawdown zones.

- *Creating complexes of large, permanent water bodies and small seasonal and semi-permanent water bodies*. Natural wetlands are a complex mixture of still and flowing, permanent and seasonal water, and this hydrological diversity underpins wetland biological diversity, providing the full range of habitats needed by many wetland plants and animals. Gravel pit complexes provide some of this habitat but there is considerable scope for restoration schemes, which incorporate flowing water, semi-permanent and seasonal standing water and seasonally inundated wetland habitats.

- *Simulating the characteristics of natural floodplains*. Mosaics of wet and dry habitats are characteristic of natural wetlands. Although often created by accident in gravel workings, good restoration designs should build-in these habitat mosaics. Wet woodland may be a particularly valuable component of natural wetlands, which can be recreated in gravel pit complexes.

- *Maximising the range of habitats* within waterbodies, especially on the margins. Lake margins, which have open, wooded, semi-shaded and densely vegetated areas will support more species than lakes with uniform margins.

- *Maximising the extent of edge habitat*, and making extensive drawdown zones.

- *Protecting water quality*. Low nutrient status waterbodies are a scarce resource making it essential to avoid adding nutrients to new lakes (e.g. by topsoiling).

- *Allowing natural colonisation*. Aquatic organisms are often rapid colonists; it is rarely necessary (except for amenity purposes) to add plants or other biota.

- *Planned disturbance*. Disturbance is a natural feature of floodplains, now much reduced by flood control measures. Simulating it is vital for maximising biological diversity and maintaining populations of vulnerable species.

Application of designs such as these could, if well monitored, provide an outstanding demonstration as well as creating exceptionally rich wetland habitats. The initial decision on after use is critical in determining the restoration of gravel pits (e.g. Pit 60 Standlake Common Nature Reserve). Those lakes identified specifically for nature conservation are likely to be automatically designed sympathetically, with limited disturbance and with the benefit of long term management provisions.

However, it is important to note that although both the Standlake Common and Rushy Common Nature Reserves are predominantly open water habitats, this is unlikely to continue to be a feature of gravel pit restoration plans in the future due to the increasing concern associated with bird strike. In future, the Ministry of Defence (M.O.D.) will be arguing for restoration to more ‘closed’ habitats, such as reedbeds, wet grassland and wet woodland, which do not attract large numbers of geese and wintering wildfowl.

These ‘closed’ habitats are likely to support different wetland plant and macroinvertebrate assemblages to those currently found in the LWV lakes. Further monitoring and research is required to assess the impact of those changes. Areas which need particular attention, in the light of the present study, are the relationship between lake succession and management, and diversity.

6.2.1.3 Large scale new wetland creation in the Lower Windrush Valley

The Lower Windrush Valley has considerable potential for the creation of extensive areas of new wetland habitat and there seems little doubt that such projects could help to fulfill local and national biodiversity objectives.

However, the practical difficulties of turning the relatively deep water of worked-out gravel pits into shallow flooded wetlands are considerable. For example, it requires the movement of large quantities of fill, with associated air pollution and road traffic problems. Indeed, the difficulties are such that working around the edges of the existing pits may be the most cost-effective and practical way of achieving any large scale development of new habitat. As noted above, future M.O.D. guidelines may have a profound impact on current gravel pit restoration practices.

6.2.2 Management of lakes where biodiversity is not the primary afteruse

Additional zoning should also be investigated as an option in lakes where pressure from amenity uses has a negative impact on biodiversity. The potential for this technique to benefit wildlife, in tandem with sound management, can be seen in Pit 37 (Witney Lake), where zoning has created a wide range of habitat types. Zoning may be particularly efficient around larger angling lakes, where some areas difficult to access may be underused by anglers and others. For example, the north western corner of Lake 35 (Hardwick Lake), could be zoned as an area which receives minimum or no management. Careful planning of access routes could also be manipulated to ensure some areas are purposefully less accessible.

Ideally, management plans should be developed for (i) the valley as a whole, to ensure a strategic approach is taken in the area, and the lakes with the most potential for biodiversity management are identified, and (ii) each lake, to ensure that management maximizes benefits to biodiversity within the constraints of the current after use.

6.2.3 Management of invasive species

Non-native invasive species should be monitored in the Lower Windrush Valley where possible, and controlled as a matter of urgency. The four species of concern in the LWV are two plant species (New Zealand Pygmyweed and Indian Balsam) and two animal species (Signal Crayfish and Zebra Mussel). Indian Balsam can easily be removed mechanically, by cutting, mowing or strimming (EA, 2004). Unfortunately, New Zealand Pigmyweed is very difficult to control and the use of herbicides may be required. Methods to effectively control Zebra Mussel and Signal Crayfish are still being developed.

Invasive plant species are often brought into a site with plants purchased from nurseries. Planting schemes as part of lake restoration or management should therefore either (i) be discouraged, or (ii) ensure supplies come from reputable nurseries or from local stock not contaminated with invasive species. In a floodplain environment, where connectivity between water bodies is high, new habitats are generally rapidly colonised and planting is not necessary.

Before undertaking management activities, professional advice should be sought from the Environment Agency and, for wetland plants, from the Center for Aquatic Plant Management (IACR).

6.3 Monitoring

The survey results presented here provide a good baseline for future monitoring of the aquatic biodiversity in the LWV gravel pits. Ideally, a monitoring programme should be set up in the LWV dealing with:

- Water quality.
- The richest gravel pits in the LWV (10% of sites), to act as an early warning signal if the biodiversity value of these site decreases.
- A cross section of sites for both biotic and abiotic variables, in order to asses the overall 'health' of the complex.
- BAP species populations (White-clawed Crayfish and Lesser Bearded Stonewort).
- Newly restored gravel pits and existing gravel pits which have been modified, to ensure optimum design for biodiversity.
- Invasive species.

6.4 Further information needs

There are six main areas where further information is needed:

- Fish biomass and management of fishing lakes, including the use of herbicides to control submerged plants.
- Dragonfly diversity.
- Contribution of other wetland habitats to the diversity of the LWV.
- Amenity use and pressures.
- Potential for habitat enhancement and creation.
- Impact of gravel pit restoration to reedbed or other 'closed' habitat on diversity.

Plans for the collection of such data could be built into long-term monitoring programmes.

7. Conclusions

The Lower Windrush Valley gravel pits are a regionally, and probably nationally, significant complex of mesotrophic/eutrophic lakes:

- The water quality is generally high.
- They support a high diversity of plant species.
- They support a significant number of scarce and uncommon plant species including the BAP and Nationally Scarce species Lesser Bearded stonewort.
- They support a high diversity of invertebrate species.
- They support a range of scarce invertebrate species including the native White-clawed Crayfish.
- They support nationally significant populations of certain bird species including gadwall and pochard.

Current data shows that main factors which affect the biodiversity of gravel pits in the LWV are:

- Water quality
- Restoration design
- After use
- Surface area
- Age
- Management practices

The key recommendations for maintaining and enhancing the biodiversity interest of gravel pits in the LWV are:

- Maintain and improve water quality.
- Maintain and enhance the biodiversity interest of existing pits through management and small-scale habitat creation of shallow waters.
- Seek opportunities to improve the restoration of future gravel pits, regardless of their after-use.
- Seek opportunities for the establishment, design and long-term management of new nature reserves.
- Control the spread of invasive non-native species.

The results of the current project should now provide the basis for a complex-wide management plan, to be carried out in consultation with lake owners and managers. The monitoring baseline established by the present project could provide the basis for a demonstration project showing the full range of gravel pit management and restoration techniques. Such a project would have the potential to widely influence lake management, and also create an outstanding new wetland habitat in the Upper Thames.

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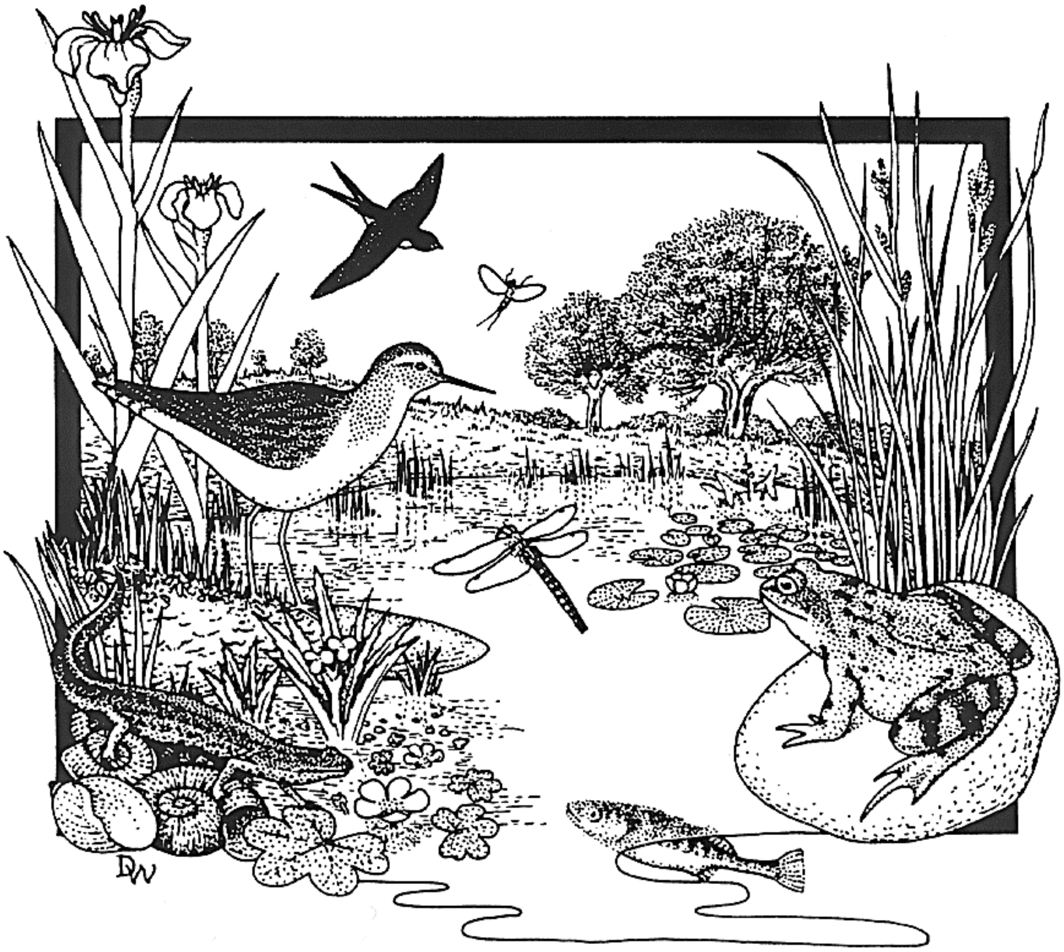
Appendix 1 Survey methods

Appendix 1.1 National Pond Survey (NPS) Methods
Appendix 1.2 LWV survey field recording sheet

A guide to the methods of the

National Pond Survey



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Contents

1. Introduction to the National Pond Survey methodology

1.1 About the guide and the National Pond Survey

This booklet describes a standard survey methodology which can be used to gather physical, chemical and biological data for ponds.

The method was originally developed for the National Pond Survey (NPS) initiated by Pond Action in 1989. It has subsequently been used as the basis for many other regional and national surveys, including the DETR[4] Lowland Pond Survey 1996[5], and Pond Action's national survey of degraded ponds which was undertaken during 1995-1998 with funding from the Natural Environment Research Council (NERC).

The aim of the survey method is to ensure consistent collection of biological and environmental data from ponds, thus:

- providing a checklist of environmental factors which can be important in describing pond types or explaining biological quality;
- enabling biological and physico-chemical data to be directly compared with the results of other regional and national surveys;
- enabling the biological *quality* of ponds to be assessed using Pond Action's assessment methods based on the plant and/or animal communities recorded from the pond; and
- providing data for the new National Pond Database collected using compatible methods.

1.2 Changes to the National Pond Survey field recording sheet

The original National Pond Survey field sheet, developed in 1989, has been progressively updated and modified over the last 9 years. Most changes have related to (i) additional areas of interest to pond recorders (such as amenity and leisure use), and (ii) measures which recent research suggests are important in determining the biological quality of ponds. The latter include factors such as 'isolation from other wetland habitats' and 'overall pollution rating'.

1.3 Background to the National Pond Survey

Ponds provide an important habitat for aquatic plants and animals in Britain: the protection of existing ponds and the construction of new ones are both believed to make a significant contribution to the conservation of freshwater communities[2].

The National Pond Survey was initiated by Pond Action in 1989, with the support of WWF-UK. The Survey has four main objectives:

(i) to develop a classification of ponds in Britain based on the composition of their plant and macroinvertebrate communities;

(ii) to investigate the principal biotic and abiotic factors influencing the composition of pond communities;

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[4] DETR: Department of the Environment, Transport and the Regions.

[5] Williams, P.J., Biggs, J., Barr, C.J., Cummins, C.P., Gillespie, M.K., Rich, T.C.G., Baker, A., Baker, J., Beesley, J., Corfield, A., Dobson, D., Culling, A.S., Fox, G., Howard, D.C., Luursema, K., Rich, M., Samson, D., Scott, W.A., White, R. and Whitfield, M. (1998). *Lowland Pond Survey 1996*. Department of the Environment, Transport and the Regions, London.

(iii) to provide a descriptive basis for future studies of pond ecology (particularly those concerned with the management of ponds for wildlife conservation);

(iv) to use the classification, with species distribution data, to develop a system for assessing the importance of individual ponds for nature conservation.

2. Summary of pond survey procedure

2.1 Ponds included in the National Pond Survey

The definition of 'pond' which was used for the National Pond Survey is:

> *'A body of water, of man-made or natural origin, between 1m^2 and 2ha, which usually holds water for at least four months of the year'.*

This definition is a broad one and potentially includes ponds of many different origins, such as: marl pits, quarry pools, heathland ponds, moats, small ornamental lakes, oxbow ponds and peat pools, together with temporary ponds like many pingos and dune slack pools.

2.2 Information gathered for the National Pond Survey

For a full National Pond Survey assessment, ponds are surveyed in **three seasons:** spring, summer and autumn. Only invertebrates and some water chemistry and environmental parameters need to be surveyed on all three visits: the following list gives a broad outline of the information gathered at each pond.

- A description of the main physical features of the pond and its surroundings, together with notes about its age, history and management (see enclosed field sheet).
- Water chemistry. The sheet shows the minimum data to be collected; normally laboratory analysis of a range of chemical determinands will be made e.g. pH, conductivity, potassium, chloride, alkalinity, suspended solids, ammonia, total nitrogen, total oxidised nitrogen, total phosphorus, soluble reactive phosphorus.
- A list of the wetland plant species found within the outer boundary of the pond, with estimates of abundance for vegetation stands occupying more than 5% of the pond.
- Lists of the aquatic macroinvertebrate species recorded from the pond, ideally for **three seasons** of the year: spring (March-May), summer (June-August) and autumn (September-November) with estimates of their abundance.
- Notes on the presence and approximate abundance of amphibians, water birds and fish.
- Desk study information describing the pond's location (grid reference), geology etc.

Table 1. Summary of the full National Pond Survey methodology

On-site survey of the pond in the first season

The basic procedure for surveying ponds is outlined below.

(i) The pond perimeter is walked: the field recording sheet is filled in where appropriate, and macroinvertebrate microhabitats are chosen for sampling. Photographs are taken.

(ii) It is also useful to draw a sketch map of the pond using a tape and compass. Alternatively, a large scale OS map of the site may be used as a base (although it is important to check the scale and accuracy of the outline, which may have changed since the map was drawn).

(iii) Before disturbing the water:

- (a) water chemistry measurements are made or water samples collected.
- (b) a list of the wetland plants in and around the pond is compiled (see survey sheet). If the pond is large and/or deep, the plant survey can be combined with the collection of the macroinvertebrate sample.

(iv) During the **summer or autumn** survey the extent of major vegetation stands is recorded.

(v) Water and sediment depths are measured and the Field Recording Sheet is completed for that season.

(vi) A 3-minute macroinvertebrate sample is collected and a quick additional search made for species such as whirligig beetles and leeches.

Laboratory analysis of invertebrate samples

(i) Macroinvertebrate samples are sorted **live**, as soon as possible after collection. Samples which cannot be sorted immediately are kept in a refrigerator or refrigerated cold room and sorted within three days after collection. Samples are not frozen or preserved.

(ii) The **whole** sample is sorted, with selective subsampling if necessary to estimate the abundance of extremely numerous taxa.

(iii) Invertebrates are preserved in alcohol for subsequent identification, except for leeches and flatworms which are identified immediately from live material.

Second and third season of the survey

In both the second and the third season:

(i) New plant species observed at the pond are added to the wetland checklist. Water chemistry parameters are measured and other seasonally variable environmental data collected (e.g. inflow information). Further 3-minute macroinvertebrate samples are collected.

(ii) The laboratory procedure is repeated.

3. Pond survey procedure: detailed description

3.1 Completing the field recording sheet

The field recording sheet provides a standard format on which to record basic physical and chemical data about the pond and its surrounds. A blank copy for photocopying is provided in Appendix 2.

3.2 Defining the pond outline

Identifying the ‘outer edge’ of the pond is important for many of the survey measurements including pond area, percentage drawdown, and wetland plant cover. For the National Pond Survey, the definition of 'outer edge' is 'the upper level at which water stands in winter’.

In practice, this line is usually readily discernible from the distribution and/or morphology of wetland plants. For example, it may be marked by a fringe of soft rush (*Juncus effusus)* or by thick bundles of fine, pink roots growing out of the trunks of willows etc., apparently several feet above water level but in fact fully submerged when the pond is at its deepest.

Alternatively, the line can often be seen as a ‘water mark’ on surrounding trees or walls and is sometimes evident as a break of slope. The outer boundary of the pond will usually, of course, be dry at the time of the survey.

3.3 Mapping the pond

Many measurements such as pond size and percentage of tree cover, are easier to estimate if a scale sketch map of the pond is made. For small or simply shaped ponds, compass and tape measurements alone are adequate for mapping the pond outline. For larger ponds, useful outlines can often be obtained from Ordnance Survey maps (1:10,000 scale enlarged on a photocopier): note, however, that the accuracy of these maps still needs to be checked in the field with a tape measure and compass.

3.4 Recording plant species and vegetation abundance

The aims of plant recording are:

- to make a complete list of wetland plants present within the outer boundary of the pond,
- to record the extent of emergent, floating-leaved and submerged plant stands, together with the approximate abundance of dominant species.

3.4.1 Recording wetland plants

Wetland plants growing within the outer boundary of the pond are noted on the field recording sheet. This gives a definitive list of the plant species regarded here as 'wetland'. In deep ponds aquatic plants are surveyed using a grapnel and/or boat. Terrestrial plants and wetland plants growing outside the pond boundary are not used in the analysis. Most wetland plants are readily identifiable using a hand lens. However, with a few species (especially fine-leaved *Potamogeton* and *Callitriche* spp.) it may be necessary to remove a small amount of plant material for later microscopic examination and confirmation.

Standard botanical texts such as Stace (1997) are adequate for most wetland plant identification. However, a number of additional guides are useful for specific groups and a list of these has been included in Appendix 1.

Table 2. Equipment needed for National Pond Survey work

General

- Chest waders or boat as appropriate
- Life jackets for use with chest waders or boat
- Camera and film
- Pencils and waterproof pens
- Labels
- Copy of the field recording sheet (if possible, on waterproof paper)

Mapping the pond

- Compass
- Tape (30m or 50m)
- Copy of large-scale OS map of the pond

Chemical survey

- Chemical test kits/meters
- Sample bottles and filtering equipment

Plant survey

- Grapnel
- Plastic bags and labels
- Plant identification guides

Sediment and water depths

- Draining rods (or equivalent)

Macroinvertebrate sampling

- Long-handled pond-net (1 mm mesh)
- Bucket (10 litre) with watertight lid
- Stopwatch (for companion)
- Label for bucket

Sorting and identification of macroinvertebrate samples

- Large sieve (0.5 mm mesh)
- White sorting tray (about 40 x 40 cm)
- Fine 'watchmaker's' forceps (curved and straight)
- Small bottles for preserving samples
- Labels (made from waterproof paper if necessary)
- Industrial methylated spirits (IMS) (70%)
- Petri dishes, microscope slides and cover slips
- Binocular microscope (x30-50)
- High power microscope (x100-400)
- Invertebrate identification keys

3.4.2 Mapping stands of wetland vegetation

During the summer or autumn survey, major stands of **emergent, floating-leaved and submerged plants** are either noted on the field recording sheet or drawn on to the base map using the conventions shown in Figure 1. On the base map, sparse stands of vegetation are noted as a mixture of plants and open water or mud (e.g. 20% floating cover, 80% open water). Where **individual species** occupy a **total of more than 5%** of the pond then these are also noted on the base map.

Estimates of the plant cover are only required to an accuracy of about 5%, so it is not necessary to mark the exact position or size of every small plant stand.

Figure 1. Conventions for mapping wetland vegetation

3.5 Sampling aquatic macroinvertebrates

3.5.1 Aims of invertebrate surveys

- To obtain, within the available sampling time (3 minutes in each of 3 seasons), **as complete a species list as possible for the pond.**
- To obtain information on the abundance of each species recorded.

3.5.2 Survey periods

Invertebrate surveys are undertaken in three seasons: **spring** (March, April or May), **summer** (June, July or August) and **autumn** (September, October or November). Surveys in adjacent seasons should ideally be two to three months apart.

3.5.3 Selecting mesohabitats for invertebrate surveys

All the main mesohabitats in the pond are sampled so that as many species are collected from the site as possible. Examples of typical mesohabitats are: stands of *Carex* (sedge); gravel- or muddy-bottomed shallows; areas overhung by willows, including water-bound tree-roots; stands of *Elodea*, or other submerged aquatics; flooded marginal grasses; and inflow areas. (As a rough guide, the average pond might contain 5-10 mesohabitats, depending on its size and variety.) It is important that vegetation **structure**, as well as plant species composition, is considered when selecting mesohabitats: it is better to identify habitats consisting of e.g. soft floating leaves, stiff emergent stems, etc. than to make each different plant species a separate habitat.

Mesohabitats are identified during the initial walk around the pond examining vegetation stands and other relevant features (this can be combined with the initial plant survey stage).

3.5.4 Method

(i) The three-minute sampling time is divided equally between the number of mesohabitats recorded: e.g. for six mesohabitats, each will be sampled for 30 seconds. Where a mesohabitat is extensive or covers several widely-separated areas of the pond, the sampling time allotted to that mesohabitat is **further divided** in order to represent it adequately (e.g. into 6 x 5 second sub-samples).

(ii) Each mesohabitat is netted vigorously to collect macroinvertebrates. Stony or sandy substrates are lightly 'kick-sampled' to disturb and capture macroinvertebrate inhabitants. **N.B.** deep accumulations of soft sediment are avoided, since this makes later sorting extremely difficult: the netted sample should be as clean and silt-free as possible. Similarly, large accumulations of plant material, root masses, and the like should not be taken away in the sample: the idea is to dislodge and capture the animals without collecting an unmanageable sample.

The sample is placed in the labelled bucket for later sorting in the laboratory. (The three-minute sampling time refers solely to 'net-in-the-water' time, and does not include time moving between adjacent netting areas.)

(iii) Amphibians or fish caught whilst sampling are noted on the field recording sheet and returned to the pond. (It is worth making a quick search through the net and removing these: dead fish, tadpoles etc. in the sample make for a very unpleasant sorting session in the laboratory later!)

3.5.5 Additional invertebrate sampling

A further 1 minute (total time, **not** net-in-the-water time) is spent searching for animals which may otherwise be missed in the 3-minute sample. Areas which might be searched include the water surface (for whirligig beetles, pond skaters etc.), and under stones and logs (for limpets, snails, leeches, flatworms etc.). Additional species found are added to the main 3-minute sample. Note: the 1 minute search should ideally be undertaken before the hand-net sample (i.e. before you disturb the water) to improve the chance of catching species.

3.5.6 Storage of invertebrate samples prior to sorting

Samples are sorted **as soon as possible** after collection since they deteriorate quickly, and animals which have died in the bucket are (a) harder to spot and therefore more likely to be missed, and (b) likely to quickly begin rotting, and so be more difficult to identify. In addition, predators in the sample may eat their way through many of your other captured specimens. If the sample cannot be sorted immediately upon return from the field it must be kept in cold storage in a refrigerator or a refrigerated cold room. It is important that all samples are dealt with within three days of collection.

3.6 Sorting and identifying macroinvertebrate samples

Samples are not frozen or preserved prior to sorting since this reduces the potential recovery and identification of some invertebrate species. All samples are sorted fresh and 'live'.

3.6.1 Preparing the sample for sorting

The sample is washed gently in a fine sieve (0.5mm mesh or less), removing as much mud and fine detritus as possible whilst ensuring the retention of delicate bodied invertebrates such as mayflies. A white sieve is preferable.

3.6.2 Sorting the sample

A small amount (less than a handful) of material to be sorted is placed in a white tray with approximately 3-5mm depth of water. This material is sorted gradually and carefully using forceps. (Fine, curved forceps, as described in Table 2, will make the sorting - and subsequent identification - very much faster and easier.) Individual animals recorded for the survey are removed and placed in a labelled bottle of 70% Industrial Methylated Spirits ('70% alcohol') for later identification. The exceptions are **leeches and flatworms,** which are not readily identifiable after preservation in IMS: these should be placed in **water** in a **covered** petri dish to be identified alive. A list of invertebrate groups included in the NPS analysis is given in Table 3 (below).

In general, the aim of sorting the sample is to remove and identify **all** individual invertebrates. In samples where one or two species are present in large numbers (i.e. thousands of specimens), specimens of these species are counted in a subsample and numbers then extrapolated to the whole sample. **All specimens** of species which cannot be reliably identified in the sorting tray should be removed from the sample with the following **exceptions**: Baetidae, Caenidae, Leptophlebiidae, Nemouridae, Gammaridae and Asellidae. In the case of these families, it is adequate to remove about 100 individuals since this provides a reasonable chance of all the species likely to be present being removed. Take particular care with pairs of species which are similar and perhaps not distinguishable by eye, where small numbers of one species often occur amongst very large numbers of the other species (e.g. *Asellus meridianus* with *A. aquaticus*, *Cloeon simile* with *C. dipterum*, *Anisus leucostoma* with *A. vortex, Lymnaea auricularia* with *L. peregra, Sigara falleni* with *S. distincta* and so on).

3.6.3 Identification of invertebrates

Some species, particularly those which are large and distinctive, are immediately identifiable whilst sorting, and are noted on a temporary "sorting list" (e.g. *Ilyocoris cimicoides*, *Nepa cinerea* and many snails). Most others require use of biological keys and a microscope with a magnification of at least x30. Relevant keys are listed in Appendix 1. Many species (especially the larval stages of insects) cannot be identified below certain sizes. Appropriate sizes are given in identification keys.

Table 3. Macroinvertebrate groups recorded for the National Pond Survey

Group	English name	Notes
Tricladida	Flatworms	Identified live
Gastropoda	Water snails	
Bivalvia (except *Pisidium* spp.)	Freshwater cockles and mussels	
Hirudinea	Leeches	Identified live
Araneae	The Water Spider	
Malacostraca, Anostraca, Notostraca	Shrimps, slaters, crayfish	
Ephemeroptera (larvae)	Mayflies	
Plecoptera (larvae)	Stoneflies	
Odonata (larvae)	Dragonflies and damselflies	
Megaloptera & Neuroptera (larvae)	Alderflies and spongeflies	
Coleoptera (adults)*	Water beetles	*As defined by Friday 1988.
Hemiptera (adults)	Water bugs	
Trichoptera (larvae)	Caddis flies	

Others

Diptera (including Chironomidae) (flies) are identified to family level but may also be retained for identification at a higher taxonomic level, if necessary, at a later stage.

Oligochaetes (segmented worms) are identified to Class level but may also be retained for identification at a higher taxonomic level, if necessary, at a later stage.

Small bivalves not identified to species level (i.e. *Pisidium* spp.) may be retained for identification at a later stage.

Watermites, zooplankton and other micro-arthropods are not included in the survey.

Appendix 1 Identification guides used for National Pond Survey work

Plants

General

Clapham, A.R., Tutin, T.G. and Moore, D.M. (1988). *Flora of the British Isles* (3rd ed.). Cambridge University Press, Cambridge.

Haslam, S., Sinker, C. and Wolseley, P. (1975). British Water Plants. *Field Studies* 4, 243-351.

Rich, T.C.G. and Jermy, A.C. (1998). *Plant Crib 1998*. Botanical Society of the British Isles, London. (particularly useful for *Potamogeton*, *Ranunculus* and *Glyceria* spp.).

Stace, C. (1997). *New flora of the British Isles*. Second Edition. Cambridge University Press, Cambridge. (useful new data and key for *Callitriche* spp.).

Grasses and Sedges

Hubbard, C.E. (1968). *Grasses*. Penguin Books. Middlesex.

Jermy, A.C., Chater, A.O. and David, R.W. (1982). *Sedges of the British Isles*. Botanical Society of the British Isles, London.

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Appendix 2 Survey data

Appendix 2.1 Physical variables
Appendix 2.2 Water chemistry
Appendix 2.3 Wetland plant data
Appendix 2.4 Macroinvertebrate data

Appendix 3 Results of univariate statistical analyses

Appendix 3.1 List of variable codes
Appendix 3.2 Physico-chemical variables
Appendix 3.3 Wetland plants
Appendix 3.4 Macroinvertebrates
Appendix 3.5 DCA axes
Appendix 3.5.1 Aquatic plant DCA axes and other variables
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Appendix 3.5.3 Macroinvertebrate DCA axes and other variables

Appendix 4 TWINSPAN constancy tables

Appendix 4.1 Aquatic plants
Appendix 4.2 Emergent plants
Appendix 4.3 Macroinvertebrates