Biological Techniques of Still Water Quality Assessment: Phase 2 Method Development

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EXECUTIVE SUMMARY

R&D project A05(94) is a three phase project to develop a biological assessment method for monitoring the quality of still waters in England and Wales.

During the first project phase (1995-1996), a rationale for still water monitoring was developed which recommended that still waters (lakes, canals, ponds, ditches, temporary waters and brackish lagoons) should be assessed using a predictive multimetric approach termed PSYM (Predictive SYstem for Multimetrics).

The method:

i) enables the unimpaired fauna and flora to be predicted for any given site,

ii) assesses the extent to which sites are degraded below the unimpaired baseline using a series of biological attributes (metrics) which together measure waterbody integrity,

iii) uses a combined metric score to provide a single value which summarises overall waterbody quality.

The current report describes Phase 2 development of the PSYM methodology, including the outcome of the first field trials and the results of a series of desk-studies to develop other aspects of the multimetric methodology.

The course of the Phase 2 project followed three main tracks:

Track 1: Field trials of PSYM (Predictive SYstem for Multimetrics)

The objective of Track 1 was to develop and trial the predictive multimetric system. The method was applied to two still water body types (canals and ponds), and was developed using two biotic assemblages: aquatic macroinvertebrates in canals and both macroinvertebrates and aquatic macrophytes in ponds.

The results showed that:

- The flora and fauna of minimally impaired ponds and canals could be successfully predicted using environmental variables alone. In ponds the main predictors were waterbody location, size and underlying geology. In canals, predictive variables were largely associated with canal location, sediment depth and bank characteristics.
- The development of multiple metrics for assessing the extent of degradation in ponds and canals was straightforward. Correlation analysis, relating biotic attributes (taxa richness etc.) to waterbody degradation (measured as water quality, intensive land-use etc.), provided an effective technique for identifying viable metrics which could track degradation in each waterbody type.
- In ponds the most effective plant metrics were based on plant species richness and rarity attributes. In both ponds and canals, the most effective invertebrate metrics were based on family richness and pollution sensitive taxa attributes.

To give an indication of the type of results produced using Pond and Canal PSYM, five case-study trials were undertaken using sites from the existing data set. Overall, the results successfully demonstrated the key features of the method. Specifically:

- The method clearly differentiated minimally impaired and degraded sites in both ponds and canals.
- The overall quality score, produced by combining metrics, was more effective than individual metrics for assessing waterbody quality.
- Family-level invertebrate metrics were as effective as species-level metrics for assessing overall waterbody quality, suggesting that, for the invertebrate component

of PSYM, an Environment Agency methodology using family level invertebrate taxonomy will be possible.

- In canals, it was possible to identify specific invertebrate metrics reflecting water quality (as opposed to habitat quality) which worked in areas both with, and without, bank reinforcement.

As a first step towards developing a lake quality assessment method, further PSYM analyses were undertaken using a small lake data set. The results provide a provisional indication that extension of the PSYM methodology to lakes would be successful.

Track 2: Desk study evaluation of multimetric assemblages and applications

Project Track 2 sought (i) to progress the application of fish and diatoms as promising biotic assemblages for multimetric assessment and (ii) to make a desk study evaluation of the potential use of PSYM for Biodiversity Action Plan monitoring.

The Phase 1 scoping study suggested that fish were a potentially useful assemblage for monitoring the quality of lakes. The Phase 2 desk study indicated that viable fish metrics could almost certainly be derived from standard Environment Agency fisheries survey data (with the exception of health and condition metrics). Fisheries data already held by the Agency, particularly a database of c.200 Fenland drains in the Anglian Region, could be used to undertake an initial trial of fish-based multimetric methods.

To progress the use of diatoms as a multimetric assemblage, diatom samples were collected from 92 ponds, using methods developed in a workshop organised in conjunction with the project in April 1997. The diatom samples, which currently await identification and analysis, have the potential to (i) provide the basis for a predictive multimetric diatom classification in ponds and (ii) enable evaluation of the relative viability of diatoms, macrophytes and macroinvertebrates in water quality monitoring.

An assessment was made of the extent to which PSYM methods could be used by the Environment Agency to monitor aquatic Biodiversity Action Plan (BAP) habitats (mesotrophic lakes and saline lagoons) and species. Multimetric methods essentially aim to measure and summarise overall habitat biodiversity, and so have considerable potential for monitoring relevant BAP habitats. Currently, using the existing work from the Phase 2 study, it would be possible to undertake provisional evaluation of small mesotrophic lakes using the pond PSYM data set. Further data sets would be needed to extend the methodology to larger lakes or saline lagoons. The use of multimetric methods for monitoring of specific BAP *species* is possible, but unlikely to be consistently useful in practice. The most likely application of PSYM methods in this context is as a means of assessing the overall quality of the aquatic habitats with which BAP species are associated.

Track 3: Diagnosing the causes of degradation: review of methods

The project scoping study developed a rationale for biological water quality monitoring which identifies water quality assessment as a 2 stage process: (i) assessment of general ecosystem quality (progressed in this project in Tracks 1 and 2) and (ii) diagnosis of problems identified by general ecosystem assessments. The project Track 3 objective was to undertake a desk-study evaluation of methods that could be used to diagnose the causes of environmental degradation.

A review of biological techniques which the Environment Agency could use for diagnosing the causes of environmental degradation suggested that, for most impact types, diagnostic biological methods are either available or could be developed relatively rapidly. Impacts for which biological diagnostic techniques are available include: acidification, eutrophication, effluent discharges, metal pollution and organic pollution.

For climate change and micro-organics, however, biological methods have been relatively little developed and applied.

In general, there appears to be considerable potential for information gathered for general ecosystem assessments (for multimetric analysis) to be re-used in diagnosing the causes of degradation. At present, acidification, organic pollution and possibly eutrophication could all potentially be diagnosed using such an approach.

1. INTRODUCTION

1.1 Project and report aims

This report describes the findings from Phase 2 of Environment Agency R&D Project A05(94) "*Biological techniques of still water quality assessment*". The overall objective of the project is to develop a biological assessment method which will enable the Agency to monitor the quality of still waters in England and Wales. The project has three phases:

- Phase 1 (1995-1996): a desk study to develop a rationale and methodology for biological monitoring of still water,
- Phases 2 and 3 (1997-1999): development and testing of the method in one or more still waterbody types.

Definitions of the still waters included in the project are given in Table 1.1.

The Phase 2 project, described in this report, is defined by three parallel tracks:

- Track 1: development of the Predictive SYstem for Multimetrics (PSYM) proposed for still water quality assessment in Phase 1, using two still waterbody types (canals and ponds) and two biotic assemblages (macroinvertebrates and aquatic macrophytes).
- Track 2: an investigation of the potential for: (i) using other biotic assemblages (fish and diatoms) in multimetric assessments and (ii) for developing other uses of multimetrics, particularly monitoring Biodiversity Action Plan habitats and species.
- Track 3: a desk-study evaluation of methods that could be used to *diagnose* the causes of environmental degradation.

General information describing the project background is given in the Phase 1 report: *Biological techniques of still water quality assessment: Phase 1 Scoping Study*, Environment Agency R&D Technical Report E7 (Williams *et al*., 1995). A brief summary of the Phase 1 results is given below.

1.2 Summary of Phase 1 project results

Phase 1 of the project was a scoping study which recommended that the quality of still waters should be assessed using a method which essentially combines the predictive approach of RIVPACS[1] with the multimetric-based methods used for water quality assessment in the United States.

Multimetric approaches aim to assess overall waterbody integrity using multiple parameters (metrics[2]) each related to degradation. Results from metric assessment are combined to give a single score, usually called an Index of Biotic Integrity (IBI), which represents the overall ecological quality of the waterbody.

Practical use of the combined predictive multimetric method (PSYM) involves four steps:

1. Comparing selected biotic assemblages with the least impaired present-day reference assemblages, using multivariate techniques to predict the expected composition of the baseline assemblage at a given site from physical variables alone.
2. Assessing the extent to which the observed biotic assemblages deviate from the reference state using a variety of metrics (e.g. taxon richness, percentage sensitive

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[1] RIVPACS. The River InVertebrate Prediction And Classification System, developed by the Institute of Freshwater Ecology (Wright *et al*. 1984, 1995).

[2] A metric is 'a calculated term or numeration representing some aspect of biological assemblage, structure, function or other measurable characteristic that changes in some predictable way with increased human influence' (Karr, 1995).

Table 1.1 Definitions of still waterbodies used for the project

Lake	Waterbodies greater than 2ha in area (Johnes *et al.*, 1994). Includes reservoirs, gravel pits, meres and broads.
Permanent and semi permanent ponds	Waterbodies between $1m^2$ and 2ha in area which usually retain water throughout the year (Collinson *et al*,. 1995). Includes both man-made and natural waterbodies.
Temporary waters	Waterbodies with a predictable dry phase, usually in the order of 3-8 months (Ward, 1992).
Brackish waters	Pools and lagoons containing between 500 and 30,000 mgl^{-1} sodium chloride (Allaby, 1985).
Canals	Artificial channels originally constructed for navigation purposes.
Ditches	Man-made drainage channels, including drains and rhines.

groups, functional feeding groups) which, together, aim to measure the integrity of the freshwater system.

3. Comparing predicted metric values with the observed values; individual metrics are then scored on a simple 1 to 5 scale (1 = high deviation from baseline, very poor quality to 5 = no deviation from baseline, good quality).
4. Combining individual metric scores to give an overall site integrity score (the IBI). This score provides an overall measure of biological water quality enabling sites to be ranked according to their degree of ecological impairment (e.g. for the 5-yearly General Quality Assessment undertaken by the Environment Agency).

A more detailed overview of the steps involved in PSYM method development is given in Appendix 1.

The PSYM approach aims to fulfil most major Environment Agency operational and policy requirements for a biological GQA method. In particular:

1. The scheme is flexible and can be applied to any region or area or still waterbody type.
2. A wide range of variables (metrics) are used to assess water quality. This gives a broad-based assessment of quality.
3. Assessment measures can be summed, without loss of information, to give a single score which forms the basis for GQA assessment and the establishment of Water Quality Objectives.
4. The method can be used to address the Agency's pollution monitoring responsibilities, conservation duties and role in protecting biodiversity.
5. The methodology fulfils many of the requirements for biological monitoring proposed in the EU framework water policy directive, as currently described. This includes requirements for (i) comparisons with minimally impacted baseline conditions, and (ii) assessments to be based on multiple parameters related to degradation.

The objective of the PSYM method, is to assess the *overall* condition of freshwater ecosystems. The system does not, in itself, aim to provide a diagnosis of the cause, or causes, of degradation. Indeed it is considered inappropriate for a general quality assessment method to be biased towards evaluation of a single impact. However, there is considerable potential for data which are collected using the scheme to be re-interpreted to diagnose the causes of degradation. This may be achieved both by inspection of individual metrics which make up the total integrity score, or by reanalysis to give pollution indices, such as trophic scores or acidification indices.

Matrix analysis undertaken in the Phase 1 study suggested that the biotic assemblages most appropriate for use as the basis for multimetric assessment varied between different still waterbody types. However, the reliability and validity of assessments is likely to be greatest if a combination of a faunal assemblage (e.g. either macroinvertebrates or fish) and a plant assemblage (e.g. either aquatic macrophytes or diatoms) is used.

The assemblages specifically recommended as a basis for monitoring in each waterbody type were:

Lakes	Macroinvertebrates	+	Aquatic macrophytes (Diatoms + Fish)[1]
Ponds	Macroinvertebrates	+	Aquatic macrophytes (or Diatoms)
Canals	Macroinvertebrates	+	(Diatoms or Fish)
Ditches	Macroinvertebrates	+	Aquatic macrophytes (or Diatoms)
Temporary waters	(Macroinvertebrates, Microinvertebrates, Macrophytes, Diatoms)		
Brackish waters	(Macroinvertebrates, Microinvertebrates, Macrophytes, Diatoms)		

1.3 Current report structure and outline

The current report describes the development of the PSYM method within the three project tracks sequentially.

Chapters 2 and 3 describe development of the predictive multimetric method in ponds and canals in terms of the methodology used (Ch. 2) and the analytical results (Ch. 3).

Chapter 4 describes the Track 2 investigation of the potential for the predictive multimetric system to be developed for other biotic assemblages (fish and diatoms) and for uses other than GQA (e.g. Biodiversity Action Plan monitoring).

Chapter 5 provides a desk-study evaluation of methods that could be used to *diagnose* the causes of environmental degradation.

Chapter 6 gives conclusions and recommendations for future development of the project in Phase 3.

[1]Assemblages in parentheses are those for which methodological viability had not been fully established.

2. TRACK 1: METHODOLOGY USED TO DEVELOP THE PREDICTIVE MULTIMETRIC APPROACH

2.1 Introduction

This chapter provides background information about the methods used to develop PSYM (the Predictive SYstem for Multimetrics) for canals and ponds.

The main sections of the chapter describe:
- choice of field survey areas and sites,
- biological and physico-chemical survey methods,
- choice of potential metrics,
- analytical techniques.

Analytical development of the PSYM method is described in detail in Chapter 3.

2.2 Selection of canal and pond survey areas

Development of the multimetric method for both canals and ponds was undertaken in pilot study areas. This allowed the method to be trialled using a smaller number of sites than would have been possible in a national survey. The survey areas chosen comprised major geographic areas covering a range of lithologies and land use types. As a result of differing constraints on the choice of pond and canal survey areas (see 2.2.2 below), the survey areas for the two waterbody types overlapped, but were not identical.

2.2.1 Pond survey area

The survey region used in the study comprised a broad transect (approximately 300 x 150 km) extending from Kent to mid-Wales. This area represents approximately 30% of the land area of England and Wales (Figure 2.1).

The area is geologically varied and includes calcareous lithologies (Chalk, Carboniferous and Jurassic limestones), sandstones (Eocene sands, Jurassic sandstones, Old Red Sandstone), clays (Oxford, London and Weald Clays) and harder rocks such as the Welsh Silurian shales. This area also includes considerable variation in topography (altitudes ranging from 20 m - 500 m asl) and land-use types. Three of the four major Institute of Terrestrial Ecology (ITE) landscape types are well-represented (arable, pastural and marginal upland[3]) and a wide range of ITE land cover types are present including semi-natural landscapes (lowland and upland heath, moorland etc.).

Land areas within the transect zone are impacted by a range of the main degradation factors affecting still waters, including eutrophication, acidification, biocide pollution, hydrological stress and urbanisation effects.

The small number of additional lakes added to the pond data set (Section 2.3.2) all fell into, or near to, this survey area.

[3] See Barr *et al.* 1993. *Countryside Survey 1990 Main Report.* Countryside 1990 series, 2. HMSO, London.

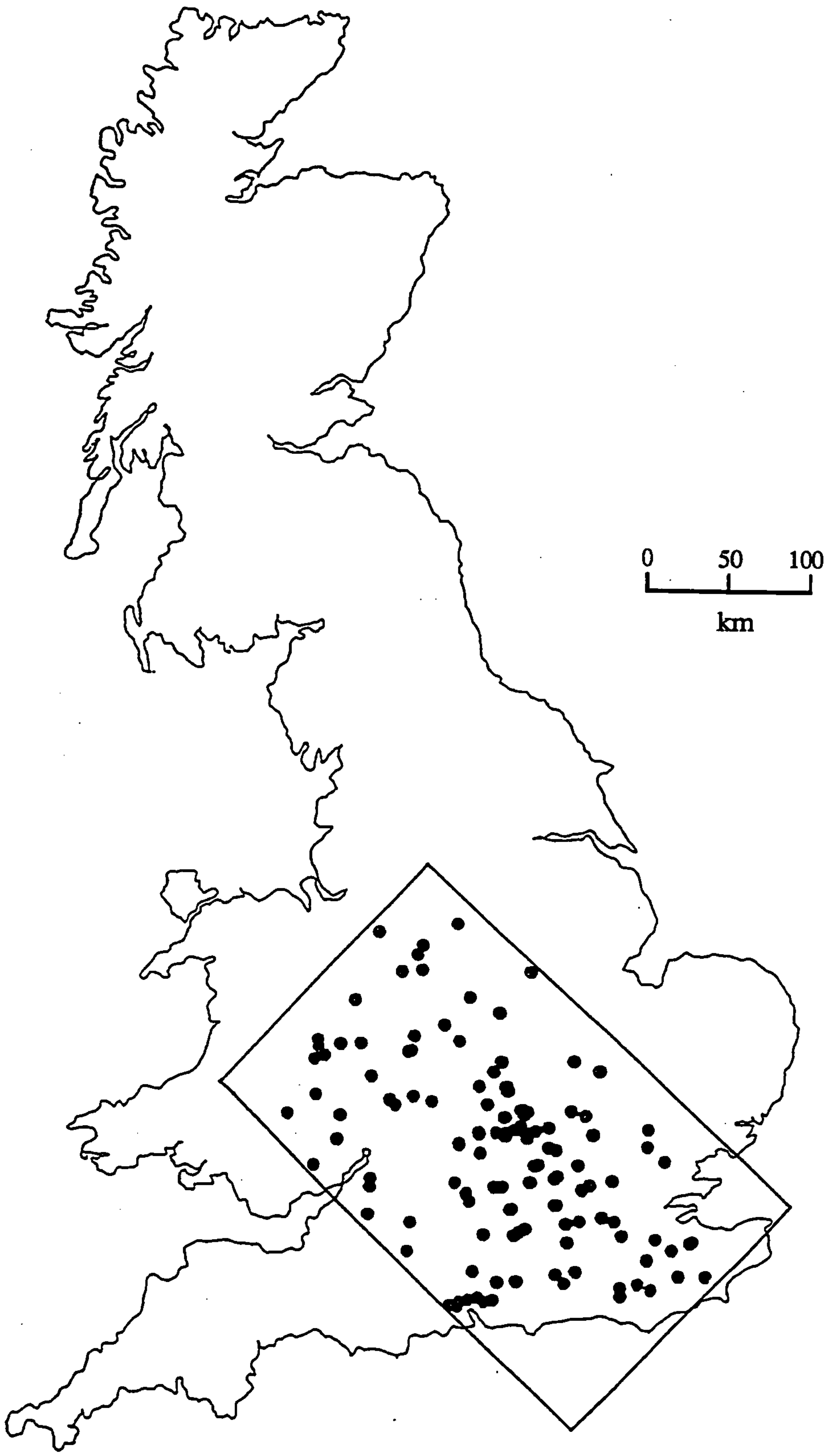

Figure 2.1 Location of survey ponds

2.2.2 Canal survey area

The choice of the canal survey area was constrained by the distribution of canals, which are largely restricted to lowland regions. The survey covered an area of about 250 x 200 km, extending from Surrey in the south to the Cheshire Plain (Figure 2.2).

The survey included the main Midland canals (e.g. Grand Union Canal, Oxford Canal), which are impacted by a range of agricultural, urban and industrial impacts, together with a number of operational rural systems (e.g. Kennet and Avon Canal) with moderate boat traffic and good water quality (e.g. Llangollen Branch of the Shropshire Union Canal) which are considered of high nature conservation interest.

The altitudinal range for this area varies from approximately 50 m - 150 m asl. Geological formations include a range of Upper Palaeozoic strata (Silurian shales, New Red Sandstone, Permian Marls) together with Mesozoic rocks which include Lower Jurassic clays, Oxford Clay and Jurassic limestones. The canal area is primarily lowland in character and includes ITE pastural and arable landscape types. Note that although canals are generally clay-lined, they do receive extensive surface water drainage from adjacent land, both in rural and urban areas.

2.3 Selection of survey sites and samples

Within the pond and canal survey areas sites were chosen to provide data from:

(i) minimally impacted reference sites for use in classification and prediction analyses (cf. RIVPACS).

(ii) a range of variably impacted sites which would enable derivation of viable metrics to assess anthropogenic impairment.

A short desk-study was undertaken to determine the optimal location for the pond and canal sites. This study aimed to ensure that the distribution of minimally perturbed and impacted sites adequately reflected the range of physical, chemical and biotic parameters likely to be acting upon each waterbody type (e.g. geology, landuse, depth, shade, anthropogenic influences). An effort was made to minimise correlation between anthropogenic stresses (e.g. nutrients and biocides) to enhance the diagnostic potential of individual metrics.

The number of pond and canal sites used to develop the predictive and the multimetric analysis was determined on the basis of waterbody variability, resources and the availability of existing data.

In practice, for ponds, data from 142 sites were used for method development. Of these, just over half (n=72) were minimally impaired sites used in the prediction analyses. All 142 sites were used for the development of metrics. Given that the pond survey area covered approximately 30% of England and Wales, the density of minimally impaired sites was similar to that used in the original RIVPACS development with 1.5 site/1000 km^2, compared to about 1.1 sites/1000 km^2 for RIVPACS (Wright *et al.*, 1984).

For canals, which are more uniform physically and chemically than ponds, fewer sites were surveyed (n = 83 of which 30 were minimally impaired, giving a density of minimally impaired sites of 0.6 sites/1000 km^2).

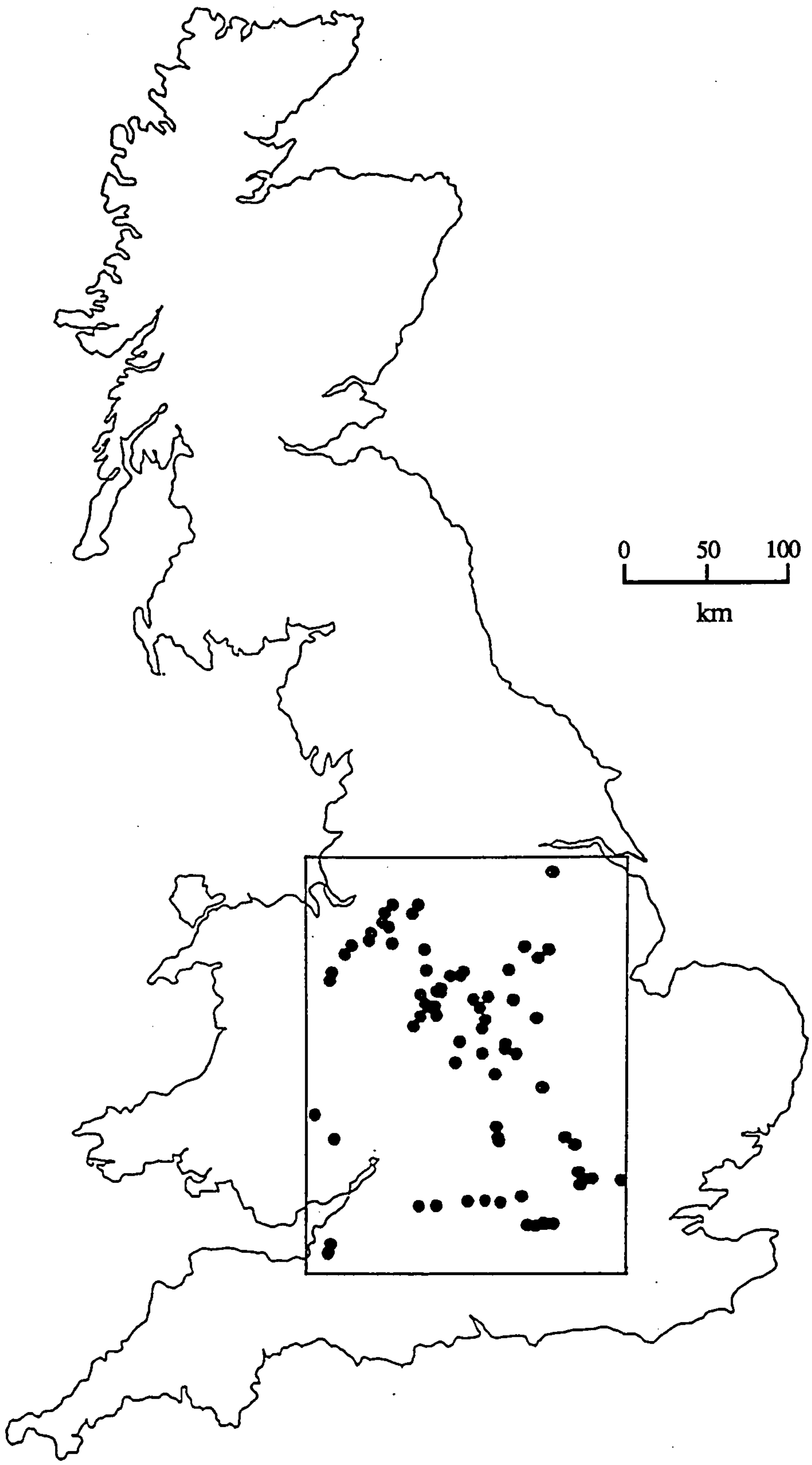

Figure 2.2 Location of survey canals

2.3.1 Pond survey sites

Pond survey data used a compatible mixture of existing and new data. This comprised:

- 68 minimally impaired ponds derived from Pond Action's National Pond Survey (NPS) database,
- 56 variably degraded ponds derived from Pond Action research work funded by NERC's ROPA (Realising Our Potential Award) scheme,
- 20 ponds surveyed specifically for the current project in summer 1997, strategically located to fill existing gaps in the database (see below).

Selection of pond reference and degraded sites

Minimally impaired ponds were all located in areas of semi-natural land use (e.g. unimproved grasslands, semi-natural woodland, lowland heathland, moorland). Data were also used from new ponds on Pinkhill Meadow in Oxfordshire which have been monitored by Pond Action as part of Environment Agency R&D Project 383 (Pond Action, 1997).

The variably impaired ponds were located in more intensively managed landscapes exposed to a variety of anthropogenic impacts. The initial selection of sites was made with reference to the Institute of Terrestrial Ecology (ITE) Land Classification system, with 1 km grid squares randomly selected to represent relevant ITE land classes (out of the total of 32 ITE land classes). Impaired ponds were chosen within (or as close as possible to) these 1 km squares. A number of additional ponds were chosen to provide a representative selection of anthropogenic impacts, including organic pollution from farm wastes, eutrophication, xenobiotic applications, sediment runoff, amenity grassland management and severe biological disturbance from wildfowl and intensive fish management.

A list of the project survey ponds is given in Appendix 2.

2.3.2 Additional lakes

A data set of 12 lakes, surveyed using the pond survey methodology, were combined with the pond data set to investigate the potential for extension of the pond methodology to lake systems. The lake data set comprised new surveys of six of the lakes used in the Environment Agency Lakes - Classification and monitoring project (Johnes *et al.*, 1994), together with the six highest-quality gravel pit lakes surveyed by Pond Action for the Environment Agency as part of work on the Datchet-Wraysbury-Staines-Chertsey Flood study. A list of the survey lakes is given in Appendix 3.

2.3.3 Canal survey sites

Canal data were specifically collected for the project in spring 1997 (April and May). The data set comprised macroinvertebrate, vegetation cover and physico-chemical data collected from 70 canal sites. To enhance the potential to identify bank-structure effects, replicate invertebrate samples and environmental data were gathered from c.20% of the canal sites, particularly focusing on sampling well-vegetated banks vs. bare, vertical reinforced bank sections. Three of the replicate samples were taken from minimally impaired canal locations and the remaining samples were taken from canals with a range of water qualities.

The majority of invertebrate samples were taken from the towpath bank of the canal, in line with current Environment Agency practice. However, a small number of replicates were collected from the opposite bank where this was necessary to provide data from contrasting bank types in close proximity. Where possible sites were located close to existing Environment Agency water chemistry monitoring sites. Major navigations (i.e.

canalised rivers), such as the Lee Navigation and Stort Navigation, were excluded from the canal survey as many sections are essentially riverine in character and, therefore, not within the scope of the study.

Selection of canal reference and degraded sites

Canals are artificial freshwater systems created and used for specific societal purposes. The selection of 'minimally impaired' canal reference sites was therefore based on the concept of 'appropriate waterbody conditions' rather than 'unimpaired state'. Appropriate waterbody conditions were defined, after consultation with the Project Board (which had both Environment Agency and British Waterways representatives), as canal sites which have:

(i) good water quality: i.e. GQA Chemical Class A or B

(ii) 'low' or 'moderate' boat traffic.

The initial selection of reference sites was primarily based on 1995 Environment Agency chemical water quality data. However, the final choice of minimally impaired baseline sites used in analysis was informed by a combination of: (i) data from Environment Agency routine chemical samples, (ii) water chemistry data collected specifically for the project and (iii) British Waterways sediment chemistry and boat traffic data. Minimally impaired canal sites were drawn from the following canals: Oxford, Kennet & Avon, Ashby, Grantham, Brecon, Shropshire, Grand Union and Taunton.

Degraded canal sites were chosen to give a representative range of water qualities and good coverage of the network. In addition, specific sites were chosen to ensure that varying sources of impairment were assessed, including agricultural runoff, sewage treatment works, urban runoff, quarry discharges and industrial effluents.

A list of the canals surveyed for the project is given in Appendix 4.

2.4 Biological data collection

In ponds, the predictive multimetric method was developed using two biotic assemblages: aquatic macrophytes and macroinvertebrate assemblages. In canals the PSYM method was developed using only macroinvertebrates. Inclusion of an additional plant assemblage would have been advantageous for assessing canal quality (Section 1.2). However field survey methods for the preferred plant assemblage (diatoms) were too poorly developed to allow an immediate field trial to be undertaken. Development of an appropriate diatom methodology was, however, progressed as a Track 2 project, described in Chapter 4.

PSYM method development in ponds was largely based on data which had been collected in the course of other projects (Section 2.3.1). In canals, PSYM was developed using aquatic macro-invertebrate assemblage data collected specifically for the project.

There are clear benefits in ensuring that new data collected for Environment Agency monitoring projects are internally compatible. Wherever possible, therefore, methods used to collect data for the project were modified from existing survey methods used for other waterbody types.

Table 2.1 Macroinvertebrate taxa included in canal and pond surveys

Taxon	*Identification level*	*Taxon*	*Identification level*
Tricladida	Species	Hemiptera	Species
Gastropoda	Species	Coleoptera	Species
Bivalvia[1]	Species	Plecoptera	Species
Crustacea (Malacostraca)	Species	Lepidoptera	Species
Hirudinea	Species	Trichoptera	Species
Ephemeroptera	Species	Oligochaeta	Class[2]
Odonata	Species	Diptera	Family[2]
Megaloptera (inc. spongeflies)	Species		

[1]Including *Sphaerium* spp., but excluding *Pisidium* spp. (which were retained for identification, if necessary, at a later stage).
[2]Groups retained for identification, if necessary, at later stage.

2.4.1 Canal invertebrate data collection

Canals are steep-sided and relatively deep waterbodies, so the area-related hand-net sampling methodologies appropriate for rivers (e.g. typical RIVPACS sampling) cannot be directly applied to canals. In particular: (i) hand-net methods are difficult to apply to the deepest open-water areas of canals, (ii) most invertebrate species are concentrated in a narrow band at the canal edge, so that an area-based sampling method can considerably under-sample invertebrate diversity.

Investigation of current practice suggested that: (i) Environment Agency biologists typically sampled canals using a methodology modified from the three-minute hand-net river techniques. However, no formal adaptation of the river methodology had been made and (ii) although IFE had a project to survey canal invertebrate communities, in April 1997 when sampling for the current project began, they had not developed a specific sampling methodology.

In the absence of a prescribed methodology, a standard canal survey technique was developed based on a hybrid between the 'three-minute hand-net sample' currently used for sampling shallow rivers, and the 'one-minute hand-net sample + dredge hauls' method which IFE recommends for sampling deep rivers. This hybrid method comprised:

1. A two-minute semi-continuous hand-net sampling of the canal margin, shallows and any emergent plant habitats present. This sample was typically taken along a bank length of 5m to 15m.
2. Four net hauls from deeper bottom sediments, elutriated on site to wash out the bulk of muds and fine sands.
3. A one-minute additional search.

Two directly compatible field techniques were employed to gather bottom sediment samples from deeper areas, the choice depending on canal depth and accessibility:
(i) where canals were shallow enough to wade, bottom samples were collected using a hand-net haul (c.3m length) taken perpendicular to the bank, (ii) where canals were too deep to use a hand net, bottom samples were collected using a Naturalist's dredge with a hand net sub-sample then taken from this dredged material.

Invertebrate samples were sorted 'live' in the laboratory. Sorting was exhaustive, and typically took five to six hours per sample (range 3 - 16 hours). Abundant taxa were sub-sampled where appropriate. Identification and enumeration of specimens was undertaken to the levels shown in Table 2.1.

2.4.2 Pond and small lake invertebrate data collection

The pond invertebrate survey methods used for the study were based on standard three minute hand-net sampling methods developed for the National Pond Survey (Pond Action, 1994). Samples were collected in the summer season (June, July, August).

The NPS invertebrate survey techniques were developed 'post-RIVPACS' in 1989-90, and were designed to be closely compatible with the RIVPACS methods, whilst allowing for differences between river and pond habitat types. The main similarities and differences between the methods are summarised below:

Similarities

- Objective of both methods: to obtain the most comprehensive species list for the site, within a reasonable amount of time.
- Sampling time and frequency: both the NPS and RIVPACS collect three minute hand net samples in the same three seasons of the year.
- Sampling efficiency: NPS sampling techniques accumulate species at a similar rate to those seen in RIVPACS.
- Sample sorting: both methods aim to remove all macroinvertebrate species from samples; in practice this can take considerably longer in pond samples which tend to be much more silty than river samples (average for ponds; 8 hours, range; 3 - 25 hours)
- Counts: both methods make an estimate of abundance.

Differences

- RIVPACS allocates sampling time on an area basis (i.e. more time is spent sampling extensive habitats). NPS allocates time according to mesohabitat types (i.e. if six main habitat types are identified time is divided equally amongst these). This change was made to allow for the fact that many ponds have extensive biologically uniform areas of open water and silt, and narrow but highly diverse marginal zones.
- RIVPACS samples are collected from an area that can be covered comfortably in three minutes and, although a survey length is not specified, this is typically a 5-20 m length of river. In the NPS the 3 minute survey subsamples are taken around the entire pond site.
- RIVPACS uses preserved samples; NPS samples are sorted live.
- RIVPACS identifies Diptera and Oligochaetes to 'furthest practical level'. For Diptera about 50% are identified to species level. Oligochaetes are generally identified to species level. In the NPS these groups are identified to Family and Class, respectively (see Table 2.1).
- RIVPACS samples were collected from deep water using a dredge. In the NPS deep water areas were sampled with a hand net using chest waders or from a boat.

2.4.3 Pond macrophyte data collection

Matrix analysis undertaken in the Phase 1 Scoping Study, suggested that *aquatic* macrophytes (i.e. submerged and floating-leaved species) were likely to be an effective assemblage for monitoring pond water quality. *Emergent* macrophytes, in contrast, respond less clearly to waterbody chemistry attributes (e.g. Palmer *et al.* 1992).

However, they are particularly valuable (i) as indicators of bank quality, and (ii) as overall quality indicators in ponds which are periodically dry and which have naturally depauperate plant communities.

For PSYM development, therefore, both aquatic and marginal macrophyte assemblages were used (together termed 'wetland plants'). A list of the species defined as wetland plants is given in Appendix 5. The glossary provides macrophyte terminology definitions.

In the field, pond macrophytes were surveyed by walking or wading the entire perimeter of the waterbody. Deeper water areas were sampled either by grapnel thrown from shallow water or from a boat. A standard wetland plant species list was used to aid searching in the field and provide the basis for comparative species richness estimates (Appendix 5). Vegetation abundance was recorded as percentage cover for
(i) each species, (ii) total cover of three aggregate vegetation categories: submerged, floating-leaved and emergent plant cover.

2.5 Physical and chemical data collection

2.5.1 Introduction

Physical and chemical data from the canals and ponds were required to:

1. Form the basis of biotic assemblage predictions developed using minimally impaired baseline sites (cf. RIVPACS).

   Variables used for this purpose needed to be easily measurable in the field (e.g. sediment type), or be simply derivable from desk study information (e.g. geology), since they may be used as predictive variables in the fully developed field method.

2. Assist in the derivation of viable metrics based on physico-chemical impairment.

   These data were specifically related to anthropogenic degradation gradients (i.e. elevated heavy metal concentrations, inputs of treated sewage effluents, nutrient levels, bank degradation, intensive surrounding land uses). The parameters will not, however, be used in routine Environment Agency field assessments so need not be amenable to simple field survey assessment.

A summary of the physico-chemical variables used in the project is given in Table 2.2. Copies of the pond and canal field survey pro-formas are given in Appendices 5 and 6.

2.5.2 Pond physical and chemical data

Existing pond physico-chemical data collected for the National Pond Survey and NERC wider countryside pond databases were analysed to identify areas and pond types which could be usefully supplemented by the additional 20 Environment Agency pond sites.

The analysis suggested collection of additional pond data to reduce existing cross correlations between pH and drawdown, easting and shade, easting and tall emergent cover, northing and shade, northing and tall emergent cover and shade and seasonality. Ponds sites and survey areas were identified to help to reduce these biases.

Field data collected are shown in the standard NPS field survey recording form (Appendix 5). Water samples from the ponds were taken in spring (April, May). Two water chemistry samples (filtered and unfiltered water) were collected at each site. Water quality determinands which required immediate analysis (pH etc.) were measured at all sites immediately after collection. The remaining analyses were undertaken at Oxford Brookes University and Reading University by Pond Action. A list of chemical determinands analysed is given in Table 2.2.

Table 2.2 Physico-chemical data gathered from water bodies

Ponds	***Canals***
Location	Location
Altitude	Altitude
Water depth	Water depth
Lithology	Flow (British Waterways data)
Drawdown	Base
Catchment size	Shade
Pond area	Bank type
Shade	Sediment
Fish	Width
Mesohabitats	Vegetation cover
Water chemistry [1]	Bank angle
Sediment depth and type	Mesohabitats
Permanence	Surrounding land use
Water source and inflows	Turbidity
Margin complexity	Water chemistry (Environment Agency and Pond Action[1] data)
Age	Sediment quality (British Waterways data)
Grazing and trampling	Boat movements (British Waterways data)
Vegetation cover	Management (British Waterways data)
Surrounding land use	
Adjacent wetlands	

[1]pH; conductivity; suspended solids; total alkalinity; total phosphorus, soluble reactive phosphorus; total nitrogen; total oxidised nitrogen; chloride; calcium; magnesium; sodium; potassium; iron; zinc; lead; copper; nickel; aluminium.

2.5.3 Canal physical and chemical data

Data collected in the field is shown on the canal survey pro-forma (Appendix 6). Additional data was provided by British Waterways and the Basingstoke Canal Company relating to (i) water flow (ii) boat movements (iii) dredging records.

Canal chemical data used in analysis was derived from three sources:

(i) water chemistry samples collected for the project at all invertebrate survey sites

(ii) Environment Agency routine water chemistry samples

(iii) British Waterways (BW) sediment chemistry data.

Canal water samples collected specifically for the project were taken during visits in April and early May. These were used to provide information on metals and nutrients not included in standard Environment Agency water analyses. Water sample collection and analysis followed the pond protocol.

Environment Agency water quality data for each canal were matched to the closest invertebrate survey site. Most were within a few hundred metres. Values for each water chemistry parameter were based on average values for 1996.

Canal sediment data were provided by British Waterways (BW) from the national sediment survey database, undertaken at 2 km intervals in 1992, to provide information on sediment contamination. This survey includes information on a suite of heavy metals and other pollutants (e.g. phenols). As with Environment Agency water chemistry, the invertebrate survey sites were matched with the closest BW sediment sample.

2.6 Selection of potential metrics

Jim Karr, who originated the metric concept in North America in the 1980's, defined a metric as 'a calculated term or numeration representing some aspect of biological assemblage, structure, function or other measurable characteristic that changes in some predictable way with increased human influence' (Karr, 1995). Metrics are, therefore, biological measures (such as taxa richness) which vary monotonically with anthropogenic degradation, and which can be used to measure the extent of ecosystem degradation.

The concept underlying multimetric assessment is that measuring and summing-together a variety of metrics enables an overall assessment of environmental degradation to be made.

The first stage of metric development is the identification of possible metrics which might have the potential to track degradation in a given waterbody type. The list of test metrics should initially be wide and should aim to include both structural measures (such as family richness and EPT, Ephemeroptera, Plecoptera, Trichoptera richness) and functional attributes (such as number of trophic specialists/generalists and number of exotic species). The 'test' list is narrowed-down to a list of viable metrics by looking at the relationship between each potential metric and anthropogenic degradation gradients (see Chapter 3).

A summary of the potential aquatic macrophyte and macroinvertebrate metrics which were calculated and evaluated in the current project is given in Tables 2.3 and 2.4. A complete list of the attributes evaluated is given in Appendix 7.

2.7 Data entry and analysis

Physico-chemical and biotic data were entered into Excel spread-sheets and re-checked against the original data sheets.

Analytical development of the PSYM method was undertaken in two main phases:

(i) development of fauna/flora baseline prediction techniques which broadly followed the RIVPACS methodology (Clarke *et al.*, 1996).

(ii) development and combination of metrics to give an overall Index of Biotic Integrity (IBI).

Table 2.3 Examples of potential invertebrate and plant metrics[1]

Invertebrate metrics	
Taxonomic richness	• Number of taxa, families, species • Number of species in each major family (e.g. Lymnaeidae) and order (e.g. Gastropoda)
Functional feeding groups	• Types of functional-feeding groups (e.g. predators, omnivores and scavengers) • Ratio and number of trophic specialists/generalists
Occurrence of sensitive taxa	• Presence of intolerant species • Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa • Ephemeroptera, Trichoptera, Odonata (ETO) taxa
Organic pollution indices	• BMWP score, ASPT
Rarity value	• Rare Species Score and Species Rarity Index based on numeric values determined by occurrence of nationally uncommon species i.e. 1=common, 2=local, 4=Nationally Scarce, 8=RDB3, 16=RDB2, 32=RDB1.
Plant metrics	
Species richness	Based on number of: • submerged species[2] • floating species • free-floating species • all aquatic species • marginal species • all wetland species
Species rarity	Species Rarity Score and Index for: • submerged species • floating species • marginal species
Conservation value	A categorisation based on a combination of rarity and richness
Endemic/exotic species	Based on the number, percentage and cover of exotic species
Key species	The occurrence of key species and families: i.e. charophytes, *Potamogeton*, *Lemna* etc.

[1]A full list of metrics is given in Appendix 7.
[2]Definitions of each plant category are given in the Glossary.

2.7.1 Development of fauna/flora baseline prediction techniques

TWINSPAN (Two-way Indicator Species Analysis) (Hill, 1979) was used to classify ponds and canals on the basis of each biotic assemblage. Invertebrate classifications were largely based on species-level data, with some taxa identified to higher taxonomic levels (i.e. Oligochaeta, Chironomidae, other Diptera) (see Table 2.1). Aquatic plant classifications used species-level data with the exception of charophytes and *Sphagnum* spp., which were identified to genus level.

MDA (Multiple Discriminant Analysis) was used to (i) identify environmental variables that could predict TWINSPAN end-group membership and (ii) to derive predictive discriminant functions. Real environmental data were substituted into the discriminant functions to predict the TWINSPAN group membership of individual sites.

Preliminary assessments of the success of MDA was made by 'backpredicting' the TWINSPAN end-group of the sites used to derive the original TWINSPAN classification, and comparing the prediction with the original TWINSPAN classification.

Knowing which TWINSPAN end-group(s) a site is predicted to belong to, and knowing the typical species composition of each end-group (in terms of the proportion of sites in which individual species occur in that group), the fauna of the site can be predicted.

For each species i, the expected probability p_i of occurrence at a new site is estimated by:

$$p_i = \Sigma\, G_j S_{ij} \qquad \text{Clarke } et\ al. \text{ (1996)}$$

where G_j is the probability of the new site belonging to a particular TWINSPAN end-group, and S_{ij} is the proportion of reference sites in group j with species i.

2.7.2 Development of metrics

Relationships between trial metrics calculated from plant and invertebrate assemblage data in ponds and canals and environmental degradation (Chapter 3) were investigated using non-parametric correlation analysis (Spearman's Coefficient of Rank Correlation). Because of the large numbers of variables analysed, only correlates which were significant at probability levels of $p<0.001$ were usually considered as viable.

2.7.3 Development of a trial Index of Biotic Integrity (IBI)

For each biotic assemblage used in pond and canal assessment, two or three viable metrics were identified (see Chapter 3).

Using the predicted species list, derived from the TWINSPAN/MDA prediction, the predicted and observed values for each viable metric (e.g. plant species richness, ASPT etc.) were compared. Sites which are minimally impaired should show no significant deviations from the baseline values.

Metrics were transformed to a five point scale (0, 1, 2, 3, 4) to enable them to be combined, and summed to give an Index of Biotic Integrity (IBI). The IBI, which can be presented either as a score, or as a percentage of the maximum score, forms the basis of GQA categorisation of a site.

3. RESULTS

3.1 Introduction

This chapter describes the results of development and testing of the predictive multimetric system (PSYM) using data from ponds, canals, and a small number of lakes.

Method development is described in terms of five main steps:

(i) Classification of the biotic data using TWINSPAN.

(ii) Multiple Discriminant Analysis to enable the TWINSPAN end groups to be predicted using physical variables.

(iii) Correlation analysis to identify the relationships between biological attributes (potential metrics) and waterbody degradation.

(iv) Choice of the best metrics.

(v) Example calculations of Indices of Biotic Integrity (IBIs).

In total, five biological data sets were analysed through these stages. They comprised the three main data sets (i) canal invertebrate assemblages (ii) pond invertebrate assemblages and (iii) pond macrophyte assemblages, together with two analyses for the lake+pond data set (Section 2.3.2) using (iv) macrophyte and (v) invertebrate assemblages. The main purpose of the lake+pond analysis was to undertake a preliminary investigation of the potential to extend the PSYM method to large waterbodies.

3.2 Site Classification: results of the TWINSPAN analysis

Classification of minimally impaired sites was undertaken for each biological assemblages, using TWINSPAN. The pond classifications were based on data from 72 sites. The canal classification used data from 30 locations. The lake+pond analysis combined the 72 pond data set with 12 (mostly small) lakes (Section 2.3.2).

The number of useful end groups produced by each TWINSPAN classification varied between four and six, with four to 28 sites included in each end group. Summary information for each of the five TWINSPAN analyses undertaken is shown in Table 3.1.

In addition, as a useful precursor to MDA analysis, a DECORANA (Hill and Gauch, 1980) ordination of each data set was undertaken to give a preliminary indication of the major natural environmental gradients in the pond and canal data sets as a whole. DECORANA analysis used only the minimally impaired data sets.

3.2.1 Pond classifications

The TWINSPAN classifications grouped the pond invertebrate data into five viable end groups and the plant data into four end groups.

DECORANA ordination suggested that similar environmental factors shaped both plant and invertebrate data sets. In each, the main environmental gradient appeared to be an acid/alkaline trend, with DECORANA Axis 1 separating acid heathland and moorland sites from circum-neutral sites. DECORANA Axis 2 values largely reflected a waterbody water depth and area gradient, separating large/deep and small/shallow ponds.

Table 3.1 Summary of the characteristics of the TWINSPAN classifications for each biotic assemblage analysed

Assemblage	*Number of survey sites*	*Number of end groups used from each TWINSPAN*	*Maximum and minimum no. of sites within the end groups*
Canal invertebrates	30	4	4 - 10
Pond invertebrates	72	5	6 - 28
Pond macrophytes	72	5	4 - 20
Lake and pond invertebrates	84	6	5 - 26
Lake and pond macrophytes	84	4	7 - 31

3.2.2 Pond and lake classifications

The addition of 12 lakes to the pond data set produced only a partial re-arrangement of the pond TWINSPANs.

In the invertebrate classification, the 12 lakes grouped together with six of the larger (0.2 ha to 0.7 ha.) National Pond Survey ponds from Hampshire, Wiltshire and Oxfordshire.

In the plant classification, eight of the 12 lakes classified together, but they were mixed together with ponds of a variety of sizes and depths including smaller permanent waterbodies of as little as 0.004 ha (40 m^2) in area. The remaining four lakes were scattered through the other end groups.

Overall, therefore, the lake sites tended to classify together as part of a large and/or deep waterbody group. They were not, however, so different that they formed independent end groups and, particularly within the plant classification, they were often classified with much smaller sites.

The trends in the pond+lake DECORANA ordination were similar to those in the pond-only ordination suggesting that major physico-chemical factors associated with assemblage composition (acidity/alkalinity, area/depth) are likely to be similar in both waterbody types.

3.2.3 Canal classification

TWINSPAN analysis of canal invertebrate data was used to place the 30 minimally impaired reference sites into four viable end groups (Table 3.1).

At three of the canal reference sites, replicate samples had been taken to investigate the differences between vegetated and reinforced (concrete or steel) banks (Section 2.3.3). On the Oxford Canal and the Basingstoke Canal these replicate samples grouped together. However, replicate samples collected on the Shropshire Union Canal classified into different end-groups.

DECORANA ordination suggested that the canal data set was influenced by strong geographic trends, again partly linked to an acid/alkaline gradient, with more acid westerly sites from the Shropshire Union and Brecon canals at one end of DECORANA Axis 1 and more easterly and southerly circumneutral sites (e.g. Grantham and Basingstoke canals) at the other.

3.3 MDA prediction of TWINSPAN end-groups from environmental variables alone

Extensive iterative MDA analyses were used to identify the physico-chemical variables which would best predict the plant and invertebrate end groups identified by TWINSPAN classification.

The number of possible variables which were available for use in the predictions was fairly extensive: c.130 for pond-only and pond+lake analyses and c.150 for canal invertebrate assemblage predictions (see Appendix 8). In practice, however, a number of physical and chemical variables were specifically omitted in order to optimise the prediction methodology at degraded sites. The most significant omissions were:

1. A range of semi-natural land use variables, particularly the percentage of heathland and unimproved grassland landuse around a pond. Both of these factors were important predictors of community composition. They are, however, by definition, largely absent from intensively managed and impaired landscapes and should not, therefore, be used as predictors of the minimally impaired baseline.
2. Water chemistry variables (particularly alkalinity, conductivity and pH), which again were significant predictive variables, but which are frequently modified by anthropogenic stresses such as eutrophication and acidification.

3.3.1 Pond MDAs

Multiple Discriminant Analysis was used with the pond data sets to identify the physical variables that were the best predictors of biological assemblage composition, and to identify the proportion of sites which could be placed in their correct TWINSPAN end group with different numbers of physical variables.

Summaries of the number of physico-chemical variables which could be used to correctly predict differing proportions of plant and invertebrate TWINSPAN end groups are given in Table 3.2 (see Appendix 9 for a full list of environmental variables). Thus, for invertebrates, 66% of sites could be placed in the correct TWINSPAN end group using five physico-chemical variables. Using 14 variables, 88% of sites were correctly placed. Plant predictions showed similar success rates (63% correctly placed with 5 variables, 84% with 14 variables).

Best predictor variables for ponds

The most important physical variables for predicting both plant and invertebrate end group membership were associated with pond substrate, geology and location. Thus using just easting, altitude and a variety of geology and sediment variables, 74% of pond invertebrate sites and 69% of pond plant sites could be placed in the correct TWINSPAN end-group. Addition of other significant environmental factors such as pond depth, area, shade and vegetation cover increased the probability of sites being correctly classified by between 10% and 20%.

The final choice of variables for the prediction was based on 14 physical variables for both the plant and invertebrate assemblages. Using these variables 88% and 84% of sites were placed in the correct TWINSPAN end-group for invertebrate and plant assemblages respectively. Table 3.3 summarises the variables used. A full list of the variables is given in Appendix 10.

Table 3.2 Pond dataset: summary data showing proportion of sites predicted to the correct TWINSPAN endgroup using MDA with different numbers of physical variables: (a) macro-invertebrate assemblage (b) plant assemblage.

(a) Macroinvertebrate assemblage

Number of variables used in prediction	14	11	9	7	6	5
Number of discriminant functions used	4	4	4	4	4	4
Percent of sites assigned to the correct classification group	88%	81%	78%	72%	69%	66%

(b) Plant assemblage

Number of variables used in prediction	14	12	10	8	6	5
Number of discriminant functions used	4	4	4	4	4	4
Percent of sites assigned to the correct classification group	84%	77%	73%	69%	67%	63%

There was a high degree of overlap in the variables used for the plant and invertebrate predictions, suggesting that (i) similar factors influenced both faunal and floral communities (ii) field data collected for the predictions will be useful for making both plant and invertebrate predictions.

In terms of the implications for Environment Agency data collection, the physical variables fall into 11 major categories (geology, land use etc.). Of these, six are relatively invariant (altitude, geology, water source etc.) which need only be assessed once. The remaining five categories of variable require on-site field measurement when each assessment is made. These are: sediment type, water depth, submerged plant cover, shade and inflow volume category (Table 3.3).

3.3.2 Lake and pond data set

The physical factors that were most useful in predicting site membership of TWINSPAN end-groups in the combined pond+lake data set were similar to those for pond-only data. In the invertebrate assemblage predictions the main change was the inclusion of grassland and grazing variables. For plants two variables were added to increase predictive power: (i) waterbody area and (ii) surface water source, and a small number of water depth and wetland connectivity variables were omitted (see Appendix 10). Using these predictive measures 83% and 84% of sites were placed in the correct lake+pond TWINSPAN end-group for invertebrate and plant assemblages respectively.

Table 3.3 Summary of pond variable categories[1]

Categories	*Invertebrate variables*	*Plant variables*
Location	Easting, altitude	Easting, altitude
Catchment geology	Sandstone, clay, limestone	Sandstone, limestone
Pond base type	Rock	Sand, peat
Sediment	Silt	-
Water source	Surface water, spring+flush	Groundwater
Size	Pond area, water depth	Water depth, drawdown (%)
Shade	-	Pond area shaded (%), Bank Shaded (%)
Surrounding landuse	Ponds in the surrounds (% of the area around the survey pond as standing water)	Deciduous woodland in the surrounds (% area)
Connectivity to other wetlands	Inflow volume	Located on a floodplain or in a traditional wetland area,
Grazing	-	-
Vegetation	Submerged plant cover (%)	-

A full list of variables is given in Appendix 10.

3.3.3 Canal MDAs

A summary of the number of physico-chemical variables which could correctly predict differing proportions of plant and invertebrate TWINSPAN end groups is given in Table 3.4 (full list of variables in Appendix 10). Thus, 81% of sites could be placed in the correct end group using five physical variables. Using nine variables, 100% of sites could be correctly placed. The relatively small number of variables which could fully predict canal end group membership is likely to at least partly reflect the relatively small number of canals used in the classification.

Best predictor variables for canals

The most effective physical variables for predicting the canal invertebrate end groups were associated with location, turbidity, sediment depth and bank characteristics. A single biotic variable (the number of submerged plant species present) was also useful as a predictive variable (Table 3.5).

Two of the canal variables (turbidity and submerged plant species-richness), were not considered ideal predictors since both can vary significantly with anthropogenic factors such as boat usage. They were, however, included in this provisional analysis because they considerably increased predictive power.

Table 3.4 Canal invertebrates: summary data comparing the prediction of a four-group site classification of 30 canal invertebrate reference sites using different combinations of variables

Number of variables used in prediction	9	7	5
Number of discriminant functions used	4	4	4
Percent of sites assigned to the correct classification group	100%	92%	81%

Table 3.5 Summary of canal predictive variable categories

Categories	Variables
Location	Northing, easting, altitude
Turbidity	Secchi depth
Bank	Bank type: % earth, bank angle, % grass in bank top zone
Depth	Sediment depth
Vegetation	Number of submerged plant species

3.4 Identification of metrics

Biological attributes (e.g. taxa richness, proportion of detritivores etc.) which could potentially be useful as metrics for tracking waterbody degradation were calculated from the pond and canal data sets. In total, 70 potential invertebrate metrics and 27 potential plant metrics were calculated. The general categories of metrics are listed in Tables 2.3 and 2.4, and a full list is given in Appendix 7.

Each biotic variable (potential metric) was correlated with physico-chemical variables associated with environmental degradation.

In ponds, degradation was assessed using three main groups of criteria:

(i) The proportion of the surrounds and surface catchment under intensive management (in individual and combined categories such as arable land, intensive agriculture, urban, all intensive land etc.).

(ii) Measured levels of chemical water pollutants (phosphate, nitrate, heavy metals etc.).

(iii) Field-based assessments of the extent to which ponds were exposed to point and non-point source pollution from their catchments (in categories including road runoff, agricultural runoff, total polluted runoff etc.).

The methods available for assessing canal degradation were more limited than for ponds. This largely reflected differences in catchment size: canal catchments are invariably extensive so land use and pollutant input measures could not be easily assessed. Water and sediment chemical quality measures were therefore used as the main degradation correlates. In addition, assessment of degradation in canals is complicated by the potential to include or exclude factors such as canal bank structure and boat traffic as forms of anthropogenic degradation.

3.4.1 Result of pond metric correlations

Tables 3.6 and 3.7 list the potential metrics which were significantly correlated with degradation factors at $p \leq 0.001$ (Spearman's Coefficient of rank correlation). The tables also include physico-chemical variables which vary naturally in ponds (e.g. water depth, area) which were correlated with the potential metrics, since these may have important implications for metric choice. Ideally, metrics which track degradation should *not* also show strong correlations with naturally variable environmental factors. The exceptions are those factors which strongly shape (and can therefore be 'factored-out' by) the TWINSPAN classification. In practice, this means that locational factors in canals and acid/alkaline correlates in ponds are likely to be acceptable co-correlates of degradation.

Physical and biological attributes which were less significantly (i.e. $0.05>p>0.001$), or not, correlated with degradation have not been included in Tables 3.6 and 3.7. A full list of all correlations is provided in the Project Record.

Pond aquatic macrophytes

In ponds, a range of plant richness and rarity parameters showed (i) strong correlations with the major degradation indicators, (ii) relatively few correlations with other physico-chemical variables. The main correlates are described briefly below.

Plant richness and rarity
Submerged plant species richness and aquatic plant species richness (i.e. submerged plus floating-leaved plants) both showed strong correlations with a wide range of degraded land use and pollutant input variables. Of the two, submerged plant species correlations were generally stronger, however.

In contrast, aquatic plant Species Rarity Index (SRI)[4] generally showed slightly more significant correlations with degradation than did the submerged plant SRI alone. Suspended solids and ammonia were common water chemistry correlates for both aquatic plant richness and rarity measures.

In common with aquatic plants, marginal plant species richness and rarity were strongly correlated with degraded land use and pollutant input variables. They were, however, also correlated with a greater number of physical variables (including area, surrounding landuse type and connectivity to other wetlands). Unlike aquatic plants, there were no strong relationships with water chemistry variables such as suspended solids and ammonia.

Free-floating species
An index of the relative occurrence of small free-floating species (e.g. *Lemna* spp. and *Azolla filiculoides*) which are often associated with hyper-eutrophication and other forms of degradation was calculated as the index 'free-floating species richness: submerged plant species richness'. This measure showed strong correlation with general land use degradation measures, particularly agricultural usage.

[4] SRIs are a measure of the average rarity value of species at a site, see Table 2.3 or Glossary.

Table 3.6 Pond macrophyte metrics which have significant relationships with environmental degradation[1]

Potential metric	Environmental factors correlated with potential metric
Aquatic plant species richness	Overall pollution index (-ve); agricultural drainage (-ve); agricultural surrounds (-ve); semi-natural catchment and surrounds; flood water source; ammonia (-ve).
Aquatic plant Species Rarity Index (SRI)	Overall pollution index (-ve); semi-natural surrounds and catchment; surrounding wetlands; intensive landuse and agriculture in surrounds and catchment (-ve); water depth; substrate type; shade (-ve); flood water source; submerged plant cover; suspended solids (-ve).
Aquatic plant Species Rarity Score (SRS)	Overall pollution index (-ve); agricultural drainage (-ve); agricultural surrounds (-ve); semi-natural catchment and surrounds; ammonia (-ve); suspended solids (-ve).
Potamogeton species richness	Intensive surrounds and catchment (-ve); semi-natural surrounds; overall pollution index (-ve); water depth and permanence.
Submerged plant species richness	Intensive surrounds and catchment, particularly agriculture (-ve); overall pollution index (-ve); agricultural runoff; agricultural surrounds and catchment (-ve), arable catchment, semi-natural surrounds and catchment, marginal complexity, ammonia (-ve), suspended solids (-ve).
Submerged plant Species Rarity Score (SRS)	Intensive surrounds and catchment, particularly agriculture (-ve), overall pollution index (-ve), agricultural runoff, agricultural surrounds and catchment (-ve); semi-natural surrounds and catchment; substrate type; marginal complexity; soluble reactive P (-ve); ammonia (-ve); suspended solids (-ve).
Submerged plant Species Rarity Index (SRI)	Intensive surrounds and catchment, particularly agriculture (-ve); overall pollution index (-ve); agricultural runoff; semi-natural surrounds and catchment; water depth and geology and substrate type; permanence; pH; suspended solids (-ve).
Marginal plant species richness *and* Marginal plant Species Rarity Score (SRS)	Intensive surrounds and catchment, particularly agriculture (-ve); overall pollution index (-ve); agricultural and urban runoff (-ve); semi-natural surrounds and catchment; pond area; unimproved grassland surrounds; parks and gardens in the surrounds (-ve); connectivity with other wetlands; location on floodplain; marginal complexity.
Marginal plant Species Rarity Index (SRI)	Intensive surrounds and catchment, particularly agriculture (-ve); overall pollution index (-ve); semi-natural surrounds and catchment; grazing; heathland surrounds; pond area; marginal complexity.
Free floating species/ submerged species	Intensive landuse and surrounds, agricultural land use and surrounds; semi-natural land use and surrounds (-ve).
Trophic ranking score (TRS)	Heathland surrounds (-ve); Ca.

[1]Correlations are positive except where stated.

Potamogeton species
The number of *Potamogeton* species recorded from sites also showed good correlation with land use and overall pollution inputs. However, this measure is not an ideal metric because the genus is often absent from ponds and can be taxonomically difficult in the field.

Trophic Ranking Score
The least successful metrics were Trophic Ranking Score (TRS), number of floating-leaved plant species and number of exotic plant species. The poor performance of TRS was rather surprising. Significant TRS correlations were restricted to a positive correlation with calcium concentration and heathland landuse. There was no significant link to agricultural land use or to pond nutrient levels and pH. In practice, the poor performance of this potential metric is likely to reflect the fact that many aquatic plants that are relatively common in ponds have not been given TRS scores, including a range of *Potamogeton*, *Ranunculus* and *Lemna* species. This situation has arisen because the current TRS values for standing waters (Palmer *et al.*, 1992) are based only on analysis of lake data.

Pond invertebrates

The invertebrate attributes which showed the strongest correlations with environmental degradation were (see Table 3.7):

- ASPT (Average Score per Taxon)
- ETO (Ephemeroptera + Trichoptera + Odonata taxa richness)
- EMO (Ephemeroptera +Megaloptera + Odonata taxa richness)
- OM (Odonata + Megaloptera taxa richness)
- Odonata richness.

Relationships between degradation and ETO, EMO, OM and Odonata were evident at both species and family level (see Table 3.7). Of these potential metrics, ETO correlations were usually slightly more significant than those for Odonata. However, including Trichoptera and Ephemeroptera in the metric brought in other correlates such as area and depth.

The number of Trichoptera taxa alone showed no relationship with degradation at any significance levels, suggesting it contributed little to the ETO index. Megaloptera (largely the presence of *Sialis lutaria*) was, in contrast, strongly associated with degradation in ponds and had few correlations with other variables. Combining EMO taxa or OM taxa to give a single measure therefore gave an apparently useful metric.

The common river index, EPT (Ephemeroptera, Trichoptera, Odonata), showed very poor relationships with pond degradation. Similarly, BMWP showed few correlations with degradation and relatively strong relationships with physical factors such as pond area and permanence.

Species, family and order richness appear to have moderate potential as invertebrate metrics. Highly significant correlations were most strongly related to physico-chemical factors such as pH, substrates and water source. However, there were consistent correlations with a wide range of degradation factors at lower significance levels than $P<0.001$.

Table 3.7 Examples of pond invertebrate metrics which have significant relationships with environmental degradation[1]

Potential metric	Environmental factors correlated with potential metric
Species richness	Unimproved catchment and surrounds; drawdown area (-ve); water depth; ducks (-ve). Strong, though less significant, relationships with pollution inputs.
Family richness	Links to adjacent wetlands; ducks (-ve); pH; sediment; depth; water source; fish. Strong, though less significant, relationships with pollution inputs and unimproved surrounds.
Order richness	Drawdown; pH; sediment; depth; water source; fish. Strong, though less significant, relationships with pollution inputs and unimproved surrounds.
Snail species richness	pH; Ca; Al (-ve); fish; geology; heathland (-ve); sediments and water source; water depth.
Snail family richness	pH; Ca; Al (-ve); fish; geology; sediments and water source; water depth.
Leech + flatworm family richness	pH; water depth.
Dragonfly species richness	Intensive land use (-ve); intensive agriculture (-ve); runoff from intensive land (-ve); semi-natural surrounds and catchment; heathland catchment; geology and substrate; water depth and drawdown; cover of submerged plants; Ca (-ve); alkalinity (-ve); conductivity (-ve).
Dragonfly family richness	Intensive land use (-ve); intensive agriculture (-ve); runoff from intensive land (-ve); semi-natural surrounds and catchment; heathland catchment; Ca (-ve); geology and substrate; water depth and drawdown; cover of submerged plants.
Mayfly species richness	pH; sediment; area and water depth; wetland surrounds.
Beetle family richness	Semi-natural surrounds and catchment; cover of submerged plants; sediment type.
Small dytiscid species richness	pH; water depth; water source.
Bug species richness	Semi-natural catchment and surrounds; area and water depth; substrate type.
Alderfly species presence	Semi-natural surrounds and landuse; polluted runoff (-ve).
ETO: Ephemeroptera + Trichoptera + Odonata (species level)	Semi-natural surrounds and catchment; other wetlands nearby; overall pollution index; intensive catchment surrounds and polluted runoff (-ve); intensive agricultural surrounds (-ve); intensive agricultural surrounds (-ve); area and depth; catchment geology; wood and scrub in the surrounds; submerged plant cover; conductivity (-ve); Mg (-ve).
ETO: Ephemeroptera + Trichoptera + Odonata (species level) (family level)	Semi-natural surrounds and catchment; other wetlands nearby; overall pollution index; intensive catchment surrounds and polluted runoff (-ve); intensive agricultural surrounds (-ve); area and depth; catchment geology; submerged plant cover; conductivity (-ve); Mg (-ve); suspended solids (-ve).
EMO: Ephemeroptera + Megaloptera + Odonata (family level)	Semi-natural surrounds and catchment; other wetlands nearby; overall pollution index; intensive catchment surrounds and polluted runoff (-ve); intensive agricultural surrounds (-ve); drawdown and permanence; catchment geology; wood and scrub in the surrounds; submerged plant cover; total P (-ve).

(cont)

[1]Correlations are positive except where stated.

Table 3.7 (continued). Examples of pond invertebrate metrics which have significant relationships with environmental degradation

Potential metric	Environmental factors correlated with potential metric
OM: Odonata + Megaloptera (family level)	Semi-natural surrounds and catchment; other wetlands nearby; overall pollution index; intensive catchment surrounds and polluted runoff (-ve); intensive agricultural surrounds (-ve); drawdown; permanence and water depth; catchment geology; wood and scrub in the surrounds; submerged plant cover; suspended solids (-ve); ammonia (-ve); total P (-ve).
Detritivore and herbivore family richness	Al (-ve); Ca (-ve); pH (-ve); water depth; sediment type; wetlands in the surrounds.
Detritivore and herbivore species richness	Semi-natural land-use and catchment; sediment type; fish (-ve); pond area and permanence.
BMWP score	Overall pollution index; area and water depth; geology; substrate and water source; other wetlands in the surrounds.
ASPT	Semi-natural surrounds and catchment; heathland catchment; overall pollution index; intensive catchment and surrounds (-ve); intensive agricultural surrounds (-ve); alkalinity (-ve); conductivity (-ve) Mg (-ve); Na (-ve); Ca (-ve).
Species Rarity Score (SRS)	Semi-natural catchment; wetlands or grasslands nearby (5-25m); overall pollution index; ducks (-ve); sediment; submerged plant cover; ammonia (-ve).
Species Rarity Index (SRI)	Semi-natural surrounds; urban surrounds; alkalinity (-ve).

There were relatively few statistically significant correlations between attributes such as broad functional feeding groups (e.g. detritivores, predators) and degradation measures. Similarly Species Rarity correlations (SRS and SRI)[5], suggest that the rarity value of invertebrate species at a site was related to only a relatively restricted number of degradation measures. Very few pond plant or invertebrate metrics showed strong relationships with specific water pollutants (e.g. heavy metals, nitrate, phosphate etc.), or pollutant input types (e.g. urban runoff), so it was difficult, in this initial analysis, to identify pollutant-specific metrics for ponds.

Overall, family and species correlations were very similar (and had similar probability levels) suggesting both that (i) the findings are robust and (ii) that family-level taxonomy will be adequate for ponds and canal quality assessments.

3.4.2 Result of canal invertebrate metric correlations

There were strong correlations between biological attributes and both chemical and bank degradation measures in canals (Table 3.8).

ASPT and BMWP score correlated strongly with a variety of water quality parameters, including heavy metals, suspended solids and chemical water quality (the overall chemical class based on suspended solids, BOD and ammonia concentrations). Neither showed strong relationships with bank degradation however.

[5] See Glossary for further definitions of SRI and SRS.

Table 3.8 Canal metrics which have significant relationships with environmental degradation[1]

Potential metric	Environmental factors correlated with potential metrics
Invertebrate species richness	Bank structure; vegetation; boat traffic (-ve); Secchi depth (-ve).
Invertebrate family richness	Bank structure; vegetation; Secchi depth (-ve).
Snail species richness	Bank structure; vegetation.
Lymnaeidae species richness	Bank vegetation; depth.
Planorbidae species richness	Vegetation; boat traffic; Secchi depth (-ve).
Crustacean species richness	Antimony (-ve); organic matter (-ve).
Damselfly species richness	Vegetation cover; suspended solids (-ve); Secchi depth (-ve).
Coenagrionidae species richness	Vegetation; Secchi depth (-ve); boat traffic (-ve)
Dragonfly species richness	Vegetation.
Mayfly species richness	Boat traffic; Secchi depth (+ve); water quality degradation (-ve).
Baetidae species richness	Vegetation; boat traffic (-ve); Secchi depth (-ve).
Mayfly family richness	Boat traffic (-ve); Secchi depth (-ve).
Bug species richness	Bank structure; vegetation cover; Secchi depth (-ve).
Bug family richness	Bank structure; vegetation.
Predatory bugs family richness	Bank structure; vegetation; Secchi depth (-ve).
Beetle species richness	Bank structure; vegetation cover; Secchi depth (-ve).
Haliplidae species richness	Vegetation cover; bank structure.
Hydrophilidae species richness	Bank structure; vegetation cover; depth.
Small dytiscid family richness	Bank structure; vegetation cover.
Beetle family richness	Bank structure; vegetation cover.
Caddisfly species richness	Bank structure; cations (-ve); sediment quality (-ve).
Leptoceridae richness	Bank structure; vegetation cover (-ve); Secchi depth (-ve); cations (-ve).
Limnephilidae richness	Bank structure; marginal vegetation; depth; cations (-ve); sediment quality (-ve).
Caddisfly family richness	Cations (-ve).
Lepidoptera species richness	Vegetation cover; boat traffic (-ve).
EPT species richness	Bank structure; boat traffic (-ve); cations (-ve); heavy metals (-ve).
EPT family richness	Water quality degradation (-ve); cations (-ve); ammonia (-ve).
Detritivore family richness	Bank structure; Secchi depth (-ve); heavy metals (-ve); polycyclic aromatic hydrocarbons (-ve); water quality degradation (-ve).
Predator family richness	Bank structure; vegetation cover.
ASPT	Heavy metals (-ve); cations (-ve); water quality degradation (-ve).
BMWP score	Suspended solids (-ve); heavy metals (-ve); water quality degradation (-ve).

[1]All correlations significant at $p<0.001$; correlations are positive unless otherwise stated.

EPT attributes (EPT species and family richness) showed similar relationships to the BMWP score and ASPT, and at family level showed few relationships with bank type and boat traffic.

In contrast bug, snail and beetle richness showed strong relationships with bank structure and boat traffic, but very few relationships with water quality attributes. Detritivore and predator family richness showed relationships with *both* water quality and bank and boat traffic-related degradation.

Using these results it appears possible to develop two relatively independent metrics to assess canal degradation. Where the main aim of canal assessments is to investigate water quality, then metrics based on ASPT and EPT taxa would be most effective. If boat traffic and hard bank structure effects are of concern, then parameters based on taxon richness or bug and beetle species richness would be combined into the final integrity index.

3.4.3 Final choice of viable metrics

Further rationalisation to choose the most effective of the viable metrics to use in an IBI was undertaken by balancing a number of concepts. In particular:

1. The final choice of metrics should ideally include attributes which respond to a wide range of degradation gradients. It is, however, also valuable to include metrics which have some diagnostic potential.
2. It is valuable to include a number of metrics which reinforce each other since this gives confidence that the degradation assessment is correct. Equally it is important to avoid too much redundancy, so that a degradation signal indicated by only one metric is not lost in the final IBI calculation.

Evaluation of the most effective metrics to use in an overall waterbody integrity index also took into consideration the following factors:

- Metrics were prioritised where they showed strong monotonic relationships to a wide range of degradation gradients and, in addition, had relatively few detracting 'natural' physico-chemical correlates.
- In principle, ratio values (e.g. ratio of free-floating to plant species) were avoided to prevent inclusion of metrics with quantities which varied together (Jim Karr *pers. comm.*).
- Family level invertebrate metrics were used in preference to species metrics so as to provide a working method more readily applicable by Environment Agency biologists as part of the normal workload.

Using this rationalisation the following biotic attributes were prioritised for selection as metrics:

Ponds:

1. Macroinvertebrate assemblages: (i) ASPT (ii) Total family richness (iii) Odonata and Megaloptera family richness (OM),
2. Plant assemblages: (i) submerged plant species richness (ii) aquatic plant Species Rarity Index (iii) marginal plant richness (ii) marginal plant Species Rarity Index.

Canal macroinvertebrates:

1. For use in water quality assessment: ASPT and EPT (Ephemeroptera, Plecoptera, Trichoptera),
2. For assessing bank impairment: number of Coleoptera families, total number of families.

3.5 Developing and testing the multimetric approach

3.5.1 Comparison of observed and predicted values

Using the existing data set of minimally impaired and degraded sites, MDA predictions were made for pond plant, pond macroinvertebrate and canal macroinvertebrate assemblages.

Predicted values for each priority metric were calculated from predicted taxonomic lists, and compared with observed values using the standard EQI (Ecological Quality Index) approach employed in RIVPACS.

In order to test the performance of the priority metrics, the EQIs of each of the chosen metrics were correlated with measures of environmental degradation.

In canals, degradation was measured in terms of (a) water quality impairment and (b) bank structure impairment. The GQA chemical water quality class was used as an approximate measure of water quality impairment, and the extent of artificial bank re-enforcement as a measure of bank structure impairment.

In ponds, environmental degradation was described in terms of overall exposure of sites to point and diffuse source pollutants based on a 1 to 10 ranked scale (Overall Pollution Index)[6].

In addition to the 'priority' metrics listed in Section 3.4.3, the relationships between a number of 'second-tier' metrics and environmental degradation were also investigated, to compare their performance.

Appendix 11 gives scatter diagrams showing the relationships between metrics and degradation measures. In practice the priority metrics performed better than the 'second tier' metrics, confirming the original metric choice. In general, metrics based on indices (such as ASPT) showed less variability than those based on taxonomic richness. For example, in canals ASPT EQIs range from about 0.50 to 1.30 (similar to ranges typically seen in rivers in RIVPACS). For many of the family richness EQIs maximum values of up to 2.5 are seen (e.g. Number of Invertebrate Families, Submerged Plant Species Richness). This reflects: (i) the greater inherent variability of taxonomic richness EQIs compared to index-based EQIs, such as ASPT EQI (ii) cases where there may be insufficient sites in the database to represent a particular type of site adequately, such as floodplain ponds with very rich plant assemblages.

It should be noted that exceptionally high EQIs may help to identify exceptionally biologically rich sites. For example, the very high plant-related EQIs for Over North Pond, (Glos.), Aldershot 41 (Hants.) and Chubbs Farm, New Forest (ringed in Appendix Figure 11.1) in part reflect the fact that these sites have exceptionally rich floral communities, standing out as some of the highest quality sites in the National Pond Survey.

Details of the performance of each of the priority metrics are given briefly below.

Pond metrics highly correlated with environmental degradation

Submerged plant species richness EQI

In ponds, submerged plant species richness EQI was strongly negatively correlated with exposure to point and non-point source pollution (Appendix Figure 11.1; note that in these figures the x axis shows an *increasing* degree of pollution i.e. ponds scoring 10

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[6] Overall Pollution Index was assessed in terms of exposure to pollution inputs (e.g. occurrence of intensive land-use around the pond, presence of drains from roads, farmyards or urban catchments etc.).

are highly polluted). EQIs showed a typical level of variation for a species richness related metric with values exceeding 2.0 at exceptionally species-rich sites.

Aquatic plant Species Rarity Index EQI
Aquatic plant Species Rarity Index EQI was also highly correlated with the risk of exposure to point and non-point source pollution (Figure 3.1). As is typical of metrics based on mean values, the EQIs for this metric showed less variation than for submerged plant species richness.

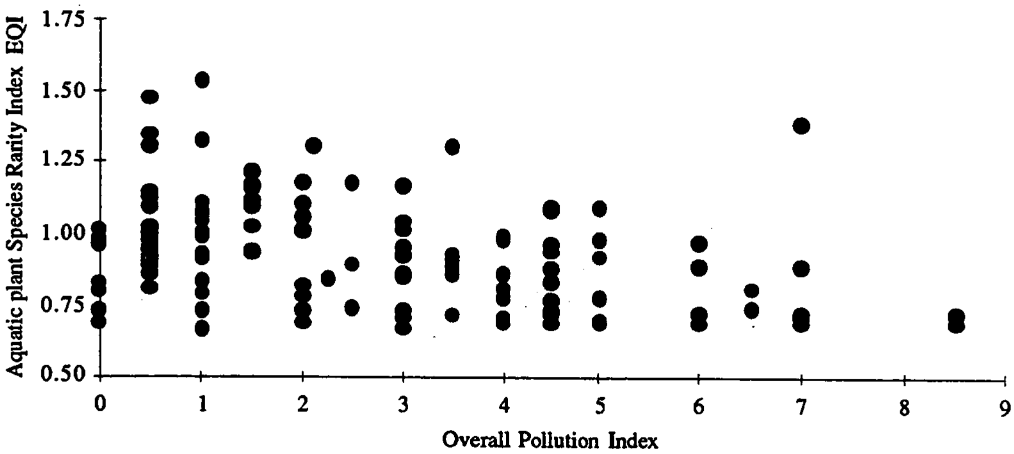

Figure 3.1 The relationship between aquatic plant Species Rarity Index EQI and risk of exposure to point and non-point source pollution.

Emergent plant species richness EQI
Emergent plant species richness EQI in ponds was strongly correlated with risk of exposure to pollutants (Appendix Figure 11.3). The level of variability in this EQI was similar to that for submerged plant species richness with a few exceptionally rich sites having EQIs over 2.00.

Emergent plant Species Rarity Index EQI
Emergent plant Species Rarity Index EQI in ponds was less strongly correlated with risk of exposure to pollution than aquatic plant Species Rarity Index EQI (Appendix Figure 11.4). This probably reflected the fact that there are rather few emergent plants with high rarity scores (i.e. most species are common, unlike submerged plants where a higher proportion of species have restricted distributions). Consequently there is rather little variation between degraded and relatively unimpaired sites.

ASPT EQI
Pond ASPT EQI was strongly correlated with the risk of exposure to point and non-point source pollution (Appendix Figure 11.5). ASPT EQI values rarely dropped below 0.8, probably reflecting the fact that expected ASPTs in still waters are relatively low.

Total family richness EQI
Total invertebrate family richness EQI was less strongly correlated with environmental degradation than ASPT EQI. Variability of total family richness EQIs was intermediate between EQIs based on plant taxonomic richness and those based on averaging indices (i.e. ASPT and SRI) (Appendix Figure 11.6).

Odonata and Megaloptera family richness

Odonata and Megaloptera family richness EQI was the metric most highly correlated with risk of exposure to pollutants of those tested (Appendix Figure 11.7). It is not yet clear why this is such an effective metric, especially as the Megaloptera component of the metric is based on the occurrence of one family. However, there was a clear indication that the proportion of sites with *Sialis lutaria* (the only megalopteran found in the study) decreased as the Overall Pollution Index value increased. Similar, but slightly less significant, relationships were seen with (i) Odonata family richness and (ii) ETO (Ephemeroptera, Trichoptera, Odonata) family richness.

Canal predicted metrics

ASPT EQI

ASPT EQI was highly correlated with water quality impairment (Appendix Figure 11.8). As expected, BMWP EQI (a 'second tier' metric choice), showed less significant relationships with overall water quality. There were no significant correlations between ASPT EQI and canal bank structure.

EPT (Ephemeroptera, Plecoptera, Trichoptera) family richness EQI

EPT EQI showed a similar trend to ASPT, although there was greater variation in values (Appendix Figure 11.9). This pattern was typical of all metrics involving taxonomic richness.

Family richness EQI

Family richness EQI was the most highly correlated metric of those tested with bank structure (Appendix Figure 11.10; $r_s = -0.66$, $p = 0.0001$). The variability of family richness EQI was similar to that for other taxonomic richness metrics.

Coleoptera family richness EQI

Coleoptera family richness EQI was also highly correlated with bank structure impairment, and was only slightly less strongly correlated with bank impairment than family richness (Appendix Figure 11.11; $r_s = -0.57$, $p = 0.0001$). Although there was a weak correlation between water quality and Coleoptera family richness, this was not statistically significant ($p > 0.05$).

3.5.2 Variability of EQIs

EQI variability is a major issue in predictive techniques and, in the long-term, requires detailed testing as part of PSYM method development.

Preliminary inspection of EQIs generated for the Pond and Canal PSYMs suggests that plant and invertebrate metrics based on averages (ASPT, SRI) showed moderate levels of variability with maximum EQI values around 1.50. Taxonomic richness based metrics generally showed greater variability, with EQIs occasionally exceeding 2.50.

3.5.3 Metric normalisation

Metric normalisation was undertaken to convert the metrics EQIs to a standard 0 to 4 scale. For the *preliminary* PSYM analyses undertaken in the current project, a simple categorisation was created by dividing the EQI range equally into five components (0 = 0-0.24, 1 = 0.25-0.49, 2 = 0.50-0.74, 3 = 0.75-0.99, 5 = 1.00 and above). In the next stages of the development of the PSYM method further work will be needed to optimise category boundaries. In particular, boundaries should be adjusted to reflect the inherent variability of the metric being categorised.

An IBI score was derived by summing the individual scores for each metric. This gives a minimum possible score of 0 for the most seriously impaired sites. The maximum score depends on the number of metrics included in the IBI. The IBI can be presented in terms of this numerical value, or as a percentage the maximum (i.e. the undisturbed state).

3.5.4 Case studies

In order to give an indication of the type of results produced using Pond and Canal PSYM, five case-study trials were undertaken using sites from the data set. These were:

1. Use of IBIs to describe the ecological integrity of ponds.
2. Use of IBIs to describe the ecological integrity of canals.
3. Use of canal metrics to distinguish the effects of water quality and bank structure.
4. Comparison of the proportion of degradation explained using single metric and multimetric assessments.
5. Preliminary use of IBIs to describe the ecological integrity of lakes.

Case study 1: Use of IBIs to describe the ecological integrity of ponds

For ponds an IBI score was calculated for two trial groups of sites, degraded and minimally impaired.

Degraded sites all had Overall Pollution Index (see Section 3.5.1) values of 7-10 (high pollutant inputs); minimally impaired sites all had Overall Pollution Index value of <1 and were very high quality sites.

To create a Pond PSYM IBI score the three priority invertebrate metrics and the four plant metrics were combined in the trial, i.e.:

- ASPT EQI,
- nFam EQI (Number of families EQI),
- OM EQI (Odonata+Megaloptera family richness EQI),
- SUB EQI(Submerged Plant Species Richness EQI),
- AQ SRI EQI(Aquatic plant Species Rarity Index EQI),
- EM EQI (Emergent Plant Richness EQI),
- EM SRI EQI (Emergent Plant Species Rarity Index),

Overall, the five trial degraded sites had IBIs that ranged from 7 to 14 (out of a possible total of 28). The trial minimally impaired sites all had IBI scores of 22 or above, reflecting their low exposure to potential water pollution stresses and location in areas of high quality semi-natural habitat (Table 3.9).

Table 3.9 Trial IBI (Index of Biotic Integrity) index for impaired and minimally impaired ponds

Site code	Overall Poll'n Rating*	ASPT EQI		nFAM EQI		OM EQI		SUB EQI		AQ SRI EQI		EM EQI		EM SRI EQI		IBI score	IBI % of unimp'd score
'Impaired'																	
Bentley Farm Pond	7	0.88	3	0.35	1	0	0	0.18	0	0.69	3	0.23	0	0.90	3	11	39%
Firlands Pond	8.5	0.88	3	0.41	1	0	0	0.70	2	0.72	2	0.17	0	0.89	3	11	39%
Harrietts Farm Pond	8	1.02	4	0.11	0	0	0	0.00	0	0.00	0	0.17	0	0.89	3	7	25%
Hillborough Farm Pond	9	0.89	3	0.37	1	0	0	0.00	0	0.00	0	0.11	0	0.90	3	7	25%
Platford Green Pond	7	0.84	3	0.92	3	0	0	0.18	0	1.39	4	0.40	1	0.90	3	14	50%
'Minimally impaired'																	
Site code	Overall Poll'n Rating	ASPT EQI		nFAM EQI		OM EQI		SUB EQI		AQ SRI EQI		EM EQI		EM SRI EQI		IBI score	IBI % of unimp'd score
Ashdown Forest Pond A	0	1.03	4	0.94	3	1.26	4	0.39	1	0.98	4	1.62	4	1.10	4	24	86%
Ashdown Forest Pond B	0	1.06	4	1.56	4	1.84	4	1.69	4	1.01	4	1.33	4	1.02	4	28	100%
Beckley Raised Bog	0	1.02	4	1.29	4	1.64	4	0.40	1	0.80	3	0.68	2	1.12	4	22	79%
Little Wittenham Upper Pond	0.5	1.04	4	1.14	4	0.59	2	0.75	3	0.92	3	0.97	3	0.95	3	22	79%
Sole Common Pond	0.5	1.09	4	0.94	3	1.24	4	0.89	3	0.98	3	1.04	4	0.97	3	24	86%

*Overall Pollution Rating is ranked on a 1 to 10 scale (10 = highly exposed to risk of pollution)

Case study 2. Calculation of an overall IBI for canals

Canals were assessed on the basis of the four priority invertebrate metrics i.e.: ASPT EQI, EPT EQI, number of Coleoptera families EQI ('Coleop') and number of families EQI ('nFam') (Table 3.10).

In the first canal trial, an overall assessment of the method was undertaken using two groups of sites: canals which had clearly degraded water quality and minimally impaired sites. The degraded canals were located in the West Midlands (Sites 39-42) and London (47). The minimally impaired sites were from the Basingstoke Canal and the Shropshire Union Canal.

Overall, the six degraded canal sites had IBI values that ranged from 3 to 5 (out of a total of 16). The minimally-impaired sites, all of which were either chemical Class A or B in terms of water quality, had IBI scores ranging from 11 to 14.

Table 3.10 Trial IBI (Index of Biotic Integrity) for impaired and minimally impaired canals

'Impaired'

		ASPT EQI		EPT EQI		Coleop EQI		nFAM EQI		IBI score	IBI % of unimpaired score
39	Birmingham	0.74	2	0	0	0	0	0.35	1	**3**	**19%**
40	Birmingham	0.61	2	0	0	0	0	0.38	1	**3**	**19%**
41	Birmingham	0.79	3	0	0	0	0	0.36	1	**4**	**25%**
42	Birmingham	0.74	2	0.21	0	0.24	0	0.58	2	**4**	**25%**
47	Regents	0.77	3	0.46	1	0	0	0.46	1	**5**	**31%**

'Minimally impaired'

		ASPT EQI		EPT EQI		Coleop EQI		nFAM EQI		IBI score	IBI % of unimpaired score
49	Basingstoke	0.98	3	0.86	3	1.17	4	1.03	4	**14**	**88%**
50	Basingstoke	0.94	3	0.67	2	1.09	4	1.02	4	**13**	**82%**
51	Basingstoke	0.99	3	0.98	3	0.94	3	0.92	3	**12**	**75%**
52	Basingstoke	1.07	4	1.17	4	0.93	3	0.67	2	**13**	**82%**
61	Shrops. Union	1.03	4	0.97	3	0.47	1	0.88	3	**11**	**69%**
62	Shrops. Union	0.96	3	0.97	3	0.70	2	1.12	4	**12**	**75%**

Case study 3 : Use of canal metrics to distinguish the effects of water quality and bank structure

Canal macroinvertebrate data were also used to investigate the relative performance of canal water quality and bank metrics.

As noted in Chapter 2, 'replicate' invertebrate samples were taken from a number of canal locations which had contrasting bank characteristics: either natural (100% earth) or reinforced (75-100% steel or concrete) banks. Three replicates were taken from minimally impaired canals, and the remaining five replicates from sites of variable water quality. This gave pairs of samples which were collected under the same chemical quality conditions, but which had contrasting levels of bank structure impairment.

The four canal invertebrate metric EQIs were calculated for each pair of sites (ASPT EQI, EPT EQI, number of Coleoptera families EQI ('Coleop') and number of families EQI ('nFam') (Table 3.11).

At all sites ASPT EQIs were very similar, showing that ASPT was, as expected, responding to water quality and not habitat structure. EPT EQI broadly followed ASPT EQI but with a slight habitat structure response (EPT was generally a little higher on natural banks than reinforced banks). Coleoptera families EQI contrasted strongly with ASPT EQI, showing a reverse trend and providing a clear index of habitat quality. Number of families showed similar trends to Coleoptera families, though slightly less strongly.

When summarised into a single index of Biotic Integrity (IBI), the sites with reinforced banks were clearly shown to be more impaired than those with natural banks. However, by breaking-down the index into its individual metric types, the source of degradation is clear.

Table 3.11 Comparison of IBI scores from 'replicate' canal sites with natural and reinforced banks

		Bank type*	Water Quality Scores			Bank Quality Scores			Index of Biotic Integrity	
Site no.	Canal		ASPT	EPT	Total water quality	No. Coleoptera families	Total no. of families	Total Bank Quality	IBI score	IBI % of unimpaired score
12	Oxford	Re	4	2	6	1	1	2	8	50%
13		Nat	3	3	6	4	4	8	14	88%
17	Grand Union	Re	4	3	7	0	1	1	8	50%
18		Nat	3	4	7	4	4	8	15	94%
23	Coventry	Re	3	0	3	0	1	1	4	25%
24		Nat	3	2	5	0	4	4	9	56%
34	Wyreley & Ess.	Re	3	3	6	0	2	2	8	50%
35		Nat	3	4	7	4	4	8	15	94%
50	Basingstoke	Re	4	3	7	1	2	3	10	63%
51		Nat	3	3	6	2	3	5	11	69%
66	Shrops. Union	Re	4	4	8	0	1	1	9	65%
67		Nat	3	4	7	2	3	5	12	75%
77	Trent & Mersey	Re	3	3	6	0	1	1	7	44%
78		Nat	3	2	5	2	4	6	11	69%
83	Basingstoke	Re	4	4	8	0	2	2	10	63%
84		Nat	4	4	8	4	4	8	16	100%

Bank types*: Re = Reinforced; Nat = Natural

Case study 4. Comparison of the proportion of degradation explained using single metrics and multiple metrics

An important concept underlying of the rationale of the multimetric method is that combining metrics leads to a more accurate assessment of overall environmental degradation.

To test whether the combined metrics in the present study were more effective than individual metrics used alone, the pond metric results (Case Study 1 above) were investigated to compare the relative proportion of degradation explained by single and multiple metrics.

The results (Table 3.12) show that the IBI, in which all metric values were summed, explained a higher proportion of the overall environmental degradation than individual metrics.

Table 3.12 Comparison of the proportion of pond degradation explained using single metrics and multiple metrics

Metric	*Proportion of pond Overall Pollution Index variation explained (r^2)*
IBI (sum of all 7 metrics)	0.30
ASPT EQI	0.05
nFAM EQI	0.13
OM EQI	0.07
SUB EQI	0.17
AQ SRI EQI	0.15
EM EQI	0.18
EM SRI EQI	0.01

Case study 5. Lake IBIs based on plant and macroinvertebrate assemblages

For the small sample of lakes in the Phase 2 data set, an IBI score was calculated using an extension of the Pond PSYM database (Table 3.12). Twelve sites were available in total, six drawn from the Environment Agency lake classification and monitoring project, and six from other projects undertaken by Pond Action for the Environment Agency.

Plant and macroinvertebrate metrics were combined to produce a seven metric IBI. The metrics used were those shown to be most relevant to assessing pond quality, i.e.: aquatic plant SRI EQI, submerged plant species richness EQI, emergent plant species richness EQI, emergent plant SRI EQI, ASPT EQI, number of families EQI and OM EQI.

IBI index values ranged from 14 (out of 28) for the badly degraded Mill Pond, Bracknell, to 28 (the maximum) for the biologically rich Hythe End near Staines which supported a rich aquatic flora including *Utricularia vulgaris* (part of the Datchet, Wraysbury, Staines, Chertsey gravel pit lake complex).

Overall, the lake analyses suggest that PSYM methods were broadly successful in assessing lake quality. These results were produced using a mixed data set, predominantly comprising much smaller waterbodies. The implication is that, data collection and analysis from lakes alone would almost certainly allow successful extension of the PSYM method to lakes.

Table 3.13 Use of the PSYM method for a trial lake data set: IBI scores for 12 lakes of with varying levels of exposure to point and diffuse pollution

Site Code	Overall Pollution Rating*	AQ SRI EQI	SUB EQI	EM EQI	EM SRI EQI	ASPT EQI	nFAM EQI	OM EQI	IBI	IBI % of unimpaired score
Mill Pond	8.5	0.67^{2}	0.22^{0}	0.83^{3}	0.87^{3}	0.78^{3}	0.57^{2}	0.36^{1}	14	50%
Sutton	5	0.71^{2}	0.73^{2}	1.01^{4}	0.91^{3}	0.93^{3}	0.58^{2}	0.35^{1}	17	61%
Caversham	4	0.62^{2}	0.19^{0}	1.38^{4}	0.97^{3}	0.97^{3}	1.34^{4}	1.06^{4}	20	71%
Frensham	4	0.89^{3}	1.20^{4}	1.23^{4}	0.97^{3}	0.99^{3}	0.82^{3}	0.35^{1}	21	75%
Fleet	4	0.92^{3}	1.57^{4}	2.25^{4}	1.01^{4}	0.91^{3}	0.95^{3}	0.36^{1}	21	75%
Datchet	3.5	0.92^{3}	1.39^{4}	0.74^{2}	0.97^{3}	1.05^{4}	0.58^{2}	0.71^{2}	20	71%
Betton	5	1.08^{4}	0.42^{1}	0.65^{2}	1.00^{4}	1.00^{4}	1.25^{4}	1.33^{4}	23	82%
Lynch Hill	4	0.93^{3}	1.35^{4}	1.05^{4}	1.01^{4}	0.93^{3}	0.76	1.06^{4}	25	89%
Longfield	4	0.85^{3}	1.19^{4}	1.06^{4}	0.99^{3}	0.99^{3}	1.27^{4}	1.41^{4}	25	89%
Shepperton	4	0.92^{3}	0.95^{3}	1.09^{4}	0.95^{3}	1.03^{4}	1.34^{4}	1.06^{4}	25	89%
Wraysbury	4	0.90^{3}	1.90^{4}	2.07^{4}	1.00^{4}	1.06^{4}	1.54^{4}	1.41^{4}	27	96%
Hythe End	3	1.01^{4}	1.35^{4}	1.09^{4}	1.02^{4}	1.01^{4}	1.20^{4}	1.41^{4}	28	100%

*Overall Pollution Rating is ranked on a 1 to 10 scale (10 = highly exposed to risk of pollution). Superscipts show the IBI score for individual metrics.

3.6 Conclusions and discussion

The principle aim of the Phase 2 project has been to develop and test the predictive multimetric assessment method (PSYM) for still water monitoring recommended in the Phase 1 scoping study.

Two very different standing water ecosystems, ponds and canals, were chosen for development and testing in the study. In ponds, PSYM assessments were based on an evaluation of two biotic assemblages: macrophytes and macroinvertebrates (see Section 1.2). In canals, metrics were developed using macroinvertebrates alone, since diatom[7] sampling methodologies were insufficiently well developed (Section 4.2).

Overall, the Phase 2 method test results suggest that PSYM is likely to prove an effective method for monitoring freshwater ecosystems. The main findings of this phase of the project indicate that:

1. *The predictive method developed for RIVPACS can be usefully applied to habitats other than rivers.* The current project appears to represent the first application of predictive (RIVPACS-type) models to still water habitats. The successful application of these techniques to canals and ponds suggests that, in principle, the methods should be equally successful in other standing water habitats (e.g. brackish waters, temporary ponds, ditches). There was specific evidence from the pilot pond+lake analysis that predictive methods could be directly extended into larger lentic ecosystems.

[7] For canal monitoring, diatoms were preferable to macrophytes as a plant assemblage because most canals support few aquatic macrophyte species and their occurrence is typically sparse (see Section 1.2).

2. *Multimetric methods can be simply and successfully developed for standing waters*

The development of multiple metrics for assessing the extent of degradation in ponds and canals proved straightforward. The project results indicate that:

- Appropriate and useful metrics can be readily identified using biological and environmental data from sites spanning a range of water/habitat qualities.

  Correlation of biotic attributes (e.g. species richness, numbers of sensitive families) with degradation measures in each waterbody type provided a quick and simple method for identifying viable metrics. In particular, inspection of correlates enabled metrics to be identified which were (i) strongly related to a broad range of degradation gradients (ii) relatively weakly associated with 'natural' variation (iii) diagnostic indicators of specific degradation types.

- The combined, multiple, metrics are superior to using individual metrics for assessing water quality. When individual metrics are combined into a multimetric score they explain a greater proportion of degradation than when a single metric is used alone.

- For invertebrates, comparisons of species-level and family-level attributes indicated that, for assessments of overall waterbody quality, both would be equally effective as metrics.

  In operational terms this has important implications, since it suggests that the macroinvertebrate component of PSYM can be based on family level identification alone. In addition, these findings indicate: (i) that family level invertebrate identification can adequately reflect the biodiversity of the assemblage as a whole and (ii) that the assessments are generally robust, giving consistent results even at differing taxonomic levels.

- In canals, where water quality often needs to be assessed irrespective of the type of bank available, it was possible to identify specific metrics (ASPT and EPT) which were relatively bank-independent. Use of such metrics should, therefore, allow the effects of canal water quality to be assessed even on sites with uniformly reinforced banks where marginal vegetation is absent.

The overall success in developing Pond PSYM and Canal PSYM prototypes suggests that extension of the method to provide national assessment methods would be likely to be successful.

There are, however, a number of areas in which further refinement is required to optimise method viability and make it available for operational use. In particular, further work is needed on: (i) metric variability (ii) quality band divisions and (iii) identification of additional diagnostic metrics.

Metric variability
Preliminary inspection of EQIs generated for the Pond and Canal PSYMs suggests that measures based on species richness can show considerable variation (see, for example, Appendix Figure 11.1 and 11.2). In general, it seems clear that taxonomic richness measures are more variable than indices based on average values, such as ASPT or SRI.

There are a number of options for dealing with metric variability, which would benefit further investigation. They include: (i) the inclusion of a greater number of reference sites in the biotic classification, to reduce variability in the TWINSPAN endgroups (ii) development and focus on metrics based on mean values (e.g. using ASPT rather than family richness). Note, however, that in using a multimetric method, where the overall assessment is based on many parameters, there is the potential to include individually more variable measures than where assessments are based on a single or small numbers of measures.

Quality bands
The quality band widths used for the current project were based on equal divisions of EQI ranges, irrespective of the differences in the variability of the EQIs of different metrics. Although acceptable for a preliminary demonstration of the method, in the longer term it will be necessary to establish band widths that relate to the variability of the EQIs (Clarke *et al.*, 1996; Biggs *et al.*, 1994). Consequently, it is clear that, even using the existing data set, it should be possible to increase the performance of individual metrics, and the multimetric method as a whole, by more effective banding.

Identification of additional diagnostic metrics
The current project identified a limited number of *diagnostic* metrics for canals (water quality vs bank quality), but principally focused on development of metrics for general/overall assessment of waterbody integrity. The existing data sets, however, contain a considerable amount of information which could be very usefully used to develop more specific diagnostic metrics. For example:

- in ponds there were strong correlations between pH and invertebrate attributes (e.g. snail, mayfly and leech species/family richness) which could be used to develop an acidification metric.
- similarly, the plant data could be used to extend the Trophic Ranking Score of Palmer *et al.* (1991) to smaller waters, to give a eutrophication metric.

Diagnostic techniques could also be further improved through more detailed analysis of the relationships between individual species/families and environmental degradation. This would enable the specific susceptibilities/tolerance to pollution of individual taxa to be used in diagnostic work, leading to the development of *species* or *mixed* taxonomic level metrics for diagnostic work.

4. TRACK 2: INVESTIGATION OF PROMISING MULTIMETRIC ASSEMBLAGES

4.1 Introduction

This chapter describes the results of Track 2 desk-study analyses which aimed:

(i) to investigate the potential for practical development of the PSYM method using diatom and fish assemblages,

(ii) to identify the potential for using PSYM as a biodiversity assessment tool for Biodiversity Action Plan monitoring.

4.2 Diatoms

The Phase 1 Scoping Study identified diatoms as a promising assemblage for water quality assessment. However, practical development of a diatom field survey methodology was required before diatom assemblages could be used in a multimetric assessment method.

The original brief for diatom work in Phase 2 was to undertake a review of the methodological problems associated with diatom survey techniques and, using this information, to make recommendations for a practical diatom survey methodology.

In practice, the need to evaluate diatom survey methods was superseded by the outputs from a diatom survey workshop organised by the Environment Agency at University College London (UCL) in April 1997. Included in the workshop outputs were recommendations for a diatom survey method for still waters. These methods were followed-up and refined during a 1 day field meeting held in Oxford in August 1997 with Environment Agency, Pond Action and UCL staff (see Appendix 12).

4.2.1 Diatom survey methodology trial

Accelerated progress in the development of a practical field survey methodology for diatoms enabled diatom work in the current project to be re-directed towards field data collection. To this end, diatom samples were collected in Autumn 1997 from 92 of the Track 1 ponds. At all of these sites macrophyte, macroinvertebrate and physico-chemical data was already available (see Chapter 3).

The diatom sampling methodology used in the survey essentially paralleled the rationale used for collecting macroinvertebrates. Representative diatom samples were collected from all appropriate pond mesohabitats (Appendix Table 12.1). Typically, ponds held between 3 and 8 mesohabitats. For each mesohabitat approximately 10 sub-samples were combined from around the pond.

The pond diatom samples are currently in storage awaiting identification. Future analysis will be of considerable interest since the data set has the potential to be used both for creation of a diatom-based PSYM method, and as a means of assessing the relative merits of diatom, macrophyte and macroinvertebrate assemblages for water quality monitoring.

4.3 Fish

4.3.1 Introduction

In Phase 1 matrix analysis fish scored highly in terms of their potential for tracking waterbody degradation. There are, however, potential difficulties in using fish assemblages for water quality assessment which might prohibit their immediate use as a PSYM assemblage. In particular:

(i) there may be inherent difficulties in using fish in predictive classification schemes due to factors such as widespread stocking and the comparatively low species richness of fish assemblages,

(ii) although field survey techniques are well-developed for stock management purposes, and the Environment Agency undertakes a considerable amount of fisheries survey work on still waters, further work is needed to determine whether suitable biological quality/integrity metrics can be developed for fish assemblages using existing survey techniques.

For Track 2, a fish assemblage desk study was undertaken:

(i) to review conceptual difficulties associated with developing fish metrics, especially the approach that should be taken for identification of suitable 'minimally impaired' baseline assemblages,

(ii) to determine whether existing Environment Agency fisheries data sets, collected to assess fish stocks, could be used to further develop fish metrics for water quality assessment.

In addition, the recently developed Environment Agency fisheries classification (Mainstone *et al.* 1994) was appraised to assess its conceptual similarity with the PSYM method.

To undertake the desk study (i) existing published literature relating to fish classification was reviewed and (ii) the main still water data sets gathered by the Environment Agency were evaluated.

4.3.2 Inherent conceptual difficulties with using fish as a PSYM assemblage

Difficulties in establishing an minimally impaired baseline

Fish assemblages are often actively and intensively managed, and there is a long history of moving fish from one waterbody to another in Britain. This human activity has greatly modified the natural distributions of fish in the British Isles, leading to the redistribution of native species and the naturalisation of continental European and (to a much lesser extent) North American fish (see Appendix 13). There is, therefore, a perception that it is difficult to identify natural community baselines and to make RIVPACS-type predictions for fish assemblages.

To assess the extent to which the widespread introduction and management of fish communities is likely to provide an obstacle for PSYM development, literature reviews were undertaken to establish:

(i) the extent to which fish assemblages are unusual in having widely modified baseline communities,

(ii) whether classification and prediction techniques have already been used successfully with fish assemblage data.

Anthropogenic modification of the distribution patterns of fish and other aquatic organisms in the British Isles

A review of the extent to which freshwater communities are affected by widespread deliberate and accidental introduction and stocking suggests that many freshwater assemblages have distribution patterns extensively altered by human activity. For example, 14% of the British aquatic macrophyte flora consists of introduced and now widespread naturalised species. This compares with 13% of the fish fauna (7 out of 53 species including euryhaline species) which is now composed of widespread introduced species (Appendix 13; Maitland and Campbell, 1992). Similarly, two of the nine amphibian species present in Britain (22%) are naturalised introductions that are fairly widely distributed (Arnold, 1995). Some of the most widespread introduced species, including plants such as Nuttall's Waterweed (*Elodea nuttallii*) and Curly Waterweed (*Lagarosiphon major*) frequently dominate aquatic communities.

Such changes from the pristine state need not prohibit the use of these assemblages in multimetric assessment. In particular metrics for assessing impairment and deviation from baseline conditions need not be based on species composition. Indeed, a fundamental feature of the multimetric method is the concept that assessments should be based on a number of different types of assemblage attributes, of which species composition might be only one component. Alternatively, it is possible to 'correct' data on which species predictions are based by using historic or other information to reconstruct 'original' community composition. Fish would be a particularly suitable assemblage for such an approach because of the long history of angling records and the considerable information base describing fish natural history (Maitland and Campbell, 1992).

In summary, although fish assemblages have been extensively altered by stocking and non-native introductions they are not unique in this respect, and it is likely that with care, appropriate 'minimally impaired' baseline fish assemblages could be identified as a viable part of a multimetric assessment.

Difficulties in using species-poor assemblages, such as fish, in prediction and multimetric assessments

Mainstone *et al.* (1994) suggested, in the development of the Environment Agency fisheries classification methodology, that the relatively species poor British fish fauna was not suitable for multivariate classifications. In practice however, the effectiveness of multivariate methods is not dependent on the species richness of assemblages but on the presence of environmental gradients influencing assemblage structure.

A literature review to establish whether classification and prediction methods could be used with relatively species-poor assemblages looked at the application of most widely used classification method, TWINSPAN. The results indicated that although this technique *is* mainly used with comparatively species-rich (fish and other) assemblages (e.g. Galactos *et al.*, 1996; Lyons, 1996; Vehanen and Aspi, 1996), there are successful applications of TWINSPAN using the abundance of single species (e.g. Masterman *et al.*, 1996), of two species (e.g. Innes and Whittaker, 1993) and of assemblages with less than 30 species (e.g. 15 species of aquatic bryophytes, 15 species of dytiscid diving beetles and 28 marine macrobenthic taxa; Karttunen and Toivonen, 1995; Behr, 1994; Gerdes *et al.* 1992).

Recent examples of fish assemblage classifications based on species-poor assemblages include the work of Boët and Fuhs (1995), who investigated the use of both multivariate techniques and neural network techniques for classifying and predicting relatively species-poor fish assemblages (n=14 species) in the R. Seine, France. Similarly, Mastrorillo *et al.* (1997), also working with neural networks, showed that presence/absence models could be developed to predict individual fish species distributions.

Taken together these observation suggest that species-poor fish assemblages could be classified using standard multivariate techniques, provided that there are strong environmental gradients influencing those assemblages.

Future development of PSYM methods for fish assemblages

Although there seem to be few strict methodological obstacles to classification of fish assemblages using multivariate methods, the widespread modification of fish assemblages by anthropogenic activity may make the description of fish baselines a more complex process than for plant, diatom or invertebrate assemblages.

In particular, it may be necessary to (i) manipulate baseline data sets to base predictions on the historic composition of fish assemblages using angling or other records (ii) remove introduced species from the baselines. Alternatively, there may be the potential to develop specific metrics which indicate impairment through management and introduction.

4.3.3 Identifying potential fish metrics using existing fisheries methodologies

The Environment Agency undertakes a considerable amount of fisheries survey work on still waters, largely related to assessment of fish stocks. An assessment of existing fisheries data sets gathered in still waters was undertaken to establish (i) how appropriate these data and survey techniques are for the calculation of metrics (ii) whether existing data sets could be used for a trial of the PSYM methodology.

In general, fish metrics for assessing water quality can be divided into four broad classes:

(i) taxonomic composition

(ii) trophic composition

(iii) biomass and abundance

(iv) health and condition

Examples of individual metrics within these groups are shown in Table 4.1.

4.3.4 Environment Agency fisheries survey methods

Environment Agency Fisheries staff use three main approaches to surveying still waters:

- *Netting*: mainly on larger ponds, canals and drains (e.g. Coles *et al.* 1985),
- *Hydroacoustics*: all water bodies,
- *Electric fishing*: margins of all water bodies.

In addition to these field survey methods, it is anticipated that increasing use will be made of catch data supplied by anglers.

None of these methods can, in isolation, provide the fisheries stock assessment data required by Environment Agency (or the data for a multimetric biological quality assessment). For reasons of the former, Environment Agency Fisheries staff are increasingly combining techniques to provide the range of data needed. At present, the most favoured option is to encourage the use hydroacoustic methods to assess numbers or biomass, combined with electric fishing or angling data to provide information on the species present (P. Hickley, *pers. comm.*).

Table 4.1 Potential fish metrics for biological integrity assessment

Species richness and composition
Total number of species
Number of water column species
Number of benthic species
Number of 'intolerant' species
% individuals as roach
Trout or pike year classes
Number of 'minor' species
Number of threatened species

Trophic composition
% of individuals as omnivores
% of individuals as 'invertivores'
% of individuals as top carnivores

Biomass and abundance
Total biomass of coarse fish
Abundance/biomass of eels
Biomass of tolerant/intolerant species
Density of salmonids
Abundance/biomass of threatened species
Catch per Unit Effort (g angler^{-1} hour^{-1})

Fish health and condition
Growth rate
Fish health e.g.:
- lesions and deformations
- histopathology
- tissue contamination

Condition index

This combined method would be appropriate for gathering data for most of the potential metrics listed in Table 4.1 since it can provide both information on composition (through electric fishing and angling data), and on population structure and abundance (through hydroacoustics). The exceptions are health and condition data which are not collected routinely in all fish surveys, although the Environment Agency does have extensive in-house expertise to undertake these assessments.

4.3.5 Trial data sets

The three largest regional fish assemblage data sets currently available from still waters were assessed in terms of their potential for developing a multimetric method trial (Table 4.2). These data sets were:

(i) Anglian Region. A data set predominantly consisting of approximately 200 fen drain sites, surveyed on a three yearly repeating cycle since 1984. A smaller number of sites on the Grand Union Canal and the Norfolk Broads have been surveyed using the same survey method.

The Fenland drain data set is by far the largest still water fish data set collected by the Environment Agency. However, there may be some difficulties with identification of minimally impaired sites, particularly sites not exposed to eutrophication. However, in this context it should be noted that the RIVPACS database includes a number of sites on eastern England rivers which also have high nutrient levels.

(ii) Midlands Region canals. This data set consists of approximately 50 sites, mainly on the Grand Union, Oxford and Staffordshire & Worcestershire canals.

The data set was collected by electric fishing from 'boom boats', so methods are not directly comparable with the Anglian data set. Sites have not been surveyed as frequently as in Anglian Region.

(iii) North West Region. This region holds a data set from 10 Lake District lakes, with a smaller number of sites in the South and Central Areas of the Region, mainly surveyed using hydroacoustic methods. The data set may be suitable for exploratory analysis.

Table 4.2 Principal still water and canal fisheries data sets suitable for classification and metric development

Region	*Waterbody type*	*Method*	*No. sites*	*Survey dates*
Anglian	GU Canal	Seine netting	28	1983/4, 1986/7, 1990, 1993/4
	Fenland drains	Seine netting	c.200	1984, 1987, 1991, 1994
	Norfolk Broads	Seine netting	10	1983/4, 1986/7, 1990, 1993/4
Midlands	Canals	Electric fishing	20	1983/4, 1986/7, 1990, 1993/4
North West	Lakes	Hydroacoustics	15	1996/7

4.3.6 The Environment Agency fisheries classification system

The Environment Agency has recently developed a fisheries classification system which is currently being applied to river fishery classification (Mainstone *et al.*, 1994; 1995). The classification is intended, conceptually, to be applicable both to still and flowing waters. In order to evaluate the potential relationships between this system and the multimetric method of water quality assessment, a comparison of the two methods was undertaken.

The Environment Agency fisheries classification system was developed 'to enable clear analysis of stock assessment data to be used for operational purposes and to estimate performance' (Mainstone *et al.*, 1994). In this context it is not immediately applicable for biological quality assessment. However, the Environment Agency system does have a number of features which could provide the basis for a multimetric assessment system:

(i) Sites can be assessed with reference to a baseline state (the 'relative classification' of this system; there is also an 'absolute classification' in which sites are compared irrespective of their natural characteristics).

(ii) The baseline for the 'relative classification' is defined using professional consensus.

(iii) Fish assemblages are described in terms of a range of measures (effectively potential metrics) including:

- salmonid density
- salmonid parr equivalents
- coarse fish biomass
- species richness (including eels and minor species)
- threatened species
- coarse fry
- mean catch per unit effort (by anglers)

A summary comparison of the key features of the Environment Agency fisheries classification and PSYM type methodologies is given in Table 4.3. Overall, although the details of the fisheries classification and PSYM methods differ, there is likely to be overlap in the field data collected. In principle, therefore, data collected for the Environment Agency classification would have a high potential for re-use value in PSYM.

As an alternative, successful development of fish-based predictive and multimetric methods for PSYM could modify some of the professional consensus concepts behind the classification, leading to the two systems merging, or interacting more proactively.

4.3.7 Recommendations for the development of the fish assemblage for multimetric assessment in still waters

In summary, the fish data review suggests that the development of a fish PSYM method is likely to be at least feasible. Fish assemblage data formed the basis of the original Index of Biotic Integrity developed in the early 1980s and is now used routinely with fish assemblages in North America. Developments in Europe have also shown that multivariate techniques can be successfully used to classify and predict even relatively species poor fish assemblages.

Given the potential for use of fish assemblages as an indicator of water quality, and the fact that Environment Agency data are routinely collected for some still waters, it is recommended that the use of fish for multimetric assessment is explored further.

A rapid initial practical test of the method could be most easily undertaken using one of the existing fisheries data sets. The most appropriate is likely to be the Anglian Region

Fenland drain and canal data sets which are extensive and likely to contain at least some relatively undegraded sites.

Further development of the fish assemblage for multimetric assessment would require:

(i) investigation of the approaches which could be taken to establishing baseline minimally impaired conditions including, especially:

- comparison of standard multivariate techniques, neural network techniques and Environment Agency fisheries classification methodologies
- a detailed review of methods for incorporating professional consensus and historical data into baseline data sets.

(ii) development of potential fish metrics (e.g. species richness, relative abundance, proportion of tolerant/intolerant species, growth rates) which can be tested against measured physical and chemical environmental degradation.

Table 4.3 Key features of the Environment Agency fisheries classification scheme

Feature of the system	Comments
1. The Environment Agency fish classification contains two approaches to classification: 'relative' and 'absolute'.	Absolute classification is a tool for angling management, comparing the biomass or abundance of fish, irrespective of water body type (i.e. the biomass of fish in a 2 m wide Welsh mountain stream is directly compared with the biomass of a large 30 m wide lowland river). This approach is now widely regarded as inappropriate for biological assessment. It is analogous to the chemical 'Spatial State' option of the proposed Environment Agency Lake classification (Johnes *et al.* 1994). The 'relative' classification is conceptually similar to the multimetric approach, and takes some account of natural variation in assemblages (enabling limited comparison of 'like-with-like').
2. The use of multivariate methods for classifying fish assemblages was ruled out because 'The relatively low number of common, freshwater fish species in Britain reduces the applicability of this technique in this country' (Mainstone *et al.*, 1994).	The effectiveness of multivariate techniques does not primarily depend on the number of species in the data set. Rather, effectiveness depends on the presence of strong environmental gradients within the data sets to which the species present respond. More technically, effectiveness also depends on ensuring that the numbers of samples used in the classification exceeds the numbers of environmental variables measured. Numerous community studies in many types of ecosystem have shown that assemblages with 30 species or less can be satisfactorily classified using multivariate methods.
3. In the relative fisheries classification, the baseline state is established using professional judgement.	Professional judgement is a valid technique for establishing baselines; however, there should be further exploration of multivariate techniques because these are (i) powerful techniques for ecological assessment (ii) widely used by fisheries scientists outside the UK (iii) promote integration of assemblage assessment methods developed elsewhere for the Environment Agency (RIVPACS, Pond/Canal PSYM) (iv) can add objectivity to professional judgements.
4. In establishing baseline assemblages, the only variables taken account of which affect fish assemblage structure are stream width and gradient.	Limited consideration of natural variation in the classification leads to unrealistic comparisons (as was recognised by the scheme authors). A classification based on multivariate description of biological communities would take account of all the main environmental natural (i.e. non-anthropogenically altered) variables influencing assemblage structure (e.g. substrates, geology, east-west species richness gradients).
5. The measurements of fish assemblage structure used in the classification are not related to environmental impairment (i.e. they have not been shown to be metrics which are specifically related to measured environmental degradation).	It was not an objective of the Environment Agency fisheries classification that the fisheries classification should describe biological impairment. This would, however, be essential in the development of a multimetric assessment technique.

4.4 Biodiversity Action Plan

The Environment Agency is the Lead Partner or Contact for several Biodiversity Action Plan (BAP) habitats and species (see Appendix 14), and is represented on a number of Action Plan Steering Groups dealing with aquatic species (Environment Agency, 1997). As part of its biodiversity responsibilities, Environment Agency staff are likely to be involved in (i) monitoring aquatic BAP species and habitats (ii) reporting on the results of the work of various BAP Steering Groups.

This section of the Phase 2 report considers the extent to which a 'biodiversity metric' could be developed to help the Agency monitor and report on the Biodiversity Action Plan (BAP) species and habitats.

4.4.1 BAP habitats and species: introduction

In 1995, the UK Biodiversity Steering Group identified a short list of 14 key habitats and 116 species for which Biodiversity Action Plans should be prepared immediately (UK Biodiversity Steering Group, 1995). Work on action plans for a middle list of habitats and species is currently in progress (Alan Law, English Nature, *pers. comm.*).

The Biodiversity Action Plan (BAP) species constitute a diverse assemblage of (mainly) very rare plants and animals. BAP habitats are, in contrast, often widespread.

4.4.2 BAP Habitats

Two still water BAP habitats are relevant to the Environment Agency: mesotrophic lakes and saline lagoons.

BAP Mesotrophic Lakes

The Lead Partner for Mesotrophic Lakes is the Scottish Environmental Protection Agency (SEPA) which co-ordinates the Mesotrophic Lakes Action Plan Steering Group. The group currently comprises representatives from Scottish Natural Heritage (SNH), RSPB/LINK, the Environment Agency (Karen Rouen), Department of Agriculture Northern Ireland (DANI), Environment and Heritage Service Northern Ireland and Countryside Council for Wales (CCW), in addition to SEPA.

At its first meeting in August 1997, the group resolved to progress the Mesotrophic Lakes Action Plan (MLAP) at individual country level and to establish an inventory of mesotrophic waters which are:

(i) 1 ha and above

(ii) natural or man-made in origin

(iii) mesotrophic, according to the definitions reproduced in Table 4.5

In addition to agreeing a definition of mesotrophic lakes, and establishing an inventory, the MLAP Steering Group will also:

(i) agree criteria for defining excessive abstraction,

(ii) agree criteria for lakes requiring remedial treatment and prepare a list of such lakes,

(iii) produce a prioritised list of SSSI mesotrophic lakes,

(iv) advise on best practice management techniques and, for polluted lakes, restoration measures.

BAP Saline Lagoons

The Lead Partner for Saline Lagoons is English Nature. Other organisations represented on the Saline Lagoons Working Group include Scottish Natural Heritage, Environment Agency (representative, Peter Nicholson, South Western Region), RSPB, University of Cambridge, University of Southampton, WWF, SEPA, DOE NI, CCW and MAFF. The Action Plan Steering Group co-ordinator is Paul Gilliland (EN).

Saline lagoons are natural or artificially created water bodies partially separated from the adjacent sea. They may be either brackish, saline or hyper-saline. The total area of lagoons in the United Kingdom is estimated to be about 1300 ha (450 ha of which is in the single largest lagoon, the Fleet, Dorset) (UK Biodiversity Steering Group, 1995). Saline lagoons are notable for supporting tassel weeds (*Ruppia maritima*), charophytes, three major groups of aquatic invertebrates (freshwater, marine/brackish and specialist lagoonal species) and important bird species (e.g. Avocet, *Recurvirostra avocetta*). They support a number of Red Data Book and Wildlife and Countryside Act scheduled species including Starlet Sea Anemone (*Nematostella vectensis*), lagoon sand shrimp (*Gammarus insensibilis*) and Foxtail Stonewort (*Lamprothamnium papulosum*). Saline lagoons seem to be equally abundant in England and Scotland; only four are so far known in Wales, perhaps 30 in Northern Ireland.

The most recent minutes of the Saline Lagoon Working Group (July 1997) note the particular need to consider monitoring techniques for lagoon systems.

4.4.3 Use of multimetrics for assessment of BAP habitats

The underlying aim of the multimetric methodology is to assess the overall biodiversity and ecological integrity of a system (Williams *et al.* 1995). Multimetric methods are therefore likely to be particularly appropriate for the assessment of BAP habitats, either for:

- initial identification of high quality sites,
- monitoring of temporal quality trends, or
- diagnosis of the causes of degradation through the evaluation of specific metrics.

Currently, using the existing work from the Phase 2 study, it would be possible to undertake provisional evaluation of small mesotrophic lakes using the pond PSYM data set. Further work would be needed to extend the methodology to larger lakes or brackish lagoons, but this would be technically quite feasible.

In principle, BAP habitats could be assessed as part of a routine national monitoring programme of lake or brackish water systems. Alternatively, a BAP habitats monitoring programme could build-on, and extend, a routine programme by:

(i) including surveys undertaken at more frequent intervals,

(ii) undertaking identification and prediction of taxa at lower taxonomic levels than is routine (i.e. species rather than family level identification of macroinvertebrates),

(iii) incorporating a greater number of biotic assemblages into the multimetric assessment, to enhance sensitivity to specific impacts or overall change.

4.4.4 Use of PSYM for BAP species assessments

A high proportion of Biodiversity Action Plan species are associated with standing waters. Of the 'short list' of 22 water-associated species, 17 (77%) are wholly or partly associated with standing waters. Only 5 (21%) are exclusively associated with streams and rivers. In addition, the UK Biodiversity Steering Group identified a 'long-list' of 136 species dependent on standing open water, only woodland had more BAP species.

The development of a useful link between multimetric assessment and the monitoring of individual BAP species is possible in theory, but is unlikely to be consistently useful in practice.

There is no reason why BAP species should not be included, in combination with other uncommon taxa, as part of a more general rare species metric such as the Rare Species Score and Species Rarity Index metrics[1] which were trialled for ponds and canals (and proved a useful metric for pond aquatic macrophytes). More general use of rarity scores and indices would not necessarily be appropriate, however, since it would require that the relevant biotic assemblage *was* proved to be associated with anthropogenic degradation and was a useful metric.

Presence or absence of a BAP species alone would be unlikely to prove a useful metric. Although many BAP species will show a strong monotonic relationship with environmental quality/degradation, BAP species are by definition, likely to be either uncommon or declining species, and most will occur too infrequently for routine surveys to provide sufficient data either for testing or use. BAP plants, invertebrates and fish for example almost all occur at less than 20 sites in Britain.

Looked at from a different angle, is there the potential for routine waterbody monitoring using PSYM, to be developed as a means of monitoring BAP species? It is likely that such an approach would be possible in certain circumstances but would not be widely applicable to (i) BAP species unlikely to be monitored for PSYM (such as amphibians, see Phase 1 report) or (ii) taxa, including most invertebrates, which would usually be identified only at family rather than species level.

In general then, where a specific BAP species is of interest, its populations are best assessed by direct monitoring of that species, rather than by extension of the PSYM method.

Overall, the most likely application of PSYM methods to protection of BAP species, is as a means of assessing the overall quality of the aquatic habitat with which BAP species are associated. In this respect the PSYM method could play an important role in ensuring that potential threats or general habitat degradation are recognised at an early stage, before they can severely impact upon BAP species' population levels.

[1] Based on numerical values for species rarity i.e. 1=common, 2=local, 4=Nationally Scarce, 8=RDB3, 16=RDB2, 32=RDB1.

5. TRACK 3: DESK STUDY TO IDENTIFY AND EVALUATE DIAGNOSTIC METHODS

5.1 Introduction

The Phase 1 scoping study outlined a two-stage protocol for biological assessment of still waters comprising (Figure 5.1):

1. Stage 1: a general environmental assessment, in which the current overall condition of the ecosystem is evaluated, in comparison to baseline conditions (i.e. PSYM)
2. Stage 2: subsequent diagnostic assessment to identify the reasons for any environmental degradation revealed.

Track 3 of the project, described in this section, was concerned with further development of diagnostic methods for identifying the causes of environmental degradation. The first stage in this process was an initial desk study of diagnostic methods, the objectives of which were:

(i) to critically review the range of biological diagnostic methods which can be applied to still waters

(ii) to recommend a suite of diagnostic methods for which further testing or development should be undertaken.

In addition, pond and canal metrics developed in Track 1 of the project were briefly evaluated in terms of their diagnostic potential.

5.2 Methods

5.2.1 Literature review

A database of approximately 300 references from the published scientific literature was reviewed. The database focused on still waters, but also included diagnostic techniques currently applied to flowing waters where these were appropriate (e.g. organic pollution diagnostics in rivers).

Following an initial screening for relevance, methods were assessed using matrix analysis techniques.

5.2.2 Matrix analysis methods

The suitability of diagnostic methods for application to still waters was assessed, using matrix analysis, in terms of two main criteria:

(i) the degree to which the method has been developed (is it at the research stage, prototype stage or routinely applied)

(ii) the extent to which the method is already applied in Europe and the UK.

Suitability was ranked on a 0-3 scale (Table 5.1). Scores for each criterion were summed and ranked as a proportion of the total possible score (see Appendix 15).

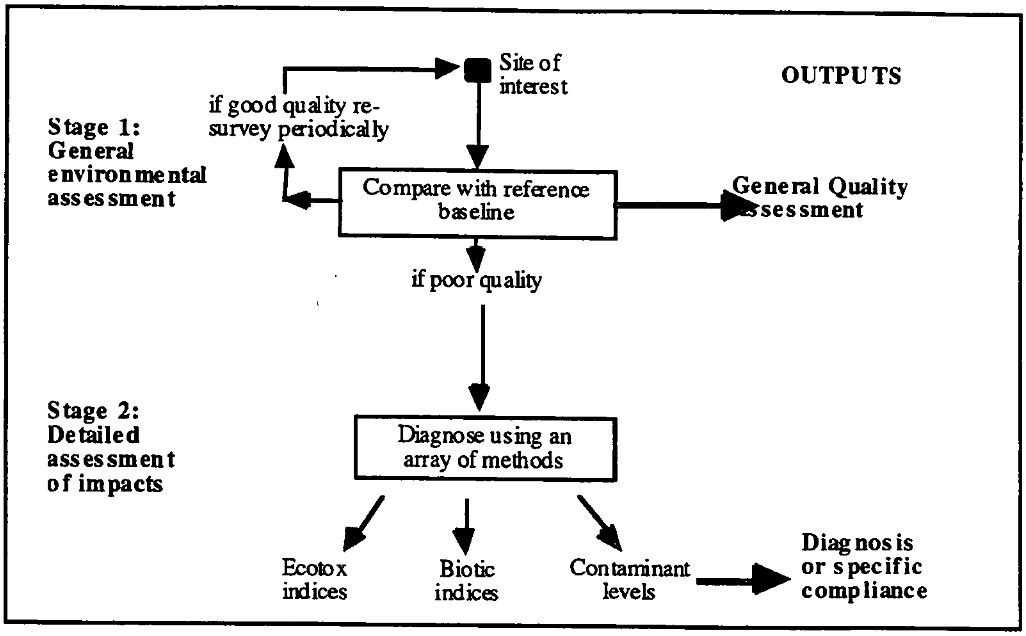

Figure 5.1 Biological assessment techniques: a framework

5.3 Environmental stresses for which diagnostic techniques have been developed

5.3.1 Environmental stresses and diagnostic methods reviewed

The review was structured to investigate potential diagnostic methods for eight major environmental stresses. The stresses considered were:

(i) acidification
(ii) effluent discharges
(iii) multiple pollutants (e.g. urban runoff impacts on receiving waters)
(iv) eutrophication
(v) metal pollution
(vi) micro-organic pollution
(vii) organic pollution
(viii) climate change

5.3.2 Diagnostic methods reviewed

Diagnostic methods were, themselves, grouped into six main categories:

(i) biological surveys
(ii) bioindicators (also termed biomarkers)
(iii) bioaccumulation studies
(iv) modelling using statistical or mathematical techniques
(v) palaeolimnological techniques
(vi) toxicity tests and bioassays

The general characteristics of these six broad method groups are briefly summarised below.

Table 5.1. Criteria and scoring for matrix analysis of diagnostic methods

Criteria for Assessing Method	Scoring
Degree to which method developed	
Scientific underpinning of the method (measured as number of publications)	0 = single publication 1 = 2 publications 2 = 3 to 5 publications 3 = >5 publications
Practical application of method	0 = still at the primary research stage 1 = field trials 2 = evidence of field application, e.g. case study 3 = widely applied
Method independent of temporal or spatial variability	0 = very high spatial and temporal variation 1 = moderate spatial and temporal variation 2 = low spatial and temporal variation 3 = independent of spatial and temporal variation
Application in Europe and the UK	
The method is applied throughout Europe	0 = no European countries 1 = one European country 2 = 2 to 3 European countries 3 = > 3 European countries and UK
There is a UK specific method	0 = no, 1 = yes

Biological surveys. Biological survey-based diagnostic methods have been developed for a range of environmental impacts using most of the major biotic assemblages (phytoplankton, periphyton, macrophytes, microinvertebrates, macroinvertebrates, fish, amphibians, birds, mammals). Biological survey methods for diagnosis involve field collection of representative samples from impacted systems, and are based on changes in the composition of the assemblage in response to environmental stress (e.g. the classical response of running water invertebrates to organic pollution stress).

Bioindicators (also known as biomarkers). Bioindicators are responses of living organisms that may simply signify exposure to damage, may predict future harm (early-warning responses) or may themselves be harmful effects (Melancon, 1994). Although sometimes interpreted to include responses at all levels of biological organisation (from sub-organism to ecosystem level), in this report only sub-organism level responses to environmental stress are considered.

Bioindicators are measurable at a molecular or cellular level and are quickly evident, but are not readily interpreted at the population level. Common biomarkers are measures of enzyme induction and metallothionein. A biomarker may be measured in the laboratory in organisms exposed to field-collected environmental media, or alternatively, the biomarker may be quantified in field-collected organisms that are exposed directly to an environmental stress.

Bioaccumulation. The bioaccumulating properties of a number of biotic assemblages, (e.g. periphyton, macrophytes, macroinvertebrates, birds) have been exploited to provide diagnostic information about contaminants, especially metals and micro-organics. Although fish and mammals have been extensively studied for their bioaccumulating properties, these groups have been less developed as diagnostic indicators.

Palaeolimnology. Palaeolimnological techniques have been used extensively to assess degradation to lakes as a result of acidification, eutrophication and other environmental stresses. Lake sediments contain biological (e.g., diatoms, pollen), chemical (e.g., metals) and physical (e.g. carbonaceous particles) information that can be used to interpret past environmental changes (Dixit *et al.* 1992). In the context of the present report, both the biological and non-biological elements of palaeolimnological methods are considered.

Toxicity tests and bioassays. Laboratory-based toxicity and bioassay methods are widely used in North America to assess the toxicity of *field-collected* aquatic media (water, sediment, pore-water). In Europe (and the UK) toxicity tests are rarely used in this way, and are more generally associated with pre-registration trials of potentially xenobiotic chemical compounds. At present the Environment Agency is developing effluent-based toxicity tests as part of its approach to discharge consenting.

As a *diagnostic* technique, toxicity tests are mainly used to assess the impacts of toxicant mixtures, (e.g. mixtures of metals and organochlorine contaminants), exposing test organisms to the potentially toxic substrate, effluent or water sample under standardised conditions. As with pre-registration toxicity tests, diagnostic toxicity tests have been developed for what are assumed to be the most sensitive life-stages of the most sensitive species.

5.4 Diagnostic methods for identifying specific environmental impacts

The results of matrix analysis are summarised in Table 5.2 and given in full in Appendix 15.

Methods which have scores of 75% or more are recommended for further investigation. Methods scoring 50-74% are identified as potentially useful, and worthy of further investigation. Assemblages or methods scoring less than 50% are either not suitable or require extensive pre-trial research and are not considered further in the present report.

Table 5.2. Summary of matrix analysis of diagnostic methods for biological assessment of still waters[1]

	Biotic groups used in diagnostic method										
	Multiple groups	Sub-organism level	Phyto-plankton	Peri-phyton	Macro-phytes	Invertebrates Micro	Invertebrates Macro	Fish	Amph-ibians	Birds	Mammals
Acidification											
Biological survey	-	-	-	10	-	30	80	-	40	-	-
Bioindicators	-	-	-	-	-	-	33	33	-	-	-
Modelling		-	-	-	-	-	-	-	-	-	-
Palaeolimnology	89	-	-	-	-	-	-	-	-	-	-
Bioaccumlation											
Toxicity/bioassay tests											
Climate change											
Palaeolimnology	67	-	-	-	-	-	-	-	-	-	-
Biological survey											
Bioindicators											
Bioaccumulation											
Modelling											
Toxicity/bioassay tests											
Effluent discharges											
Biological survey	-	-	-	-	-		60	-	-		-
Bioindicators	-	-	-	-	-	-	-	44	-	-	-
Toxicity/bioassay tests	-	-	56		78	89	78	89	-	-	-
Bioaccumlation											
Modelling											
Palaeolimnology											
Eutrophication											
Biological survey	-	-	60	40	60	-	60	-	-	-	-
Palaeolimnology	89	-	-	-	-	-	-	-	-	-	-
Modelling	56	-	-	-	-	-	-	-	-	-	-
Bioindicators											
Toxicity/bioassay tests											
Bioaccumlation											
Metal pollution											
Bioaccumlation	-	-	-	33	56	-	56	-	-	-	-
Bioindicators	-	44	-	-	-	56	44	-	-	-	-
Toxicity/bioassay tests	-	-	-	-	-	56	89	-	-	-	-
Biological survey											
Modelling											
Palaeolimnology											
Mixed contaminants											
Biological survey	-	-	-	-	-	-	60	-	-	-	-
Bioindicators	-	-	22	-	33	56	56	56	-	-	-
Toxicity/bioassay tests	-	-	56	-	78	89	78	89	-	-	-
Bioaccumlation											
Modelling											
Palaeolimnology											
Micro-organics											
Bioaccumlation	-	-	-	-	-	-	-	-	-	22	25
Bioindicators	-	44	-	-	-	-	56	-	-	44	-
Palaeolimnology	44	-	-	-	-	-	-	-	-	-	-
Biological survey											
Modelling											
Toxicity/bioassay tests											
Organic pollution											
Biological survey	-	-	10	50	40	50	80	-	-	-	-
Bioindicators	-	-	-	-	-	-	56	44	-	-	-
Toxicity/bioassay tests											
Bioaccumulation											
Modelling											
Palaeolimnology											

[1]Matrix scores are the percentage of the maximum score possible. Methods shown in small type are those for which no current practical applications were available for assessing specific impact types.

5.5 Evaluation of methods for specific impact types

The following section summarises the diagnostic methods that matrix analysis indicates as suitable for use or development for impact diagnosis. Individual methods considered in the review are briefly described in Appendix 16.

5.5.1 Acidification

Acidification is known to affect a wide variety of biotic assemblages (e.g. diatoms, fish, amphibians, birds), and is one of the most thoroughly researched environmental impacts (Sparling, 1995). However, despite the fact that the *impacts* of acidification are widely recognised, available diagnostic techniques are relatively limited and include:

(i) biological survey methods
(ii) bioindicators
(iii) palaeolimnological techniques

Matrix analysis indicates that, as would be expected, palaeolimnological techniques score highly for diagnosing acidification, reflecting their key role in this area. Although Battarbee (*in press*) notes that palaeolimnology is "not yet fully developed as a management method" it is clear that any work necessary work for further refinement of diagnostic methods could be completed fairly easily. A number of biological survey methods for acidification diagnosis have been proposed but only macroinvertebrate based methods are well-enough developed to be recommended for further testing. Macroinvertebrate methods have particularly been developed in Norway, with the Acidification Index described by Fjellheim and Raddum (1990), but have not yet been applied systematically in the UK. Although promising, this approach would require further development under specific UK conditions before it could be routinely applied for diagnostic work.

5.5.2 Climate change

Many freshwater biotic assemblages can be expected to show responses to climate change but at present documented examples are known from very few detailed research studies. For example, Beebee (1995) reported evidence of earlier breeding of amphibians in the UK over a 17 year period (1978-1994). Bothwell *et al.* (1994) reported that chironomids and benthic algae were differentially sensitive to increased near ultra-violet (UVA) and mid ultra-violet (UVB) light penetration in water. They suggested that observed increases in biologically active ultra-violet light penetration in high-latitude lakes (Schindler *et al.*, 1996) could have complex and counter-intuitive effects, such as causing increases in algal biomass owing to negative impacts on algal grazers.

Biological studies of the effects of climate change are therefore currently very limited. The long timescales associated with climate change mean that, at present, only palaeolimnological methods are likely to provide data that can be used to identify impacts due to climate change. Methods for inferring climate change are still at the research development stage but include transfer functions for water temperature based on chironomids and diatoms (Smol *et al.*, 1995).

Diagnostic techniques relating to climate change are, therefore, in the pre-application stage but palaeoecological methods merit further investigation to assess their likely practical relevance.

5.5.3 Effluent discharges

In England and Wales, consents to discharge effluents direct to surface waters are primarily assessed by considering the final concentration in the receiving water of any potentially polluting substances in the effluent. However, because of the difficulty of assessing the likely affects of many effluents, the Environment Agency is currently investigating the wider use of diagnostic toxicity-based methods of assessing effluent impacts (David Forrow, *pers. comm.*).

In contrast to the UK, toxicity-based assessments of effluent impacts are widely used in North America to set effluent discharge standards (e.g. for Section 403 of the US Clean Water Act, the program for controlling point source effluent discharges). Consequently, a wide range of effluent assessment methods based on ecotoxicological and bioassay methods have been developed, and are available for practical application.

Matrix analysis indicates that tests involving four of the major biotic assemblages, macrophytes, micro- and macroinvertebrates and fish, all score highly, with a range of methods either routinely applied or close to practical application. Most of the effluent assessment tests are essentially applicable to all freshwaters, either by testing effluents at the 'end of pipe' or by collecting natural media (water, sediment) and testing these under controlled conditions in the laboratory. There are also a range of bioindicator tests, although these are still at the research development stage and are not yet suitable for further investigation.

Broadly techniques can be resolved into three main groups:

(i) sub-organism level tests

(ii) single species ecotoxicological tests (e.g. duckweed toxicity tests, *Daphnia magna* bioassay)

(iii) multi-species ecotoxicological tests (especially those using microcosms and artificial streams and ponds).

A wide range of tests are currently being investigated by the Environment Agency in the current R&D programme. Overall, however, it is clear that a suite of tests in the three main groups noted above will be suitable for further development.

5.5.4 Eutrophication

Cultural eutrophication is a widely investigated, and well-documented, environmental impact affecting still water ecosystems. It is a "pan-European problem of major concern" (Stanners and Bourdeau, 1995). There is clear evidence that all major assemblages occurring in still waters are affected by eutrophication but, despite this, there are few biological diagnostic techniques that specifically address eutrophication impacts.

Matrix analysis indicates that, although pre-application biological survey based methods are available for phytoplankton, periphyton, macrophytes and macroinvertebrates, none are sufficiently well-developed to be routinely applied as diagnostic methods.

At present only palaeoecological methods are sufficiently advanced to be recommended as suitable for further testing. Diatom-inferred transfer functions for phosphorus have, for example, been used to asses eutrophication in a variety of locations world-wide (see Appendix 16 for examples) (Battarbee, *in press*). In addition to palaeolimnological techniques, the multimetric methods being developed in the current project, and in Environment Agency R&D Project 286 "Lakes - Classification and Monitoring", could effectively lead to the development of appropriate diagnostic techniques.

Modelling based on physical, chemical, and biological data (Dorge 1994; Van der Molen *et al.*, 1994) may also provide useful diagnostic methods for assessing eutrophication. However, these techniques would require extensive development before they could be used routinely for diagnosis (see Table 5.2).

5.5.5 Metals

Diagnostic techniques for metal contamination fall into three main classes of methods:

(i) toxicity test and bioassays
(ii) bioindicator tests
(iii) bioaccumulation studies (see Appendix 16).

Several major assemblages have been investigated for their potential to provide diagnostic techniques for assessing metal contamination (periphyton, macrophytes, microinvertebrates and macroinvertebrates). However, of these only macroinvertebrate based toxicity tests are sufficiently well-developed to be recommended for further development. These tests have been most extensively developed for cationic metals (e.g., Cd, Cu, Zn).

Bioaccumulation is well-documented in a wide range of taxa but has not yet proved suitable as the basis for standard diagnostic techniques.

5.5.6 Micro-organic pollution

Micro-organics include a large group of mostly human-made chemicals including pesticides (e.g., chlordane, DDT, DDE, toxaphene), industrial chemicals (e.g., PCBs, dioxins, furans) and PAHs.

Two main classes of method are available for diagnosing micro-organic effects in freshwaters: bioindicators and bioaccumulation studies. No individual methods scored highly for this impact type although matrix analysis indicates that bioindicators, in particular methods developed for macroinvertebrates, could provide the basis for suitable methods. Other methods all require further basic research before they could be considered appropriate for development as diagnostic methods.

Note that diagnostic methods that assess mixed contaminants, discussed below, may also be useful for assessing micro-organics in freshwaters.

5.5.7 Mixed contaminants

Related to effluent tests are a wide range of non-specific 'mixed contaminant' diagnostic tests (see Section 5.3.3 and Appendix 16). These take a similar approach to effluent testing and have an ecotoxicological or bioassay basis. They are widely used in North America but, as yet, are rarely used in Britain. For a typical mixed contaminant test, samples of potentially contaminated water or sediment are returned to the laboratory for testing under controlled conditions.

The main disadvantage of 'diagnostic' use of mixed contaminant tests is that they are essentially non-specific, being intended to determine whether water and sediment samples are toxic to a limited range of organisms under controlled conditions. They are primarily used to screen water and sediment samples. This approach can be seen as an ecotoxicological analogue of the field-based general ecological assessment methods described in Tracks 1 and 2 of this report.

The main approaches to 'mixed contaminant' assessment are:

(i) toxicity testing
(ii) bioindicators (Appendix 16).

Standardised toxicity test methods, protocols, and guidelines have been proposed by the Organisation for Economic Co-operation and Development (OECD), and the US and Canadian governments. In the UK an extensive review of screening tests has been undertaken for the Environment Agency by Johnson (1995). Species and endpoints of such tests can vary. However, the majority of acute and chronic water based tests are performed with three species of invertebrates (*Daphnia magna*, *Daphnia pulex*, and *Ceriodaphnia dubia*) and four species of fish (fathead minnows, bluegill, rainbow trout, and brook trout). More recently, test methods have been designed for assessing the toxicity of sediments and include the use of amphipods, aquatic insect larvae, and oligochaetes (Cooney 1995; Keddy et al. 1995; Traunspurger and Drews 1996). Further development of this area will to some extent depend on the outcomes of existing Environment Agency initiatives dealing with ecotoxicology and biomarkers.

Toxicity tests are generally further developed than biomarker based tests, and macrophyte, micro- and macroinvertebrate and fish methods are all recommended for further development.

Biomarker methods for fish, macroinvertebrates, and microinvertebrates may also be useful, but are generally less well developed and should not be considered further as part of the suite of potential standard diagnostic methods.

5.5.8 Organic pollution

As would be expected, the familiar macroinvertebrate-based biological survey techniques for assessing organic pollution, which are applied virtually world-wide, scored highly in the matrix analysis. The majority of these methods are concerned with running waters, and methods specifically designed for standing waters are much less well-developed. However, techniques based on oligochaetes (Milbrink, 1994; Sarkka, 1994, 1996), and chironomids (Petridis, 1993; Wilson, 1994) have been proposed. To date, the littoral macroinvertebrates have not been considered for assessing the degree of organic pollution in standing waters. Given the relatively detailed knowledge of the organic pollution/ freshwater biota interaction, it seems likely that techniques for still waters could be developed relatively easily.

Although a range of biotic assemblages have been investigated for relationships with organic pollution, only macroinvertebrate methods scored sufficiently highly in matrix analysis to be recommended for further development. Potentially suitable methods include biological surveys of diatoms (van Damm *et al.* 1994) and microinvertebrates; both methods would, however, require further practical development before they could be tested.

Biomarkers for organic pollution diagnosis have been developed to a very limited extent. For example Fisher *et al.* (1983) suggested that pectoral fin fanning by the Bluegill (*Lepomis macrochirus*) could be used as a measure of organic stress. Kramer *et al.* (1990), using a similar type of approach showed valve movements of Zebra Mussels (*Dreissena polymorpha*) responded to organic stress. Biomarker methods have not yet been demonstrated beyond the research level and are not recommended for further development.

Table 5.3. Summary of recommended and suitable methods for diagnosing impacts in still-waters.

Shaded methods can be derived from metrics derived from biological surveys.

Impact type	Recommended method(s): matrix scores ≥ 75%	Potential method(s): matrix scores ≥ 50% and < 75%
Acidification	Palaeolimnology Biological survey: macroinvertebrates	None (all methods require basic research)
Climate change	No usable biological methods at present.	Palaeolimnology
Effluent discharges	Toxicity/bioassay: macrophytes Toxicity/bioassay: microinvertebrates Toxicity/bioassay: macroinvertebrates Toxicity/bioassay: fish	Toxicity/bioassay: phytoplankton
Eutrophication	Palaeolimnology	Biological survey: phytoplankton Biological survey: macroinvertebrates Biological survey: macrophytes Modelling
Metal pollution	Toxicity/bioassay: macroinvertebrates	Bioaccumulation: macrophytes Bioaccumulation: macro-invertebrates Bioindicators: microinvertebrates Toxicity/bioassay: microinvertebrates
Mixed contaminants	Toxicity/bioassay: periphyton Toxicity/bioassay: microinvertebrates Toxicity/bioassay: macroinvertebrates Toxicity/bioassay: fish	Biological survey: macroinvertebrates Bioindicators: microinvertebrates Bioindicators: macroinvertebrates Bioindicators: fish
Micro-organics	No usable biological methods at present.	Bioindicators: macroinvertebrates
Organic pollution	Biological surveys: macroinvertebrates	Biological surveys: periphyton Biological surveys: microinvertebrates Bioindicators: macroinvertebrates

5.6 Conclusions and recommendations

Table 5.3 gives a summary of the diagnostic methods which the review and matrix analysis suggest are (i) suitable for immediate testing or use (ii) likely contenders for further development as diagnostic methods.

Currently recommended usable or prototype methods for the main impact types are:

- Acidification — Palaeolimnological methods and macroinvertebrate surveys.
- Effluent discharges — Toxicity tests and bioassays using macrophytes, micro- and macroinvertebrates, fish.
- Eutrophication — Palaeolimnological methods.
- Metal pollution — Toxicity tests/bioassays using macroinvertebrates.
- Mixed contaminants — Toxicity tests and bioassays using the same range of organisms as effluent discharge tests.
- Organic pollution — Macroinvertebrate surveys.

For climate change and micro-organics there currently appear to be no biological diagnostic techniques which could be both quickly and easily applied in the short term although methods using palaeolimnology and bioindicators, respectively, could be developed in the long term.

As highlighted in the Phase 1 scoping study, there appears to be considerable potential for information gathered for PSYM analysis, to be re-used as a biological method for diagnosing the causes of degradation. Diagnosis could, for example, be achieved either through examination of individual metrics which make up the multimetric score, or through re-analysis of the original data.

Appraisal of the data in Table 5.3 suggests that at present, acidification, organic pollution and possibly eutrophication could all potentially be diagnosed using such an approach.

Metal contamination, micro-organics and other toxic pollutants are currently less amenable to diagnosis using biological field monitoring techniques such as those used to gather PSYM data. For these impacts, biological diagnostic methods are primarily focused on laboratory-based toxicity tests or bioassays. However, because of the cost effectiveness of data re-use approaches it is recommended that there is further exploration of field biological data to, at least, investigate the potential for assessing metal, micro-organic and non-specific pollutants in field-collected data sets.

6. CONCLUSIONS AND FUTURE OPTIONS

Phase 2 of the Still Water Quality Assessment project followed three tracks which, together, aimed to develop and test the PSYM method for still water monitoring.

This chapter gives a broad overview of the main findings from each of the three project tracks and includes recommendations for future development which arise from these findings. An evaluation of the potential to extend the PSYM method to other standing water habitats (lakes, brackish, temporary waters and ditches) is also included.

6.1 Track 1 field trials of the multimetric method

In Track 1, PSYM methods were trialled in two still water body types (canals and ponds) using data sets that covered a limited area (approximately 30% of England and Wales). In canals, the PSYM method was developed using aquatic macroinvertebrate assemblages. In ponds, the method was trialled for both macroinvertebrates and aquatic macrophytes.

6.1.1 Development of the PSYM method

Overall the project results successfully demonstrated the key features of the still water assessment rationale outlined in Phase 1 of the project and established a prototype PSYM method. Outcomes from the main steps associated with developing PSYM are briefly summarised below.

Multivariate predictions for ponds and canals

Predictive multivariate techniques (cf. RIVPACS) were successfully applied to both ponds and canals. In ponds, 14 physical variables were used to predict macrophyte and invertebrate assemblages. The main predictors were related to waterbody location, size and underlying geology. In canals, nine variables were used for prediction, largely related to canal location, sediment and bank characteristics.

Metric development

Biological metrics for describing waterbody quality were identified by correlating biological attributes (taxa richness etc.) with environmental degradation measures (water and sediment pollutants, catchment land-use attributes etc.), using data from both minimally-impaired and degraded ponds and canals.

A range of biological attributes were shown to have strong monotonic relationships with degradation in both waterbody types:

- In ponds, the most effective metrics were (i) submerged plant species richness (ii) aquatic plant species rarity (iii) emergent plant species richness (iv) emergent plant species rarity (v) ASPT (Average Score per Taxon) (vi) total invertebrate family richness and (vii) OM (Odonata+Megaloptera) family richness.
- In canals, ASPT and EPT (Ephemeroptera+Plecoptera+Trichoptera) were both effective metrics for assessing water and sediment pollutants. In contrast, metrics based on Coleoptera richness and total family richness were valuable as indicators of bank structure impairment.

The identification of both water quality-sensitive and bank quality-sensitive metrics in canals means that, in practice, ASPT and EPT could either be used alone to assess canal water quality, or combined with the bank-sensitive metrics to provide an assessment of overall waterbody impairment.

Calculation of IBI (Index of Biotic Integrity)

EQI values for each metric (the ratio between the observed and predicted values) were calculated and normalised by placing them into a provisional five category banding system (scored 0 = poor to 4 = good). The scores for each metric EQI were summed to give a single PSYM total which represents the overall quality of the site. This single total score is equivalent to the North American Index of Biotic Integrity.

6.1.2 Tests to assess PSYM performance

As an initial practical trial of the method existing project data were used to test different aspects of PSYM use. The results suggest that:

- The method as a whole could be used to successfully differentiate minimally impaired and degraded sites in both ponds and canals.
- Scores produced by *combining* metrics (i.e. multimetric methods) were more effective than individual metric scores for assessing waterbody quality.
- Family-level invertebrate metrics were as effective as species-based metrics for assessing overall waterbody quality, suggesting that an Environment Agency methodology using family level invertebrate taxonomy will be viable.
- In canals where water quality often needs to be assessed *irrespective* of the type of bank available, it was possible to identify specific metrics (ASPT, EPT) which were relatively bank-independent.

6.2 Future work to develop PSYM for ponds and canals

The Phase 2 project successfully developed PSYM prototypes. However, to make the method fully operational in ponds and canals further development work is required in a number of areas. These include:

- Extension of the survey area and seasons for ponds and canals.
- Further development and testing of PSYM methodologies.
- Development of front-end software for the model.

6.2.1 Extending to three seasons and to all of England and Wales

In Phase 2, pond PSYM and Canal PSYM were developed using data from a limited area (comprising c.30% of England and Wales) and based on samples from 1 season of the year (spring for canals, summer for ponds). To make the system fully operational for the Agency it will be necessary to extend the survey geographically, to cover all England and Wales, and temporally, to allow its use throughout the year.

6.2.2 Variability studies

In order to operate PSYM effectively at national level, studies will be needed to identify sources of variability associated with data collection and analysis.

In terms of data collection, keys areas for investigation relate to:

- Sampling/survey variability,
- Sample sorting variability (invertebrates only)
- Specimen identification variability.

In terms of analysis, as RIVPACS development has shown, there will be a number of statistical issues that need to be addressed with respect to metric variability and banding sites for use in General Quality Assessment.

Metric variability
Preliminary inspection of EQIs generated for the preliminary Pond and Canal PSYMs suggested that some metrics, particularly those based on species/family richness, were moderately variable. Further investigation of the extent of metric variability would be valuable as part of the Phase 3 project. Note, however, that using a multimetric method, where the overall assessment is based on many parameters, there is the potential to include individually more variable measures than where an assessment is based on an assessment of a single, or small numbers of, measures.

Banding
The banding categories used for the current project were based on very simple (equal) divisions of the EQI range. It is clear that, as with RIVPACS, additional analyses are likely to be required concerned with (i) the probability of correctly banding sites (ii) the level of improvement needed for a grade change (up or down) (iii) defining confidence limits for metric values. As with other aspects of the prediction work, this process is likely to be made much simpler as a result of the work undertaken for RIVPACS development.

6.2.3 Field testing

Additional data will inevitably be required to explore and validate the method, and its applications. This includes:

- Collection of additional biological data from minimally impaired sites for validation of the prediction model.
- Field testing, by Environment Agency staff, to assess the method's practical effectiveness in general use.

6.2.4 Computer front end and other materials

For the current project, calculations for PSYM were made from spreadsheet data. To make the system more fully operational, PC/Macintosh based versions of the system need to be developed to enable users to enter data (from the keyboard or from data files) and specify appropriate outputs.

Additionally, the development of support materials (field data pro-formas, methodology descriptions etc.) will be required to enable practical use of the method in the field and laboratory.

6.3 Track 2: Desk study evaluation of multimetric assemblages and applications

Project Track 2 sought (i) to progress the application of fish and diatoms as promising biotic assemblages for multimetric assessment and (ii) to make a desk study evaluation of the potential use of PSYM for Biodiversity Action Plan habitat and species monitoring.

6.3.1 The potential for use of fish in multimetric assessments

Fish are, potentially, a useful biotic assemblage for multimetric assessments of water quality. Track 2 investigated the extent to which existing fisheries data could be used for PSYM assessments.

The assessment suggested that fish assemblages in England and Wales, despite being relatively species-poor and anthropogenically altered, are likely to be amenable to the multivariate, predictive techniques used for PSYM (i.e. TWINSPAN classification, MDA, development of metrics).

In addition, the desk study results indicated that viable fish metrics could almost certainly be derived from standard EA fisheries survey data (with the exception of health and condition metrics).

Recommendations for further work

It is recommended that, in the first instance, existing Environment Agency data is used for further development of the fish assemblage including:

- exploratory tests of classification methods (comparing them with professional consensus classifications)
- testing potential metrics to determine whether they have measurable relationships with environmental degradation.

Of existing fisheries data held by Environment Agency, a database of information from c.200 Fenland drains in the Anglian Region, mostly surveyed 3 or 4 times since 1983, seems likely to be suitable for an initial trial of multimetric methods.

6.3.2 Development of a PSYM method based on diatom assemblages.

To progress the use of diatoms as a multimetric assemblage, diatom samples were collected from 92 survey ponds using field survey methods developed in an EA workshop in April 1997. These samples currently await identification.

Future identification and analysis of these diatom data would be valuable:

(i) to assess the potential use of diatom assemblages within the PSYM method

(ii) for specific development of a diatoms as a Pond PSYM assemblage

(iii) to enable evaluation of the relative viability of diatoms, macrophytes and macroinvertebrates in water quality monitoring.

6.3.3 Use of PSYM for monitoring Biodiversity Action Plan habitats and species

An assessment was made of the extent to which PSYM methods could be used by the Environment Agency to monitor aquatic Biodiversity Action Plan (BAP) habitats and species.

Multimetric methods essentially aim to measure and summarise overall habitat biodiversity, so they are likely to be directly applicable to monitoring relevant BAP habitats. Currently, using the existing work from the Phase II study, it would be possible to undertake provisional evaluation of small mesotrophic lakes using the pond PSYM data set. Further data sets would be needed to extend the methodology to larger lakes or saline lagoons, but the approach is proven and feasible.

The development of a useful link between multimetric assessment and the monitoring of specific BAP *species* is possible in theory, but is unlikely to be consistently useful in practice. The most likely application of PSYM methods in this context is as a means of assessing the overall quality of the aquatic habitat with which BAP species are associated.

6.4 Track 3: Diagnosing the causes of degradation: review of methods

Project Track 3 was a desk-study evaluation of methods that could be used to *diagnose* the causes of environmental degradation.

In the review, methods were grouped into three categories: (i) methods already in use in monitoring programmes (or which could be used with little further development) (ii) promising methods at the prototype stage (iii) potential methods for which there was only preliminary research data. Using the results of matrix analysis, recommendations were made for methods which would be viable for diagnosis of eight environmental stresses types (acidification, climate change, eutrophication etc.).

For most impact types, diagnostic biotic methods were either available or could be developed relatively rapidly. For climate change and micro-organics, however, biotic methodologies have been little developed and applied.

It was recognised that there is considerable potential for information gathered for PSYM analysis to be re-used in diagnosing the causes of degradation. This could be achieved either through inspection of individual metrics, or by reanalysis of the site data.

The current project identified a limited number of diagnostic metrics for canals (water quality vs bank quality), but principally focused on development of metrics for general/overall assessment of waterbody integrity. Even within the existing data-sets, however, there is a considerable amount of information which could be usefully used to develop more specific diagnostic metrics. At present, impacts such as acidification, organic pollution and possibly eutrophication could all potentially be diagnosed using such an approach. For example:

- in ponds there are strong correlations between pH and invertebrate attributes such as snail, mayfly and leech richness, which could be used to develop an acidification metric,
- existing macrophyte data could be used to extend the lake-based Trophic Ranking Score to smaller waters to give a eutrophication metric,
- there is the potential to identify specific biota/sediment contaminants relationships by comparing invertebrate dredge samples from the canal data set with British Waterways sediment chemistry data,
- detailed analysis of individual species distribution patterns could also be used to identify pollutant tolerance levels for individual species. This could potentially allowing the development of pollutant diagnostic indices based on *species* or *mixed* taxonomic data.

6.5 Extending the PSYM method to other standing waters

The PSYM method provides a unified flexible framework for biological monitoring of all surface waters. Prototype development of the current project shows that the method is likely to be effective for canal and pond quality assessment. It is probable that it will be equally effective in other freshwater habitats.

6.5.1 Developing Lake PSYM

Lakes are a strong candidate for biotic method development, partly because they have a high biodiversity value, and partly because, once impacted, lakes are prohibitively difficult to restore. Lake quality assessment is currently being addressed through the Environment Agency Lakes - Classification and Monitoring project. Biotic methods would provide a useful complement to this essentially chemical approach to lake monitoring.

As a result of discussions with the Lakes Classification Project Board and Agency biologists, a small number of lakes were included in the trial Pond-PSYM dataset. The results provided encouraging indications that the PSYM method could be successfully extended to lakes.

The main obstacle to immediate development of Lake PSYM is lack of standard sampling methodologies (cf. RIVPACS, National Pond Survey) for the most viable monitoring assemblages (invertebrates, fish, diatoms, macrophytes). Choice of sampling methodologies is of particular importance in this instance both because: (i) the potential necessity for boat use has considerable resource implications for the cost of the final monitoring method (ii) the methodological approach needs to consider the likely requirements of the EU framework water policy directive.

Given that there is currently Agency interest in developing a Lake PSYM method, the most pragmatic option for field method development would be a rapid desk study to investigate sampling techniques, potentially using analysis of existing lake data sets.

6.5.2 Developing PSYM for other standing water habitats

Based on evidence from the current project, the development of PSYM methods for other standing water systems (including biologically important coastal ditch systems, temporary waters and brackish lagoons) would be likely to be relatively straightforward.

The most feasible approach to progressing PSYM development in these waters is likely to be a staged approach comprising (i) initial standardisation of field survey methods (ii) trial development of all PSYM phases (iii) full development and testing.

7. GLOSSARY

Aquatic plants: A group combining both submerged and floating-leaved plant species.

ASPT: Average Score per Taxon (see BMWP).

BAP: Biodiversity Action Plan.

BIDS: Bath Information and Database Services.

Biological Monitoring Working Party: the Biological Monitoring Working Part score system is a macroinvertebrate-based biological index widely used in UK for diagnosing organic pollution (Armitage, 1983). Invertebrate families are scored 1 to 10 according to their sensitivity to organic pollution (10 = highly sensitive to pollution). Three metrics are produced in this system: BMWP score (the sum of the scores for families present), the ASPT (the average BMWP score of families found) and the number of scoring taxa present.

BMWP: see Biological Monitoring Working Party.

BOD: Biochemical Oxygen Demand.

BW: British Waterways.

CCW: Countryside Council for Wales.

DANI: Department of Agriculture Northern Ireland.

DECORANA: Detrended Correspondence Analysis.

Distribution status: Distribution status (Common, local, etc.).

DETR: Department of the Environment, Transport and the Regions.

DOE: Department of the Environment (now the Department of the Environment, Transport and the Regions).

DTA: Direct Toxicity Assessment.

EA: Environment Agency.

Emergent plants: Wetland species which typically have most of their leaves above water level, e.g., tall emergent species such as Bulrush (*Typha latifolia*) and Soft Rush (*Juncus effusus*); wetland herbs such as Water Forget-me-not (*Myosotis scorpioides*) and Purple Loosestrife (*Lythrum salicaria*); and low-growing grasses such as Creeping Bent (*Agrostis stolonifera*).

EMO: Ephemeroptera, Megaloptera, Odonata. A metric based on numbers of families in these three Orders.

EN: English Nature.

EPT: Ephemeroptera, Plecoptera, Trichoptera. A metric based on numbers of families in these three Orders.

EQI: Environmental Quality Index. Sometimes called Ecological Quality Index.

ETO: Ephemeroptera, Trichoptera, Odonata. A metric based on numbers of families in these three Orders.

Floating-leaved plants: Aquatic plants with most of their leaves floating on the water surface, e.g., Common Duckweed (*Lemna minor*), water lilies.

GQA: General Quality Assessment.

IBI: Index of Biotic Integrity.

IFE: Institute of Freshwater Ecology.

ITE: Institute of Terrestrial Ecology.

Macrophyte: Larger wetland plant species. In the context of the current report taken to includes vascular wetland plants, aquatic mosses and liverworts and charophytes.

MAFF: Ministry of Agriculture Fisheries and Food.

MDA: Multiple Discriminant Analysis.

MLAP: Mesotrophic Lakes Action Plan.

NERC: Natural Environment Research Council.

NPS: National Pond Survey.

OECD: Organisation for Economic Co-operation and Development.

OM: Odonata and Megaloptera.

PA: Pond Action.

PCB: Polychlorinated biphenyl.

PSYM: Predictive SYstem for Multimetrics

RDB: A nationally uncommon species listed in the Red Data Book for that taxonomic group. Three RDB categories are recognised: RDB3 = rare species, RDB2 = vulnerable species , RDB1 = endangered.

RIVPACS: River InVertebrate Prediction And Classification System

RSS: Rare Species Score. Value representing sum of numerical scores given to uncommon species in order to reflect their rarity value i.e. 2= locally common species, 32 = RDB1.

SEPA: Scottish Environmental Protection Agency.

SNH: Scottish Natural Heritage.

Species richness: The number of plant or animal species recorded.

SRI: Species Rarity Index. A numerical assessment of the average species rarity of a particular community or sample. Calculation of SRIs is explained in Appendix 6.

SSSI: Site of Special Scientific Interest.

Submerged plants: Aquatic plants which are generally submerged for most of the year (except for flowers), e.g., hornworts (*Ceratophyllum* spp.), water milfoils (*Myriophyllum* spp.), Canadian Pondweed (*Elodea canadensis*).

TRS: Trophic Ranking Score. A biotic measure of water body nutrient status.

TWINSPAN: Two-way Indicator Species Analysis

Wetland plants: All wetland plant species, including those which are emergent, floating-leaved, and submerged. Plants included as 'wetland' in this study are listed in the National Pond Survey Wetland Plant List.

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APPENDICES

Appendix 1. Stages in the development of a multimetric assessment method for still waters

Choice of sites and survey techniques for the creation of a minimally impacted baseline dataset

For any waterbody type (pond, canal etc.), a minimally impacted baseline data set needs to be created for assemblage groups to be used in the assessment. The preferred method, is to use minimally impacted present-day reference sites. The major concern in selection of these reference sites is to ensure that they are as unaffected as possible by major anthropogenic influences, and not moderately disturbed, producing mediocre expectations.

Selection of reference sites, on whatever basis, needs to consider the principle natural chemical, physical and biotic parameters likely to be acting upon each waterbody type (e.g. longitude and latitude, geology, watershed characteristics, depth, shade). The number of regional reference sites chosen should be a function of regional variability and the desired level of detectable change. In practice, the ideal also needs to be balanced against budget realities.

Methods used to collect and analyse the reference data, will inevitably form the basis of subsequent methodologies (as was the case with RIVPACS, for example). Poor choices at this stage will, therefore, be perpetuated in all future surveys.

Collection of data and classification of unimpaired reference sites

Selection of reference sites is followed by:

- Collection of appropriate biological data from these sites, together with sufficient physical and chemical information to characterise them.
- Classification of biological communities based on this data to minimise natural variation and give better within-class impairment resolution.
- Analysis to identify the natural environmental parameters which characterise (i.e. can be used to predict) each community type.

Survey data for a range of variably impaired sites

Surveys of *impaired* sites (good to very poor) are also essential in order to determine degradation gradients for metric discrimination. This survey may be undertaken consecutively with or following collection of baseline data set. There may also be potential for using existing data from 'impacted' sites, where they exist, providing data is fully compatible in terms of survey methodology and quality.

Identification and development of viable metrics

To determine the discriminatory power of metrics within a waterbody class potential metrics are chosen for assessment. The list of potential metrics should initially be extensive, and include parameters relating to a wide range of community interactions and health (e.g. species/family richness, proportion of functional feeding groups, wet weight, proportion of sensitive taxa etc.).

These variables are tested against the range of best quality and impaired data to identify parameters which show a significant relationship with damage. Clearly, metrics which show a strong monotonic gradient to degradation are likely to be the most effective in accurately expressing degradation through the range of impact intensities. Metrics are rejected if they:

- show high variability in response to *natural* environmental stress,

- they are cost prohibitive,
- have superior measures.

All successful metrics are normalised against the baseline sites and divided to give simple scoring categories (i.e. 1= good, 2=fair, 3=poor, 4=very poor). The process of normalisation provides a mean of combining scores across metrics despite their initially dissimilar values. The division of sites on what is, in reality, a quality continuum, can be undertaken in a number of ways (simple division of the frequency distribution of data into percentiles; proportion of maximum levels etc.).

Combining metrics

Use of the metric data in practice involves combining the normalised metric results to give a single score which represents the overall integrity of the system. This score can be derived from the metrics of a single assemblage, or from the combined results of a number of taxonomic groups. Individual metrics may be weighted if appropriate.

Since metrics are not combined until the final analysis, new metrics or new assemblages can be developed independently, over different timescales, and added into the system as they become available. This gives a very flexible methodology which can be improved and refined without undermining the rationale for the method as a whole.

Testing

A trial phase, during which metrics are tested against new sites, is required to validate and refine the methodology. If there is evidence of poor performance this is most likely to indicate that the initial data set was not adequate to reflect natural variability and will suggest a need to collect further data.

Further use of data to provide additional information on the causes of degradation

The approach described above does not aim to determine the specific causes of degradation, although clearly the assessment will suggest factors which may be important. Investigating the cause(s) of degradation is, conceptually, a separate stage, which is likely to require application of a wide array of methods to disentangle the complexities of causation.

It is clear, however, that the data already gathered for multimetric analysis may have additional potential in providing clues to the causes of impairment. Thus, component parameters can be examined for their individual effects on the aggregated values providing further insight into the factors responsible for degradation. In addition, there is considerable potential for correlation of individual metrics with specific pollutants or other data from impaired sites (collected either during biological surveys, or from other Environment Agency sampling programmes). The results of such analysis (e.g. development of trophic ranking scores etc.) may offer a considerable diagnostic capability.

Appendix 2. List of survey ponds included in the analysis

Code	Name	Grid reference
AFPA	Ashdown Forest Pond A	TQ446328
AFPB	Ashdown Forest Pond B	TQ447329
AL41	Aldershot Pond 41 ('Proposal')	SU889514
AL48	Aldershot: Small Hottonia pond near proposal	SU885515
ASHR	Ashridge	SP982126
ASME	Asham Meads	SP595135
BEGW	Begwyns	SO141448
BERB	Beckly Raised Bog	TQ861254
BHNF	Buck Hill Pond	SU380056
BLHP	Blashford Pond 102	SU146026
BMNF	Burley Moor East	SU211047
BOCO	Bookham Common	TQ124558
BRMO	Brown Moss	SJ562397
BRPO	Brechfa Pool	SO116376
BRWP	Brasenose Wood Newt Pond	SP559055
BUBE	Burnham Beeches Upper Pond	SU949845
BUCO	Burwash Field Pond	TQ679247
CAEN	Cadmore End Common	SU794927
CASS	Cassington Pit	SP455102
CEPO	Central Pond Otmoor	SP569145
CFNF	Chubbs Farm Pond	SU199021
CHOE	Chiddingstone	TQ500450
COFE	Cothill Fen	SU460996
CRHI	Crickley Hill	SO950170
DELL	The Dell Cardiff	ST143778
DSMP	Dry Sandford Pit Main Pond	SU468996
EAMA	Eathorpe Marsh	SP389689
EMHI	Emmett Hill	SU009901
EPFO	Epping Forest	TQ415967
EV02	Eversley Elodea	SU813617
EV2a	Eversley black bag	SU808617
FEWM	Feckenham Wylde Moor	SP012603
FFFA	Fford Fawr	SO187400
FIML	Micheldean Fairplay Iron Mine Main Pond	SO658164
FMIS	Micheldean Fairplay Iron Mine Small Pond	SO658165
FOPI	Fowl's Pill Otmoor	SP572141
FWBR	Micheldean Fairplay Westbury Brook Reservoir	SO658168
FYDO	Fyfield Down NNR	SU138718
HEHE	Headley Heath - Heath End House	TQ204541
IBCO	Ibstone Common	SU749938
KEPO	Kennington Pit	SP518033
LALA	Lashford Lane	SP468014
LLCO	Llandeilo Common	SO132485
LPST	Stiperstones Long Pool	SN355977
LWLP	Little Wittenham Lower Pond	SP571927
LWUP	Little Wittenham Upper Pond	SP571927
MAEL	Maelienydd	SO138174
MAME	Marden Meadow	TQ762445
MAQU	Malvern Quarry	SO771445
MBTP	Matley Bog Tree Pool	SU336075

Appendix 2 (continued). List of survey ponds included in analysis

Code	Name	Grid reference
MOCO	Moor Copse SSSI	SU636740
MUME	Maulden Meadow	TL059383
NCCO	North Chailey Common	TQ390190
NRRA	New River Ray	SP558141
NTHD	Newtimber Hill Dew Pond	TQ272124
OVNP	Over North Pond (Azolla)	SO820193
OVSP	Over South Pond (Lemna)	SO820193
PIGR	Pinkhill Groundwater Pond	SU439068
PIMA	Pinkhill Main Pond	SU439068
PISC	Pinkhill Scrape	SU439068
PISW	Pinkhill Surfacewater	SU439068
PPM1	Priddy Pool Mineries (Pool 1)	ST545518
SAFN	Savernake Forest North	SU217666
SAFS	Savernake Forest South	SU221652
SNCO	Snelsmore Common	SU460710
SOCO	Sole Common SSSI	SU412707
STMB	Staines Moor Butts Pond	TQ030736
THCO	Thursley Common	SU903406
TRBR	Trotton Bridge	SU837224
WEPO	Welford Pools	SU174999
WICO	Wimbledon Common	TQ232718
WIWO	Wilmington Wood	TQ567089
WSNF	Warwickslade	SU272062
WYC1	Wychwood New Hill 1 (top right)	SP339169
WYC2	Wychwood Forest New Hill 2 (top left)	SP338169
WYC3	Wychwood Forest New Hill 3 (bottom)	SP338170
BAHO	Bankhouse House Hotel G & CC	SO805532
BASI	Barrow common silt trap	ST549675
BECK	Beckley Moat	SP577120
BENT	Bentley Farm Pond	TQ482163
BRSC	Brecon School Pond	SO522293
BURA	Burcot Rail	SU983709
CASP	Cawarden Springs Farm	SK067181
CHCR	Chipperfield	TL040020
CHEC	Checkendon Stables	SU663835
CHFA	Charnage Farm	ST832318
CLCA	Clatford Carp	SU357434
COLA	Cornwall laughing	SP275270
DOWL	Dowlais Bridge (no plants)	ST304929
DUVP	Dummer Village Pond	SU586459
EUDO	Eudon Burnell	SO698895
FAWA	Farleigh Wallop	SU620475
FCLR	Friars Court LARGE	SP289001
FCMO	Friars Court Moat	SP285009
FCSM	Friars Court small	SP293004
FIRL	Firlands (sewage)	SU464166
GIZZ	Gizzel	SP582020
GOYT	Goytre Hall Garden (no plants)	SO319065
GRBA	Great Bayhall	TQ623394
GRFA	Grange Farm Pond	SP885147
HAFA	Harriots Farm Pond	SJ834048
HAYT	Haythog Farm Pond	SP457273

Appendix 2 (continued). List of survey ponds included in analysis

Code	Name	Grid reference
HIDU	Hillborough Duck Pond	SP120520
JEWE	Jewel House Pond	TQ747436
KEWG	Kew Gardens Pond	TQ181765
KICP	Kingsclere Church Pond	SU524585
KIDI	Kingston ditch	SP409011
KIMA	Kingston Marsh	SP405012
KINN	Kinnersley Manor	TQ263462
LARK	Larkings barn	SU893178
LIMB	Limbo Farm Pond	SU968244
LRUD	Little Rudge	SP289001
LUS1	Lushill 1 (less organic)	SU154936
LUS2	Lushill 2 (more organic)	SU153942
MARS	Malvern Roadside	SO792454
MPLA	Milton Pools A	SP655030
MPLB	Milton Pools B	SP655031
NAZE	Nazeing Whitehouse (Honeysuckle) Pond	TL414065
NEWE	Newels Pond	SU604988
NILL	Nill Farm	SP371355
PAPA	Patshull Park Hotel Golf Club	SO801997
PLGR	Platford Green	TQ544891
POCP	Popham Court Pond	SU559438
POTC	Potcote Pond	SP466251
RACA	Ravens Causeway	SO436477
REDD	Reddings large	SJ695138
RSPO	Ruscombe Pond	SU798765
SCFA	Scarlett's Farm Pond	SU812779
SHBY	Shrewsbury Bypass	SJ524114
SHEN	Sherfield English	SU293221
SRCH	Stoke Row Cherry Orchard	SU681841
SWAN	Upper Swanmore small	SU584177
SWGO	Swindon GC (Wolverhampton)	SO840910
THOU	Thoulstone golf club pond	ST842484
TICK	Tickford Field Pond	SP888434
TIGR	Tilehouse Green	SP178768
TODU	Towersey Duck Pond	SP737051
TSSS	Tower Sub station small	SN936059
UFVP	Uffington Village Pond	SU306893
WALF	Walford	SO383719
WETO	West Town	TQ270168
WICH	Winforton Church	SO298469
WOFP	Wolfhall farm Pond	SU243622
WORP	Worplesdon	SU974533
WRBO	Wroxton Bottom	SP418414
WRTO	Wroxton Top	SP417413

Appendix 3 List of survey lakes used in the analysis

Code	Name	Grid Reference
BETP	Betton Pool	SJ510078
FLPO	Fleet Pond	SU 820560
FRGP	Frensham Great Pond	SU845402
LHLA	Linch Hill Lake	SP420045
MHPO	Mill Hill Pond	SU858682
SUPO	Sutton Poools/ Wyndley Pool	SP113958
DATC	Datchet Common Central	TQ000750
HYTH	Hythe End	TQ017723
LONG	Longfield Farm	TQ011726
SHEP	Shepperton Large	TQ061673
WRAY	Wraysbury 2	TQ007735
SILT	Silt Lake	SU735747

Appendix 4. List of canal survey sites

Site no.	Site name	Canal	Grid reference
1	Shipton-on Cherwell	Oxford	SP48121660
2	Oxford	Oxford	SP50300720
3	Kennington	Oxford	SP49500950
4	Reading	Kennet and Avon	SU67707078
5	Thatcham	Kennet and Avon	SU52846633
6	Marsh Benham	Kennet and Avon	SU42006707
7	Little Bedwyn	Kennet and Avon	SU29506637
8	All Cannings	Kennet and Avon	SU07066235
9	Seend	Kennet and Avon	ST94886180
10	Clayden	Oxford	SP45755124
11	Welton	Grand Union	SP59756537
12	Barby	Oxford	SP52537116
13	Barby	Oxford	SP52537116
14	Offchurch	Grand Union	SP35856470
15	Wilmcote	Stratford-upon-Avon	SP16755808
16	Cosgrove	Grand Union	SP78954355
17	Aldbury/Tring	Grand Union	SP95481095
18	Aldbury/Tring	Grand Union	SP95481095
19	Hemel Hempstead	Grand Union	TL1800650
20	Harefield/Denham	Grand Union	TQ05108805
21	Yiewsley	Grand Union	TQ06808005
22	Coventry	Coventry	SP35078135
23	Hartshill	Coventry	SP33139497
24	Hartshill	Coventry	SP33139497
25	Market Bosworth	Ashby	SK38700239
26	Bradley Green	Coventry	SK28350033
27	Kings Bromley	Trent and Mersey	SK11111521
28	Great Bowden	Grand Union	SP73448957
29	Hose	Grantham	SK73202980
30	Redmile	Grantham	SK79603530
31	Stragglethorpe	Grantham	SK63403655
32	Penperlleri	Brecon	S031500400
33	Llangynidr	Brecon	SO16501960
34	Pelsall Wood	Wyrley Essington	SK01350435
35	Pelsall Wood	Wyrley Essington	SK01350435
36	Brownhills	Wyrley Essington	SK04600445
37	Holland Park, Birmingham	Wyrley Essington	SK04650700
38	Oxley, Wolverhampton	Staffs and Worcs.	SJ90200185
39	Ettingshall, Wolverhampton	Birmingham	SO93759645
40	Sandwell, Birmingham, South	Birmingham	SP02058888
41	Sandwell, Birmingham, North	Birmingham	SP01908900
42	Stone Cross, West Bromwich	Birmingham	SP00509450
43	Ocker Hill, West Bromwich	Birmingham	SO97809410
44	Ocker Hill, West Bromwich	Birmingham	SO97809415
45	Brockmoor, Dudley	Stourbridge	SO90808770
46	Caunsall	Staffs and Worcs.	SO85608115
47	Victoria Park, London	Regents	TQ34008380*
48	Horsenden Hill, Perivale	Grand Union	TQ13808400
49	Fleet	Basingstoke	SU83405358

Appendix 4 (continued). List of canal survey sites

Site no.	Site name	Canal	Grid reference
50	North Warnborough	Basingstoke	SU72935180
51	North Warnborough	Basingstoke	SU72705180
52	Crookham Wharf	Basingstoke	SU78305170
53	Bedworth, Coventry	Coventry	SP37208685
54	Leicester	Grand Union	SK56900105
55	Loughborough	Grand Union	SK52852090
56	Loughborough	Grand Union	SK52852090
57	Burton-under-Needwood	Trent and Mersey	SK20301843
58	Lapworth	Grand Union	SP19327200
59	Willoughby	Oxford	SP52306820
60	Muston	Grantham	SK80508690
61	Welshpool	Shropshire Union	SJ24150893
62	Wem	Shropshire Union	SJ25181425
63	Queens Head	Shropshire Union	SJ34002690
64	Ouston, Ellesmere	Shropshire Union	SJ38483295
65	Platt Lane, Whixall	Shropshire Union	SJ51103670
66	Whitchurch	Shropshire Union	SJ52454145
67	Whitchurch	Shropshire Union	SJ52454145
68	Market Drayton	Shropshire Union	SJ67833525
69	Audlem	Shropshire Union	SJ64904625
70	Wenbury	Shropshire Union	SJ60704870
71	Hurlston Junction, Nantwich	Shropshire Union	SJ61955505
72	Church Minshall	Shropshire Union (Middlewich)	SJ67056085
73	Congleton	Trent and Mersey	SJ85856135
74	Church Lawton, Alsager	Trent and Mersey	SJ82005565
75	Stone	Trent and Mersey	SJ91583195
76	Acton Trussell	Staffs and Worcs	SJ93501835
77	Wychnor, Alrewas	Trent and Mersey	SK18351608
78	Wychnor, Alrewas	Trent and Mersey	SK18351608
79	Outward, Taunton	Taunton and Bridgewater	ST30302830
80	Bankland, Taunton	Taunton and Bridgewater	ST30802945
81	Huntworth, North Petherton	Taunton and Bridgewater	ST31803440
82	Eelmoor, Farnborough	Basingstoke	SU84005290
83	Ash Vale	Basingstoke	SU89445335
84	Ash Vale	Basingstoke	SU89445335

Appendix 5 NPS Survey Sheet

NATIONAL POND SURVEY 1997 Recording Sheet (1)

Site name ______________________ Code __________

Nearest town or village ______________________ County __________

Access/contact ______________________ Altitude __________

Map number & scale ______________________ Survey __________

SURVEY SEASON	SPRING (Mar-May)	SUMMER (Jun-Aug)	AUTUMN (Sept-Nov)
Surveyor(s)			
Date			

Brief description of the pond

____

____

____

Photograph taken? ☐

Geology

Geology underlying pond		Rock type	
Geology of catchment		Rock types	

Nature of pond base

Tick any of the following:

- Clay/silt ______
- Butyl/synthetic ______
- Concrete ______
- Gravel/sand ______
- Bed rock (specify) ______
- Others (specify) ______

Sediment

Approximate % of the following:

- Decomposing leaves and twigs ______
- Coarse organic debris (c.0.05mm-10mm diam) ______
- Ooze (i.e. non-particulate) ______
- Gravel/sand (often stream-borne) ______
- Others (specify) ______

Water source

Estimate the importance of the following water sources (NB this is a very difficult estimation)

Water source	%	Water source	%	Water source	%
Groundwater/water table		Runoff & near surface water		Direct precipitation	
Spring (<25m long)		Stream or ditch		Other (state)	
Flood water		Flush			

Seasonal water fluctuation and permanence

Drawdown height: The height difference between maximum and current water levels.

Spring	Summer	Autumn
cm	cm	cm

Drawdown area: Proportion of water present in the pond

Spring	Summer	Autumn
%	%	%

Permanence: 1=pond never dries, 2=pond rarely dries, 3=pond sometimes dries, 4=pond dries annually ☐

NATIONAL POND SURVEY 1997 Recording Sheet (2)

Surrounding land-use

Land-use zones

Estimate the percentage of surrounding land-use within the three land-use zones and the catchment

LAND-USE	<5m	5-25m	25-100m	0-100m	Surfacewater catchment
Deciduous woodland					
Coniferous woodland					
Scrub/hedge					
Moor/lowland heath					
Bog					
Fen/marsh					
Rank vegetation					
Unimproved grassland					
Semi-improved grass					
Improved grassland					
Arable					
Parks and gardens					
Buildings and concrete					
Roads					
Rock, stone, gravel					
Ponds and lakes					
Streams, ditches etc					
Other (please state)					

Size of surfacewater catchment?

☐ Very large catchment (>100,000)(<1000mx1000m)

☐ Large catchment ($10,000m^2$-$100,000m^2$)(<100mx1000m)

☐ Moderate catchment ($1,000m^2$-$10,000m^2$ (<100mx100m)

☐ Small catchment ($100m_2$-$1,000m^2$ (<10x100)

☐ Tiny catchment ($<100m^2$) (=10mx10m)

Other adjacent wetlands & water bodies

Are there any OTHER wetlands within 500m of the pond? ☐ If so, record whether the pond is connected to adjacent wetlands (P - permanent connection; T - temporary connection (including flooding); N - not connected.

Wetlands/waterbodies adjacent to the pond

Wetland:	<5m (connections)	5-25m (connections)	25-100m (connections)
Pond/lake			
Ditch/stream			
Fen/marsh			
Bog			
Other (specify)			

Assessing amenity value

Is there a clear view of the pond from the following public rights of way?

Score each on a five point scale (1 = totally obscured; 5 = clearly visible)

• footpath ________ • bridle path ________ • A road ________ • B-road ________

• minor road ________ • other public road or track (please state) ____________ ________

Is the pond located in areas of open public access?

Yes ☐ No ☐

Is there any evidence of formal amenity use?

Tick

☐ Fishing (e.g. fishing platforms, pegs, swims, embayments)

☐ Shooting (e.g. hides, blinds)

☐ Ornamental fish (e.g. goldfish, Koy carp)

☐ Ornamental and other pinioned wildfowl (e.g. nesting/roosting boxes, feeders, platform)

Tick

☐ Pond dipping and other wildlife interests (e.g. dipping platforms, bird hides)

☐ Boating and other water sports (e.g. boat, boathouse)

☐ Model boating

☐ Other (please state) ________________

NATIONAL POND SURVEY 1997 Recording Sheet (3)

History and use of the pond

What is the origin of the pond? ______________________________

How old is the pond? ("at least *x* years if exact dates unknown") ______________

Pond Grazed

Is the pond grazed: Yes ☐ No ☐

% of margin grazed ☐ %

Grazed by:

Grazed by		Grazing intensity	
Cattle	☐	☐	0 = Not grazed
Sheep	☐	☐	1 = Very light or periodic grazing (e.g. natural deer grazing)
Horses	☐	☐	2 = Light grazing/poaching
Deer	☐	☐	3 = Moderate grazing/poaching
Duck	☐	☐	4 = Heavy grazing/poaching
Other	☐	☐	5 = Very heavy grazing/poaching

Pond edge trampled by people

Is the pond edge trampled by people:
Yes ☐ No ☐

% of margin trampled ☐ %

☐	0 = Not trampled
☐	1 = Very light or periodic trampling
☐	2 = Light trampling
☐	3 = Moderate trampling
☐	4 = Heavy trampling
☐	5 = Very heavy trampling

Pond Management

Is there evidence that the pond has been recently managed? Yes ☐ No ☐

Tick		How much (% pond)	How recently?
☐	Marginal trees cut back	☐	☐
☐	Pond dredged	☐	☐
☐	Emergent or submerged plants cut back	☐	☐
☐	Surrounding vegetation strimmed/cut	☐	☐
☐	Edges mowed	☐	☐
☐	Other	☐	☐

Amphibians, fish and ducks

Are fish present in the pond? (? if only probable) Yes ☐ No ☐ Don't know ☐
Record the species and abundance ______________________________

Are amphibians present in the pond? Yes ☐ No ☐ Don't know ☐
Record the species and abundance ______________________________

Are ducks/waterfowl present in the pond? Yes ☐ No ☐ Don't know ☐
Record the species and abundance ______________________________

NATIONAL POND SURVEY 1997 Recording Sheet (4)

Inflows and outflows

Does the pond have any inflows or outflow channels (either dry or wet)? ☐

If yes, estimate their average width and depth. Where possible note the flow rate. Where this is difficult, estimate the flow category: 1 - dry at time of survey 2 - imperceptible; 0-10 cm/sec 4 - moderate; 51-200 cm/sec
3 - slow; 11-50 cm/sec 5 - fast. 201+ cm/sec

	INFLOWS			OUTFLOWS		
	Water width (cm) (if wet)	Water depth	Flow rate or Flow category	Water width (cm) (if wet)	Water depth	Flow rate or Flow category
SPRING						
SUMMER						
AUTUMN						

Water quality

Turbidity	Spr.	Sum.	Aut.	Spr.	Sum.	Aut.	Spr.	Sum.	Aut.	Spr.	Sum.	Aut.
	1=Clear			2=Moderately clear			3=Moderately turbid			4=Turbid		

Water colour Spring ________ Summer ________ Autumn ________

Probable source of colour ________ ________ ________

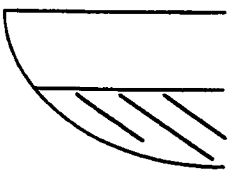
Rubbish, Rubble and other obvious pollutants

% of pond infilled with rubbish or rubble ☐ Type of infill ________

Any oil or other obvious pollutants ☐ Type ________

Sediment and water depths

Season measured? Spr/Sum/Aut



	Transect A (longest dimension) 1/4	1/2	3/4	Transect B (right angles to A) 1/4	3/4	Max. depths
Water depths (cm)						
Silt depths (cm)						
Total depth (silt and water) (cm)						

NATIONAL POND SURVEY 1997 Recording Sheet (5)

Water chemistry

	Spr.	Sum.	Aut.
pH			
Time			

	Spr.	Sum.	Aut.
Conductivity (us cm^{-1})			
Alkalinity (m mol^{-1})			

	Spr.	Sum.	Aut.
Temperature			
Calcium (mg l^{-1})			

Water sample taken? ☐ **Exlox sample taken?** ☐

Sources of pollution

Rank individual pollutant sources on a scale of 1-5 (1=little polluted or affected, 5=very polluted)

☐ Stream quality ☐ ______

☐ Road runoff quality ☐ ______

☐ Surrounding land use quality ☐ ______

Order the main sources of pollution entering the pond in terms of their **relative** importance (giving percentages where possible).

% ______

% ______

% ______

% ______

% ______

% ______

Give an **overall** rating of the extent to which the pond is likely to be polluted (from 0= not polluted to 10=as bad as it can get). ☐

Diatom habitats

______ ______

______ ______

______ ______

______ ______

NATIONAL POND SURVEY 1997 Recording Sheet (6)

Pond size: calculated from summer survey map

Pond circumference ______ m   Pond area ______ m^2 Maximum dimensions ______ x ______ m

Water circumference ______ m   Water area ______ m^2

Overhanging trees & shrubs

% pond overhung ______   % water overhung ______

% total pond margin overhung ______   % water margin overhung ______

Scale

North

Macroinvertebrate micro-habitats

SPRING

SUMMER

AUTUMN

Macroinvertebrates seen or returned to the pond

SPRING

SUMMER

AUTUMN

NATIONAL POND SURVEY Wetland Plant Recording Sheet (7)

Submerged Species

Apium inundatum
Aponogeton distachyos
Callitriche hamulata
Callitriche hermaphroditica
Callitriche obtusangula
Callitriche platycarpa
Callitriche stagnalis
Callitriche truncata
Callitriche sp. (undetermined)
Ceratophyllum demersum
Ceratophyllum submersum
Egeria densa
Elatine hexandra
Elodea canadensis
Elodea nuttallii
Eleogeton fluitans
Groenlandia densa
Hippuris vulgaris
Hottonia palustris
Isoetes lacustris
Juncus bulbosus
Lagarosiphon major
Littorella uniflora
Lobelia dortmann
Myriophyllum alterniflorum
Myriophyllum aquaticum
Myriophyllum spicatum
Myriophyllum verticillatum
Oenanthe aquatica
Oenanthe fluviatilis
Potamogeton alpinus
Potamogeton berchtoldii
Potamogeton coloratus
Potamogeton crispus
Potamogeton friesii
Potamogeton gramineus
Potamogeton lucens
Potamogeton obtusifolius
Potamogeton perfoliatus
Potamogeton pectinatus
Potamogeton praelongus
Potamogeton pusillus
Potamogeton trichoides
Potamogeton hybrid(s)
Ranunculus aquatilis
Ranunculus baudotii
Ranunculus circinatus
Ranunculus fluitans
Ranunculus peltatus
Ranunculus penicillatus
Ranunculus trichophyllus
Sagittaria sagittifolia
Sparganium angustifolium
Sparganium emersum
Sparganium minimum
Stratiotes aloides
Subularia aquatica
Utricularia australis
Utricularia intermedia
Utricularia minor
Utricularia vulgaris
Wolffia arriza
Zannichellia palustris

Charophytes:
Chara sp.
Nitalla sp.
Tolypella sp.

% Submerged spp ____________

Bryophytes:
Fontinalis antipyretica
Riccia fluitans
Ricciocarpus natans
Sphagnum sp.

Algae:
Enteromorpha sp.
Filamentous
Planktonic

% algae ________

Trees and shrubs:

Alnus glutinosa
Frangula alnus
Populus sp.
Salix sp.

Floating-leaved species

Azolla filiculoides
Lemna gibba
Lemna minor
Lemna minuscula
Lemna polyhriza
Lemna trisulca
Luronium natans
Hydrocharis morsus-ranae
Nymphaea alba
Nymphoides peltata
Nuphar lutea
Potamogeton natans
Potamogeton polygonifolius

% Floating-leaved spp. ________

Emergent wetland plants

Achillea ptarmica
Acorus calamus
Agrostis stolonifera
Alisma lanceolatum
Alisma plantago-aquatica
Alopecurus aequalis
Alopecurus geniculatus
Anagallis tenella
Andromeda polifolia
Angelica archangelica
Angelica sylvestris
Apium nodiflorum
Baldellia ranunculoides
Barbarea intermedia
Barbarea vulgaris
Berula erecta
Bidens cernua
Bidens tripartita
Blysmus compressus
Butomus umbellatus
Calamagrostis canescens
Calamagrostis epigejos
Caltha palustris
Cardamine amara
Cardamine pratensis
Carex acuta
Carex acutiformis
Carex curta
Carex demissa
Carex diandra
Carex disticha
Carex flacca
Carex hostinana
Carex laevigata
Carex lasiocarpa
Carex lepidocarpa
Carex nigra
Carex otrubae
Carex panicea
Carex paniculata
Carex pendula
Carex pseudocyperus
Carex pulicaris
Carex riparia
Carex rostrata
Carex spicata
Carex vesicaria
Catabrosa aquatica
Cicuta virosa
Cirsium dissectum
Cirsium palustre
Cladium mariscus
Conium maculatum
Crassula helmsii
Crepis paludosa
Cyperus longus
Dactylorhiza fuchsii
Damasonium alisma
Deschampsia caespitosa
Drosera rotundifolia
Eleocharis acicularis
Eleocharis multicaulis
Eleocharis palustris
Eleocharis quinqueflora
Eleocharis uniglumis
Equisetum fluviatile
Equisetum palustre
Epilobium hirsutum
Epilobium nerteroides
Epilobium obscurum
Epilobium palustre
Epilobium parviflorum
Epilobium tetragonum
Epipactis palustris
Erica tetralix
Eriophorum angustifolium
Eriophorum latifolium
Eriophorum vaginatum
Eupatorium cannabinum
Filipendula ulmaria
Galium boreale
Galium palustre
Galium uliginosum
Geum rivale
Glyceria declinata
Glyceria fluitans
Glyceria maxima
Glyceria plicata
Hydrocotyle vulgaris
Hypericum elodes
Hypericum tetrapterum
Impatiens capensis
Impatiens glandulifera
Impatiens noli-tangere
Iris pseudacorus
Isolepis cernua
Isolepis setacea
Juncus acutiflorus
Juncus articulatus
Juncus bufonis agg.
Juncus compressus
Juncus conglomeratus
Juncus inflexus
Juncus subnodulosus
Juncus effusus
Lotus uliginosus
Lychnis flos-cuculi
Lycopus europaeus
Lysimachia nemorum
Lysimachia nummularia
Lysimachia vulgaris
Lythrum hyssopifolia
Lythrum portula
Lythrum salicaria
Menyanthes trifoliata
Mentha aquatica
Mimulus guttatus
Mimulus luteus
Molinia caerulea
Montia fontana
Myosotis laxa
Myosotis scorpioides
Myosotis secunda
Myosoton aquaticum
Myrica gale
Narthecium ossifragum
Nasturtium microphyllum
Nasturtium officinale
Oenanthe aquatica
Oenanthe crocata
Oenanthe fistulosa
Oenanthe lachenalii
Osmunda regalis
Parnassia palustris
Pedicularis palustris
Petasites hybridus
Phalaris arundinacea
Phragmites australis
Pilularia globulifera
Pinguicula vulgaris
Polygonum amphibium
Polygonum hydropiper
Polygonum lapathifolium
Polygonum persicaria
Potentilla erecta
Potentilla palustris
Pulicaria dysenterica
Ranunculus flammula
Ranunculus lingua
Ranunculus hederaceus
Ranunculus omiophyllus
Ranunculus sceleratus
Rhynchospora alba
Rorippa amphibia
Rorippa palustris
Rorippa sylvestris
Rumex hydrolapathum
Rumex maritimus
Rumex palustris
Sagina procumbens
Saggitaria sagittifolia
Schoenoplectus lacustris
ssp lacustris
ssp tabernaemontani
Schoenus nigricans
Scrophularia auriculatas
Scutellaria galericulata
Senecio aquaticus
Senecio fluviatilis
Sium latifolium
Solanum dulcamara
Sparganium erectum
Stachys palustris
Stellaria alsine
Stellaria palustris
Symphytum officinale
Thalictrum flavum
Thelypteris palustris
Tofieldia pusilla
Tricophorum cespitosum
Triglochin palustris
Typha angustifolia
Typha latifolia
Valeriana dioica
Veronica anagallis-aquatica
Veronica beccabunga
Veronica catenata
Veronica scutellata
Viola palustris

% Emergent spp. ____________

% Total cover ____________

Plant habitats for invertebrates

Estimate the % plant cover within the WATER area of the pond

	Spring	Summer	Autumn
Above water level: % cover of all emergent plants			
Below water level: % of plants with rigid narrow-leaves e.g. bulrush, bur-reed			
Below water level: % plants with flexible leaves e.g. water mint, grasses			
Below water level: % 'true aquatic' plants e.g. water starwort, pondweeds			
Water surface: % cover of all floating leaved e.g. floating grasses, duckweed			

Appendix 6. Canal field survey sheet

Location	

Site number		Grid reference	
Canal		Altitude	
Surveyor		Date	

Which bank sampled	

Flow (m/sec)		Flow direction	

Turbidity (Secchi disk depth)	

Shading 50 m reach (%)

	Sample area	50 m spl side	50 m other side
Edge length on sampling side			
Water area on sampling side (to mid way)			

Channel vegetation 50 m reach (% cover)

	Sample area	50 m sampling side	50 m other side
Marginal/emergent (%)			
Width of vegetation strip			
%of bank vegetated			
Aquatic (%)			
Floating (%)			
Filamentous algae (%)			

Bank type (%)	Sampling area	Sampling	Other side
Earth			
Concrete			
Metal piling			
Wood			
Other			
Angle of bank at edge			

Management

Evidence of dredging ....

Other management ....

Other waterbodies/wetland around e.g floodplain, river, ponds

....

....

Pollution evidence ....

Additional notes..

Surrounding vegetation	**0-5 m spl. area (%)**	**0-5 m other (%)**	**5-100 spl. area (%)**	**5-100 other**
Woodland (state)				
Scattered trees				
Scrub				
Hedge				
Moorland/heath				
Bog/acid flush				
Fen/marsh/alkaline flush				
Wetland plants				
Rank vegetation				
Unimproved grassland				
Semi-improved grassland				
Improved grassland				
Arable				
Buildings and concrete				
Gardens/parks				
Roads				
Tracks				
Paths				
Ponds/lakes				
Rivers/streams				
Ditches				
Other				

Substrate	%	%	%
Boulders/cobbles (64 -265+ mm)			
Pebbles/gravel (2-64 mm)			
Gravel (2-16 mm)			
Sand (0.0625 -2 mm)			
Silt/Clay (0.0625 mm)			
Coarse detritus (2mm+)			
Fine detritus (<2mm)			
|2| 16 | 64 |			

Nature of canal base	

Depth (m)	**1 m**	**2 m**	**3 m**	**4 m**	**Maximum**
Water depth					
Sediment depth					

Invertebrate sampling habitats (%)	

Canal width (m)	

Photograph	

Appendix 7. Biological attributes tested as possible metrics

Appendix 7a. Invertebrate attributes tested as possible metrics

Code	*Attribute description*
INV_N.SP	Number of invertebrate species
INV_N.FA	Number of invertebrate families
INV_N.OR	Number of invertebrate orders
INV_SRS	Invertebrate Species Rarity Score
INV_SRI	Invertebrate Species Rarity Index
S_TRIC	Number of Tricladia species
S_GAST	Number of Gastopoda species
S_BIVAL	Number of Bivalve species
S_HIRU	Number of Hirdinea species
S_ARAN	Number of Araneae species
S_DECA	Number of Decapoda species
S_ISOP	Number of Isopoda species
S_AMPH	Number of Amphipoda species
S_EPHE	Number of Ephemera species
S_PLEC	Number of Plecoptera species
S_ODON	Number of Odonata species
S_HEMI	Number of Hemiptera species
S_COLE	Number of Coleoptera species
S_MEGA	Number of Megaloptera species
S_NEUR	Number of Neuroptera species
S_TRICH	Number of Tricoptera species
S_LEPID	Number of Lepidoptera species
S_DIPT	Number of Diptera species
S_LYMN	Number of Lymnaeidae species
S_PLAN	Number of Planorbidae species
S_BAET	Number of Baetidae species
S_COEN	Number of Coenagrionidae species
S_HALIP	Number of Haliplidae species
S_HYDR	Number of Hydrophylidae species
S_LIMN	Number of Limnephilidae species
S_LEPT	Number of Leptoceridae species
S_SM_DY	Number of small Dytiscidae species
S_CM	Number of Crustacea + Mollusca species
S_HTR	Number of Hirudinea + Tricladia species
S_PHEMIP	Number of predatory Hemiptera species
S_DHEMIP	Number of detritivore Hemiptera species
S_EPT	Number of Ephemeroptera + Plecoptera + Tricoptera species

(cont.)

Appendix 7a (cont.). Invertebrate attributes tested as possible metrics

Code	*Attribute description*
S_ETO	Number of Ephemeroptera + Tricoptera + Odonata species
F_TRICLA	Number of Tricladia families
F_GASTRO	Number of Gastopoda families
F_BIVALV	Number of Bivalve families
F_HIRUDI	Number of Hirdinea families
F_ARANEA	Number of Araneae families
F_DECAPO	Number of Decapoda families
F_ISOPOD	Number of Isopoda families
F_AMPHIP	Number of Amphipoda families
F_EPHEME	Number of Ephemera families
F_PLECOP	Number of Plecoptera families
F_ODONAT	Number of Odonata families
F_HEMIPT	Number of Hemiptera families
F_COLEOP	Number of Coleoptera families
F_MEGALO	Number of Megaloptera families
F_NEUROP	Number of Neuroptera families
F_TRICHO	Number of Tricoptera families
F_LEPIDO	Number of Lepidoptera families
F_DIPTER	Number of Diptera families
F_PHEMIP	Number of predatory Hemiptera families
F_DHEMIP	Number of detritivore Hemiptera families
F_PRED	Number of predator families
F_DETR	Number of detritivore families
F_HERB	Number of herbivore families
F_CM	Number of Crustacea + Mollusca families
F_HTR	Number of Hirudinea + Tricladia families
F_EPT	Number of Ephemeroptera + Plecoptera + Tricoptera families
F_ETO	Number of Ephemeroptera + Tricoptera + Odonata families
F_MO	Number of Megaloptera + Odonata families
F_OME	Number of Odonata + Megaloptera + Ephemeroptera families
BMWP_N_F	Number of BMWP families
BMWP	BMWP score
ASPT	ASPT score

Appendix 7b. Macrophyte attributes tested as possible metrics

Code	*Attribute description*
PL_N.TX	Number of all wetland plant species
MARG_N.TX	Number of marginal plant species
SUB_N.TX	Number of submerged plant species
FLT_N.TX	Number of floating plant species
FRE_SP	Number of free-floating plant species
POT_SP	Number of Potamogeton species
PL_SRS	Species Rarity Score for all wetland plant species
MARG_SRS	Species Rarity Score for marginal plant species
SUB_SRS	Species Rarity Score for submerged plant species
FLT_SRS	Species Rarity Score for floating plant species
AQ_SRS	Species Rarity Score for aquatic plant species
PL_SRI	Species Rarity Index for all wetland plant species
MARG_SRI	Species Rarity Index for marginal plant species
SUB_SRI	Species Rarity Index for submerged plant species
FLT_SRI	Species Rarity Index for floating plant species
AQ_SRI	Species Rarity Index for aquatic plant species
AQ_TNT	Aquatic plant Trophic Ranking Score (TRS): number of species used
AQ_TS	Aquatic plant TRS: total score of taxa
AQ_TI	Aquatic plant TRS: index i.e. score/number of species
SUB_EX	Number of submerged exotic species
FLT_EX	Number of floating exotic species
AQ_EX	Number of aquatic exotic species
AQ_EX	Number of marginal exotic species
EX_SP	Total number of exotic species
FFL0/AQ	Free-floating plants/aquatic plants
FFL0/SU	Free-floating plants/submerged plants
SUB/FLO	Submerged plants/floating plants

Appendix 8. Environmental attributes

Appendix 8a. Pond environmental attributes

EASTING	Easting
NORTHING	Northing
ALTITUDE	Altitude
CTM_SST	Catchment geology: Sandstone
CMT_CLAY	Catchment geology: Clay
CMT_LST	Catchment geology: Limestone
CMT_IG	Catchment geology: Igneous and Metamorphic
BASE_CL	Pond base: Clay, silt
BASE_GRA	Pond base: Gravel, sand
BASE_ROC	Pond base: Rock
BASE_PT	Pond base: Peat
BASE_STO	Pond base: Stone blocks
AREA	Pond area
M_COMPLX	Pond margin complexity ranking
AGE	Age
SHADE_%	Shade: % of pond area overhung
SHADE_MR	Shade % of pond margin overhung
WTR_DEPT	Water depth (average)
SILT_DPT	Silt depth (average)
DRAW_CM	Drawdown height
DRAW_%	Drawdown area (% water remaining)
PERM	Permanence (ranked)
CONNECT	Adjacent waterbodies: number permanently connected
TCONNECT	Adjacent waterbodies: number seasonally connected
NCONNECT	Adjacent waterbodies: number not connected
SED_LEAV	Sediment: % leaves
SED_DEBR	Sediment: % coarse debris
SED_OOZE	Sediment: % clay and silt
SED_SAND	Sediment: % sand
SED_GRAV	Sediment: % gravel
SED_PEBS	Sediment: % pebbles
SED_BOLD	Sediment: % boulders
SED_PEAT	Sediment: % peat
WS_GWTR	Water Source: % groundwater
WS_SWTR	Water Source: % surfacewater
WS_PPT	Water Source: % precipitation
WS_STR	Water Source: % stream or ditch

Appendix 8 (continued). Environmental attributes

Appendix 8a.	**Pond environmental attributes**
WS_FLOOD	Water Source: % flood
WS_FLSP	Water Source: % flush+Spring
WS_GSF	Water Source: % groundwater+spring+flush
INFL_VOL	Inflow volume
G_LIV_01	Grazed by livestock
GRAZED%	% grazed
GRAZTRAM	% grazed or trampled
FISH	Fish present
FL`PLAIN	Landscape connectivity: proximity to floodplain (ranked)
ISOLATIO	Landscape connectivity: isolation (ranked)
TRAD_WET	Landscape connectivity: proximity to traditional wetlands (ranked)
C_SIZE	Catchment Size
DECID100	Land cover % within 100m: deciduous woodland
CONIF100	Land cover % within 100m: coniferous woodland
SCRUB100	Land cover % within 100m: scrub and hedge
HEATH100	Land cover % within 100m: heath
BOG100	Land cover % within 100m: bog
MARSH100	Land cover % within 100m: marsh
RANKG100	Land cover % within 100m: rank vegetation
UNIMPG10	Land cover % within 100m: unimproved grassland
S`IMPG10	Land cover % within 100m: semi-improved grassland
IMPRG100	Land cover % within 100m: improved grassland
ARABL100	Land cover % within 100m: arable
PARKS100	Land cover % within 100m: parks and gardens
BUILD100	Land cover % within 100m: buildings
ROADS100	Land cover % within 100m: roads
ROCK100	Land cover % within 100m: rock, stone, gravel
PATHS100	Land cover % within 100m: paths and tracks
PONDS100	Land cover % within 100m: ponds and Lakes
STREAM10	Land cover % within 100m: streams and ditches
ALLWDSC1	Land cover % within 100m: total wood and scrub
ALLGRASS	Land cover % within 100m: total grassland
ALLWET10	Land cover % within 100m: total wetland
ALLS`NAT	Land cover % within 100m: total semi-natural land use
ALLIMPAG	Land cover % within 100m: total agriculturally improved
ALLURB10	Land cover % within 100m: total urban
ALLIMP10	Land cover % within 100m: total improved
C_DECID	Land cover % catchment area: deciduous woodland

Appendix 8 (continued). Environmental attributes

Appendix 8a. Pond environmental attributes

C_CONIF	Land cover % catchment area: coniferous woodland
C_SCRUB	Land cover % catchment area: scrub and hedge
C_HEATH	Land cover % catchment area: heath
C_BOG	Land cover % catchment area: bog
C_MARSH	Land cover % catchment area: marsh
C_RANKG	Land cover % catchment area: rank vegetation
C_UNIMPG	Land cover % catchment area: unimproved grassland
C_S_IMPR	Land cover % catchment area: semi-improved grassland
C_IMPRG	Land cover % catchment area: improved grassland
C_ARABL	L Land cover % catchment area: arable
C_PARKS	Land cover % catchment area: parks and gardens
C_BUILD	Land cover % catchment area: buildings
C_ROADS	Land cover % catchment area: roads
C_ROCK	Land cover % catchment area: rock, stone, gravel
C_PATH	Land cover % catchment area: paths and tracks
ALLWDS_C	Land cover % catchment area: total wood and scrub
ALLGRASS	Land cover % catchment area: total grassland
ALLWET_C	Land cover % catchment area: total wetland
ALLS`NAT	Land cover % catchment area: total semi-natural land use
ALLIMPAG	Land cover % catchment area: total agriculturally improved
ALLURB_C	Land cover % catchment area: total urban
ALLIMP_C	Land cover % catchment area: total improved
POL_STR	Pollution input: stream (ranked)
POL_ROAD	Pollution runoff: road (ranked)
POL_AGR`	Pollution runoff: agriculture (ranked)
POL_URBA	Pollution runoff: urban (ranked)
POL_DUCK	Pollution: ducks (ranked)
POL_FISH	Pollution: fish stocking and management (ranked)
POL_OVER	Overall Pollution Rating (ranked)
POLGW	Overall Pollution Rating/% groundwater input
POLGWSF	Overall Pollution Rating/% groundwater+spring+flush input
SUB`PLT%	Vegetation cover: % submerged plants
FLT`PLT%	Vegetation cover: % floating-leaved plants
EMG`PLT%	Vegetation cover: % emergent plants
TOT_PLT%	Vegetation cover: % total plants
ALGAE%	Vegetation cover: % algae (excluding-charophytes)
TURBID	Water Turbidity (ranked)
PH	pH
COND	Conductivity

Appendix 8 (continued). Environmental attributes

Appendix 8a. Pond environmental attributes

ALK	Alkalinity Meql-1
CA	Calcium ppm
K_PA	Potassium mg/l (measured by Pond Action)
CL	Chloride mg/l
SS	Suspended Solids mg/l
TON	T.O.N mg/l
TN	Total N mg/l
SRP	S.R.P. mg/l
TP	Total P mg/l
AMM	Ammonia mg/l
ZN	Zinc mg/l
NI	Nickel mg/l
FE	Iron mg/l
MG	Magnesium mg/l
AL	Aluminium mg/l
CU	Copper mg/l
NA	Nickel mg/l
K_GEOL	Potassium mg/l (measured by Oxford Brookes Geology Dept.)

Appendix 8 (continued). Environmental attributes

Appendix 8b. Canal environmental attributes

Code	*Attribute description*
EASTING	Easting
NORTHING	Northing
ALTITUDE	Altitude
DATE	Day from start of survey
SECCHI	Turbidity (Secchi disk depth cm)
%SHADE_B	% of bank edge overhung
%SHADE_W	% of water area overhung
%VEGB_SA	% bank vegetated in the sampling area
%MARG_SA	Marginal emergent plant cover (%) in the sampling area
%AQUA_SA	Aquatic plant cover (%) in the sampling area
%FLOA_SA	Floating plant cover (%) in the sampling area
%ALG_SA	Filamentous algae cover (%) in the sampling area
%VEG_SA	Total vegetation cover (%) in the sampling area
%VEG_SA_	Total vegetation cover (%) including algae in the sampling area
%VEGB_50	Length of bank vegetated (%) along 50m bank length
%MARG_50	Marginal emergent plant cover (%) along 50m bank length
%AQUA_50	Aquatic plant cover (%) along 50m bank length
%FLOA_50	Floating plant cover (%) along 50m bank length
%ALG_50	Filamentous algae cover (%) along 50m bank length
%VEG_50	Total vegetation cover (%) along 50m bank length
%VEG_50_	Total vegetation cover (%) including algae along 50m bank length
%EARTH	Bank type: Earth (%)
%CONC	Bank type: Concrete (%)
%METAL	Bank type: Metal piling (%)
%WOOD	Bank type: Wood (%)
%OTHER_S	Bank type: Other: stone or concrete blocks (%)
%OTHER_B	Bank type: Other: brick (%)
%HAR_EXS	Bank type: Total hard bank excluding stone (%)
%HAR_INS	Bank type: Total hard including stone (%)
GRASS	Land cover 0-5m sample side: % all grassland
WATER	Land cover 0-5m sample side: % waterbodies
SEMI_N	Land cover 0-5m sample side: % seminatural
URBAN	Land cover 0-5m sample side: % urban
INT_AG	Land cover 0-5m sample side: % intensive agriculture
INT_ALL	Land cover 0-5m sample side: % total intensive
GRASS	Land cover 0-5m far bank: % all grassland
WATER	Land cover 0-5m far bank: % waterbodies
SEMI_N	Land cover 0-5m far bank: % seminatural

Appendix 8 (continued). Environmental attributes

Appendix 8b. Canal environmental attributes

Code	*Attribute description*
URBAN	Land cover 0-5m far bank: % urban
INT_AG	Land cover 0-5m far bank: % intensive agriculture
INT_ALL	Land cover 0-5m far bank: % total intensive
GRASS	Land cover 5-100m sample side: % all grassland
WATER	Land cover 5-100m sample side: % waterbodies
SEMI_N	Land cover 5-100m sample side: % seminatural
URBAN	Land cover 5-100m sample side: % urban
INT_AG	Land cover 5-100m sample side: % intensive agriculture
INT_ALL	Land cover 5-100m sample side: % total intensive
BGRASS	Land cover 0-100m far bank: % all grassland
BWATER	Land cover 0-100m far bank: % waterbodies
BSEMI_N	Land cover 0-100m far bank: % seminatural
BURBAN	Land cover 0-100m far bank: % urban
BINT_AG	Land cover 0-100m far bank: % intensive agriculture
BINT_ALL	Land cover 0-100m far bank: % total intensive
%BOULDER	Substrate at edge: % boulders and cobbles
%PEBBLES	Substrate at edge: % pebbles
%GRAVEL	Substrate at edge: % gravel
%SAND	Substrate at edge: % sand
%SILT	Substrate at edge: % Silt/clay
%COARSE	Substrate at edge:% coarse detritus
%FINE	Substrate at edge: % fine detritus
AV_BOUL	Substrate average: % boulders and cobbles
AV_PEBB	Substrate average: % pebbles
AV_GRAV	Substrate average: % gravel
AV_SAND	Substrate average: % sand
AV_SILT	Substrate average: % Silt/clay
AV_COAR	Substrate average:% coarse detritus
AV_FINE	Substrate average: % fine detritus
B_ANGLE	Angle of bank
DEPTH_ED	Water depth at the canal edge
DEPTH_1	Water depth 1m from the canal edge
DEPTH_2	Water depth 2m from the canal edge
DEPTH_3	Water depth 3m from the canal edge
DEPTH_MX	Maximum water depth
DEPTH_AV	Average water depth 1 m - 3 m from the canal edge
SED_1	Sediment depth 1m from the canal edge
SED_2	Sediment depth 2m from the canal edge

Appendix 8 (continued). Environmental attributes

Appendix 8b. Canal environmental attributes

Code	*Attribute description*
SED_3	Sediment depth 3m from the canal edge
SED_TOT	Average sediment depth 1 m - 3 m from the canal edge
TOTAL_D1	Sediment + water depth 1m from the canal edge
TOTAL_D2	Sediment + water depth 2m from the canal edge
TOTAL_D3	Sediment + water depth 3m from the canal edge
TOT_DAV	Average sediment + water depth 1 m - 3 m from the canal edge
WIDTH	Canal width
FLOW	Average flow (Ml/day)
BOATS	Boat traffic (movements/yr)
EM_SPP	Number of emergent plant species recorded (50m length)
SUB_SPP	Number of submerged plant species (50m length)
FLOA_SPP	Number of floating plant species (50m length)
AQU_SPP	Number of aquatic plant species (50m length)
TOT_SPP	Total number of aquatic plant species (50m length)
CHE_QUAL	Chemical Water Quality class
SED_QUAL	Sediment Quality class
AUNZD_M	Unionised ammonia (mg/l)
AUNZD_R	Unionised ammonia (mg/l)
AMMN_M	Ammoniacal nitrogen (mg/l)
AMMN_R	Ammoniacal nitrogen (mg/l)
BOD_M	Biochemical oxygen demand (mg/l)
BOD_R	Biochemical oxygen demand (mg/l)
DO_MEAN%	Dissolved oxygen (percentage saturation)
DO_MEANC	Dissolved oxygen (mg/l)
POTASSIU	Potassium (mg/l)
CHLORIDE	Chloride (mg/l)
ALKALINI	Alkalinity (mg/l)
SUSSOLID	Suspended solids (mg/l)
TON	Total oxidised nitrogen (mg/l)
TOTALN	Total nitrogen (mg/l)
SRP	Soluble reactive phosphorus (mg/l)
TOTALP	Total phosphorus (mg/l)
AMMONIA	Ammonia (mg/l)
ZN	Zinc (mg/l)
PB	Lead (mg/l)
NI	Nickel (mg/l)
FE	Iron (mg/l)
MG	Magnesium (mg/l)

Appendix 8 (continued). Environmental attributes

Appendix 8b. Canal environmental attributes

Code	*Attribute description*
AL	Aluminium (mg/l)
CA	Calcium (mg/l)
CU	Copper (mg/l)
NA	Sodium (mg/l)
K	Potassium (mg/l)
AIRDRIED	Air dried sediment (mg/l)
LOSSONIG	Sediment loss of weight on ignition (mg/l)
ORGANICM	Organic matter (mg/l)
PH	pH
ANTIMONY	Antimony (mg/kg sediment)
ARSNICMG	Arsnic (mg/kg sediment)
BARIUM	Barium (mg/kg sediment)
BERYLLIU	Beryllium (mg/kg sediment)
BORON	Boron (mg/kg sediment)
AVBORON	Average boron (mg/kg sediment)
CADMIUM	Cadmium (mg/kg sediment)
CHROMIUM	Chromium (mg/kg sediment)
COBALT	Cobalt (mg/kg sediment)
COPPER	Copper (mg/kg sediment)
CYANIDE	Cyanide (mg/kg sediment)
PAH	Polycyclic aromatic hydrocarbons (mg/kg sediment)
TOTALPHO	Total phosphorus (mg/kg sediment)
PHENOL	Phenol (mg/kg sediment)
LEAD	Lead (mg/kg sediment)
MERCURY	Mercury (mg/kg sediment)
MOLYBDEN	Molybdenum (mg/kg sediment)
NICKEL	Nickel (mg/kg sediment)
SELENUIM	Selenuim (mg/kg sediment)
SILVER	Silver (mg/kg sediment)
TIN	Tin (mg/kg sediment)
THALLIUM	Thallium (mg/kg sediment)
TUNGSTEN	Tungsten (mg/kg sediment)
VANADIUM	Vanadium (mg/kg sediment)
ZINC	Zinc (mg/kg sediment)
DR	Water Quality Class

Appendix 9. The proportion of minimally impaired reference sites predicted to the correct TWINSPAN endgroup using MDA

Appendix Table 9.1. Pond macroinvertebrates: comparison of the prediction of a five-group site classification of reference sites using different combinations of variables

Number of physical variables used	**14**	**11**	**9**	**7**	**6**	**5**
Easting	+	+	+	+	+	+
Altitude	+	+	+			
Catchment geology: sandstone (%)	+	+	+	+	+	+
Catchment geology: clay (%)	+	+				
Catchment geology: limestone (%)	+	+	+	+		
Pond base rock (%)	+					
Pond sediment: clay and silt (%)	+	+	+	+	+	+
Water source: surface water (%)	+	+	+	+	+	+
Water source: spring and flush (%)	+					
Pond water depth	+	+	+			
Pond area	+	+	+	+	+	
Surrounding land cover: ponds&lakes (%)	+	+				
Inflow volume (ranked)	+	+	+	+	+	+
Vegetation cover: Submerged plants (%)	+					
Percent of sites asigned to the correct classification group	**88**	**81**	**78**	**72**	**69**	**66**

Appendix Table 9.2. Pond macrophytes: comparison of the prediction of a five-group site classification of reference sites using different combinations of variables

Number of physical variables used	**14**	**12**	**10**	**8**	**6**	**5**
Easting	+	+	+	+	+	+
Altitude	+	+	+	+	+	+
Catchment geology: sandstone (%)	+	+	+	+	+	+
Catchment geology: limestone (%)	+	+	+	+	+	+
Pond base sand and gravel (%)	+	+	+	+	+	
Pond base peat (%)	+	+	+	+	+	
Water source: groundwater (%)	+	+	+	+	+	+
Pond water depth	+	+	+			
Drawdown: % of water remaining	+	+				
Shade: % pond area overhung	+	+	+			
Shade: % pond bank area overhung	+			+		
Surrounding land cover: deciduous (%)	+	+	+			
Connectivity: floodplain location	+					
Connectivity: traditional wetland location	+	+				
Percent of sites asigned to the correct classification group	**84**	**77**	**73**	**69**	**67**	**63**

Appendix Table 9.3. Canal macroinvertebrates: comparison of the prediction of a four-group site classification of reference sites using different combinations of variables

Number of physical variables used	**9**	**7**	**5**
Northing	+	+	+
Easting	+		
Altitude	+	+	+
Turbidity: secchi depth	+	+	+
Adjacent land cover 0-5m: % grassland	+		
Bank type: earth (%)	+	+	+
Bank angle	+	+	+
Sediment depth	+	+	
Number of submerged plant species	+	+	
Percent of sites asigned to the correct classification group	**100**	**92**	**81**

Appendix 10. Environmental variables used to predict TWINSPAN endgroups for each biotic assembledge in each waterbody data set

Appendix Table 10.1. Pond invertebrate assemblage: environmental variables used to predict TWINSPAN endgroups

EASTING	Easting
ALTITUDE	Altitude
CATCH_SS	Catchment geology: sandstone (%)
CATCH_CL	Catchment geology: clay (%)
CATCH_LS	Catchment geology: limestone (%)
BASE_ROC	Pond base rock (%)
SED_OOZE	Pond sediment: clay and silt (%)
WS_SFWTR	Water source: surface water (%)
WS_FLSP	Water source: spring and flush (%)
W_DEPTH	Pond water depth
AREA	Pond area
PONDS_4	Surrounding land cover: ponds and lakes (%)
INFLW_VOL	Inflow volume (ranked)
PLT_SUB%	Vegetation cover: Submerged plants(%)

Number of variables: 14

Percent of sites asigned to the correct classification group: 88%

Appendix Table 10.2. Pond macrophyte assemblage: environmental variables used to predict TWINSPAN endgroups

EASTING	Easting
ALTITUDE	Altitude
CTM_SS	Catchment geology: sandstone
CMT_LS	Catchment geology: limestone
BASE_SAN	Pond base: sand
BASE_PEA	Pond base: peat
WS_GWTR	Water source: % groundwater
W_DEPTH	Water depth (average)
DDZ%	Drawdown: % water left in pond
SHADE_%	Shade: area (%) of pond overhung
SHADE_BK	Shade: area (%) of pond margin overhung
DECID_4	Surrounding land cover: % deciduous wood within 100m
FL`PLAIN	Floodplain: proximity (ranked)
TRAD_WET	Traditional wetland: association (ranked)

Number of variables: 14

Percent of sites asigned to the correct classification group: 84%

Appendix Table 10.3. Lake and pond invertebrate assemblage: environmental variables used to predict TWINSPAN endgroups

EASTING	Easting
ALTITUDE	Altitude
CATCH_SS	Catchment geology: sandstone
CATCH_CL	Catchment geology: clay
CATCH_LS	Catchment geology: limestone
BASE_ROC	Pond base: rock
SED_OOZE	Sediment: % clay and silt
WS_SFWTR	Water source: % surface and near surface runoff
WS_FLSP	Water source: % spring and flush
W_DEPTH	Water depth
AREA	Pond area
PONDS_4	Surrounding land cover: % ponds and lakes 100m
ALL_GR_4	Surrounding land cover: % total grassland
GRZ_LIV_01	Grazed by livestock
INFLW_05	Inflow volume
PLT_SUB%	Vegetation cover: % submerged plants

Number of variables: 16

Percent of sites asigned to the correct classification group: 83%

Appendix Table 10.4. Lake and pond plant assemblage: environmental variables used to predict TWINSPAN endgroups

EASTING	Easting
ALTITUDE	Altitude
CTM_SST	Catchment geology: sandstone
CMT_LST	Catchment geology: limestone
BASE_SAN	Pond base: sand
BASE_PT	Pond base: peat
WS_GWTR	Water source: % groundwater
WS_SWTR	Water source: % surface and near surfce runoff
AREA	Pond area
SHADE_%	Shade: area (%) of pond overhung
SHADE_MR	Shade: area (%) of pond margin overhung
DECID100	Surrounding land cover: % deciduous wood within 100m

Number of variables: 12

Percent of sites asigned to the correct classification group: 84%

Appendix Table 10.5. Canal invertebrate assemblage: environmental variables used to predict TWINSPAN endgroups

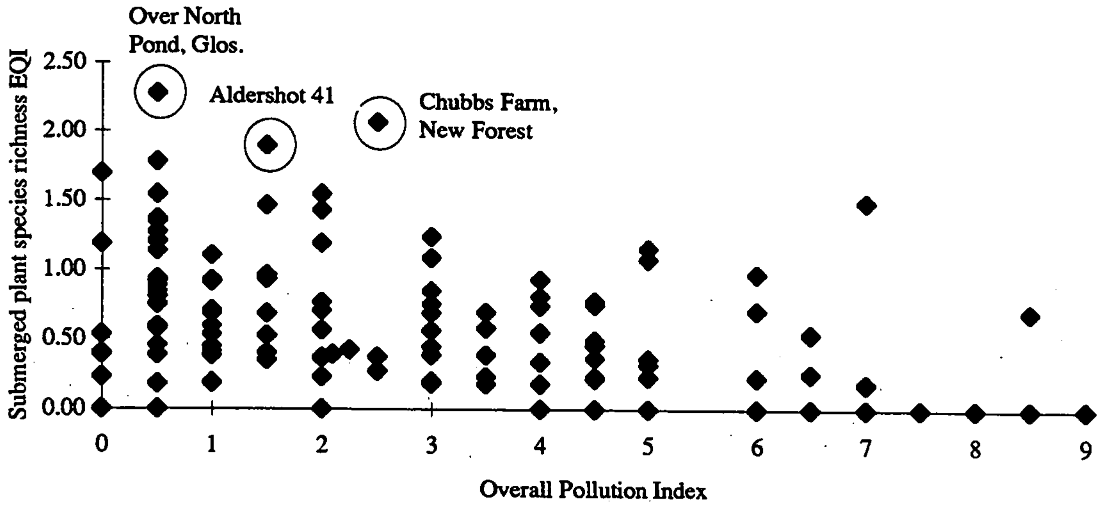
EASTING	Northing
NORTHING	Easting
ALTITUDE	Altitude
SECCHI	Turbidity: secchi depth
EARTH	Adjacent land cover 0-5m: % grassland
GRASS	Bank type: earth (%)
B_ANGLE	Bank angle
SED_TOT	Sediment depth
SUB_SPP	Number of submerged plant species

Number of variables: 9

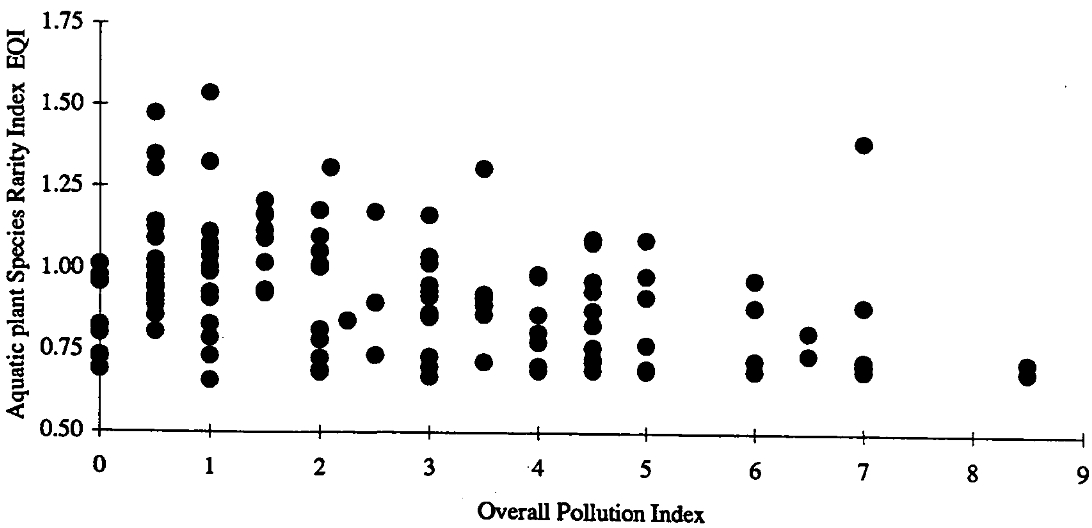
Percent of sites asigned to the correct classification group: 100%

Appendix 11. Relationships between plant and invertebrate metrics and environmental degradation.

Pond metrics

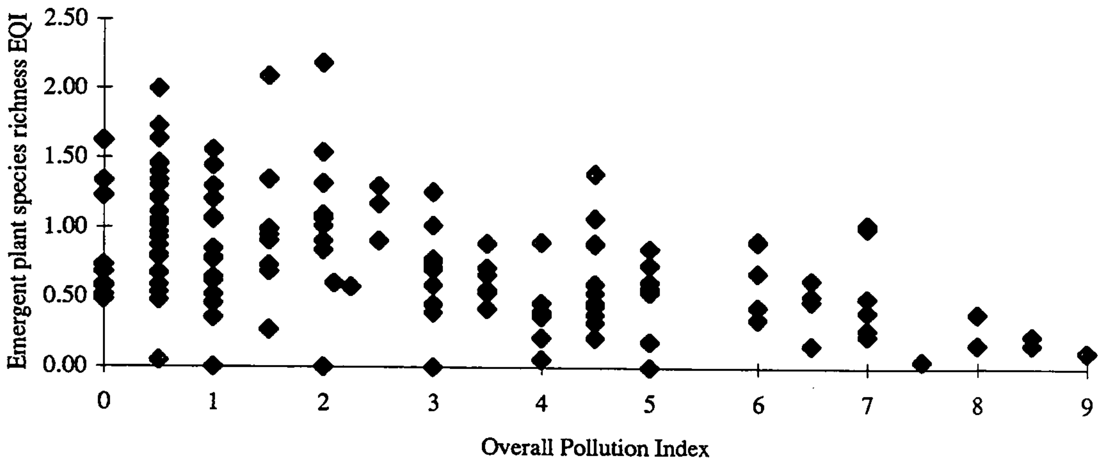


Appendix Figure 11.1. The relationship between pond Submerged Plant Species Richness EQI and exposure to point and diffuse source pollutants (measured as Overall Pollution Index). r_s = -0.42, p = 0.0001.

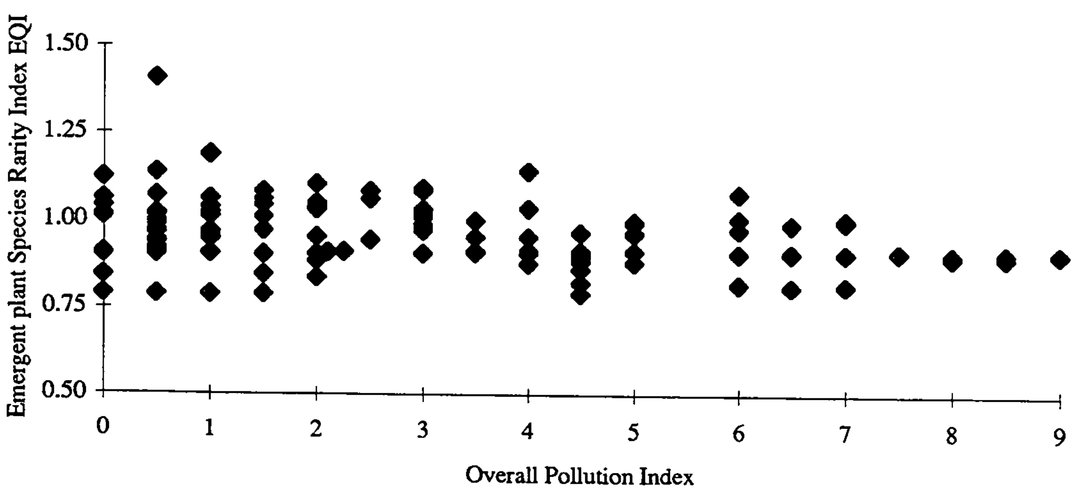


Appendix Figure 11.2. The relationship between pond aquatic plant Species Rarity Index EQI and exposure to point and diffuse source pollutants (measured as Overall Pollution Index). r_s = -0.38, p = 0.0001.

Appendix 11 (continued). Relationships between plant and invertebrate metrics and environmental degradation.

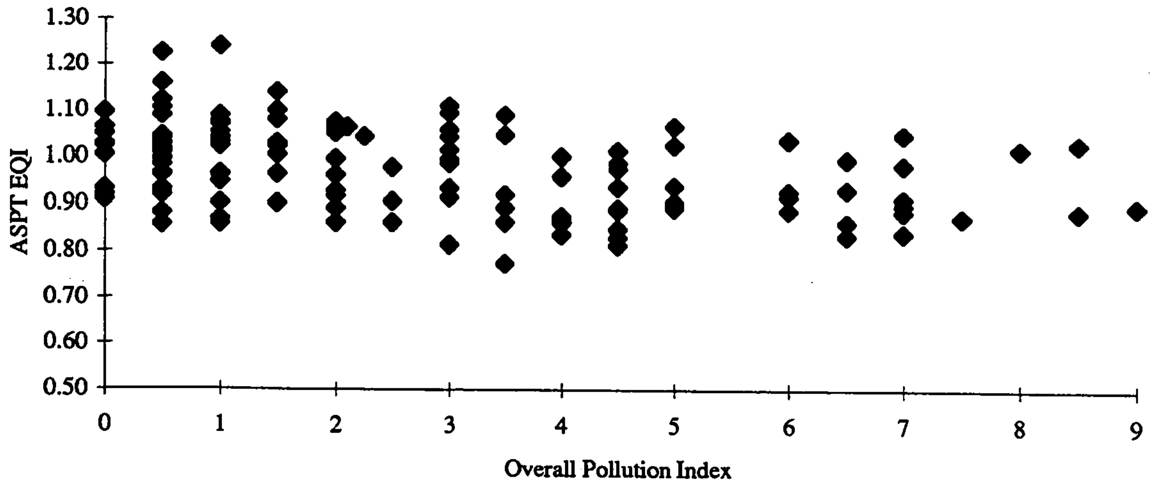


Appendix Figure 11.3. The relationship between pond emergent plant species richness EQI and exposure to point and diffuse source pollutants (measured as Overall Pollution Index). $r_s = -0.46$, $p = 0.0001$.

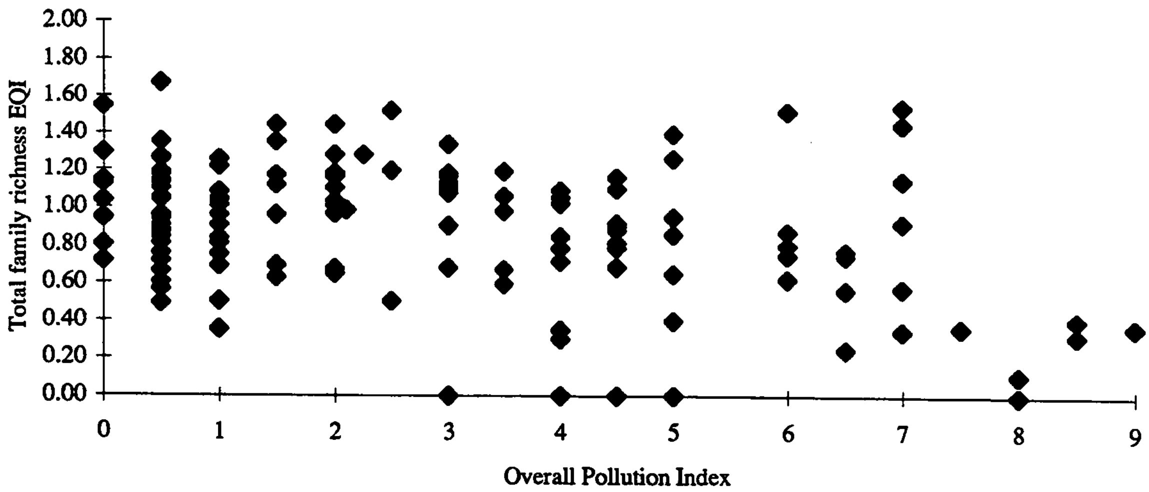


Appendix Figure 11.4. The relationship between pond emergent plant species richness EQI and exposure to point and diffuse source pollutants (measured as Overall Pollution Index). $r_s = -0.28$, $p = 0.0009$.

Appendix 11 (continued). Relationships between plant and invertebrate metrics and environmental degradation.

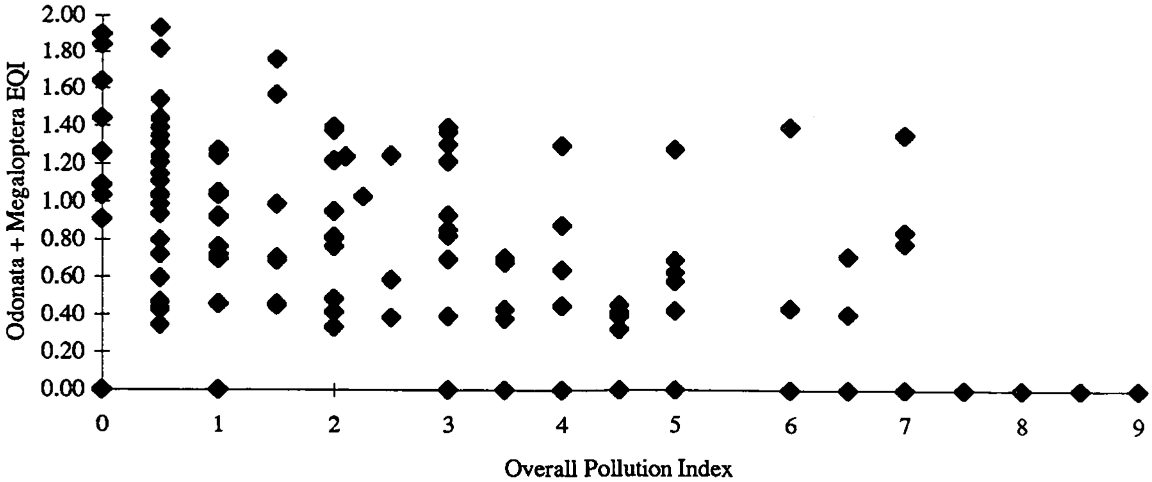


Appendix Figure 11.5. The relationship between pond ASPT EQI and exposure to point and diffuse source pollutants (measured as Overall Pollution Index). $r_s = -0.43$, p = 0.0001.



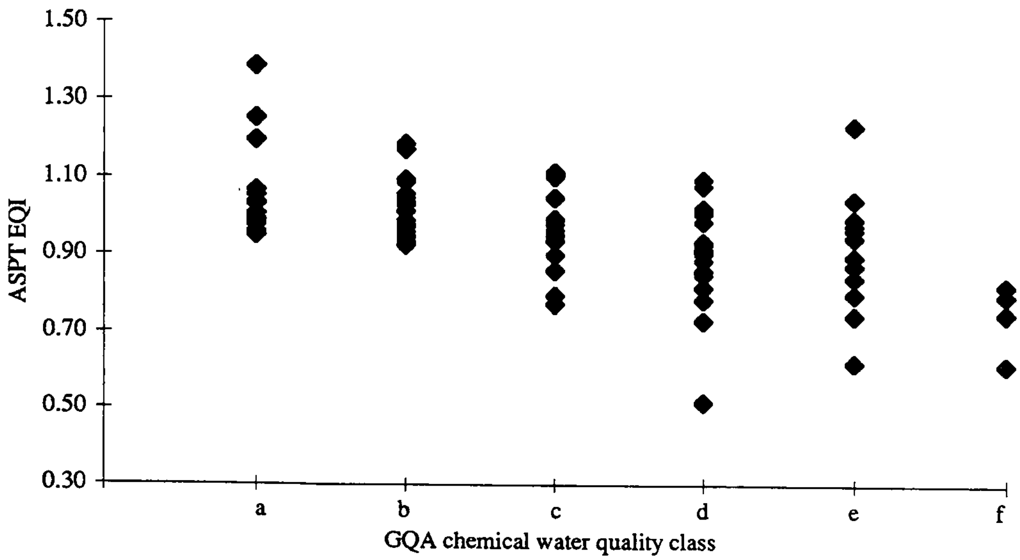
Appendix Figure 11.6. The relationship between pond total invertebrate family richness EQI and exposure to point and diffuse source pollutants (measured as Overall Pollution Index). $r_s = -0.30$, p = 0.0004.

Appendix 11 (continued). Relationships between plant and invertebrate metrics and environmental degradation.



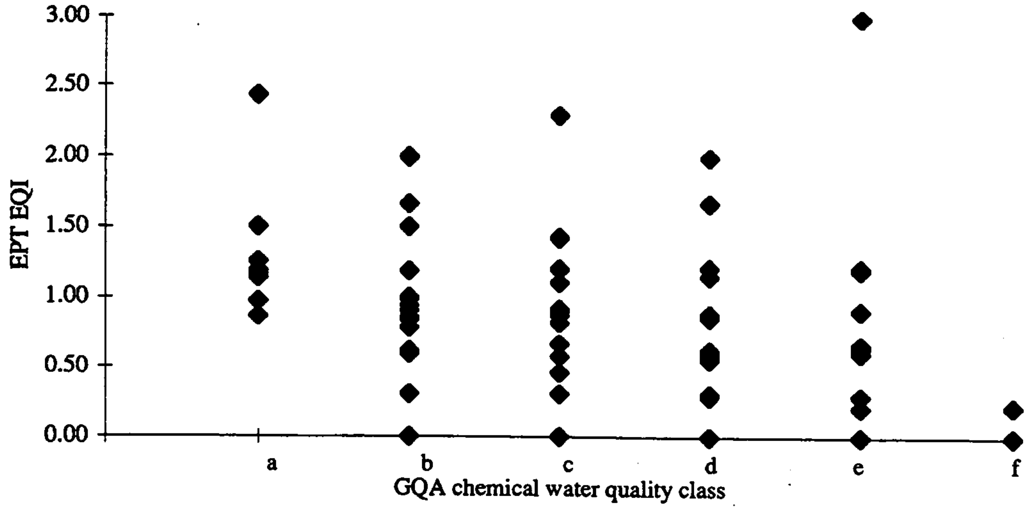
Appendix Figure 11.7. The relationship between pond Odonata + Megaloptera (OM) family richness EQI and exposure to point and diffuse source pollutants (measured as Overall Pollution Index). $r_s = -0.55$, $p = 0.0001$.

Canal metrics

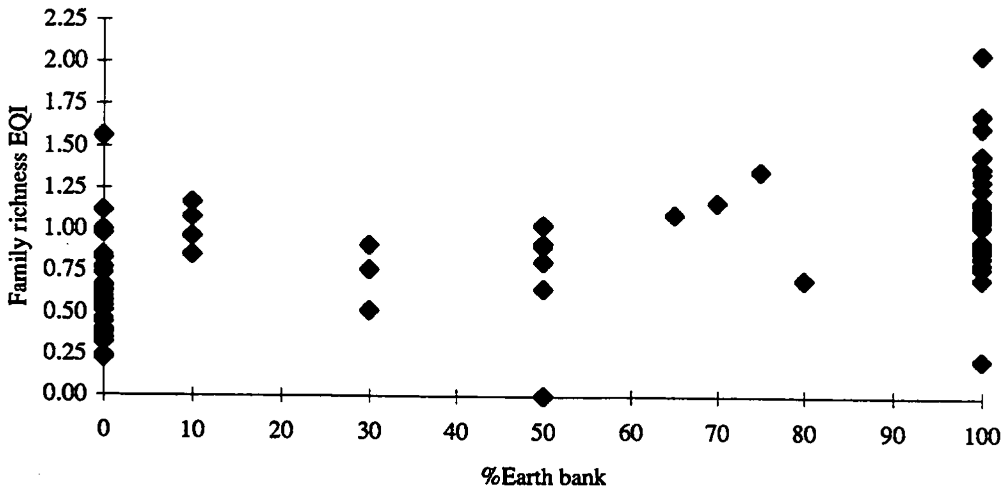


Appendix Figure 11.8. The relationship between canal ASPT EQI and water quality impairment (measured as GQA chemical class). $r_s = -0.50$, $p = 0.0001$.

Appendix 11 (continued). Relationships between plant and invertebrate metrics and environmental degradation.

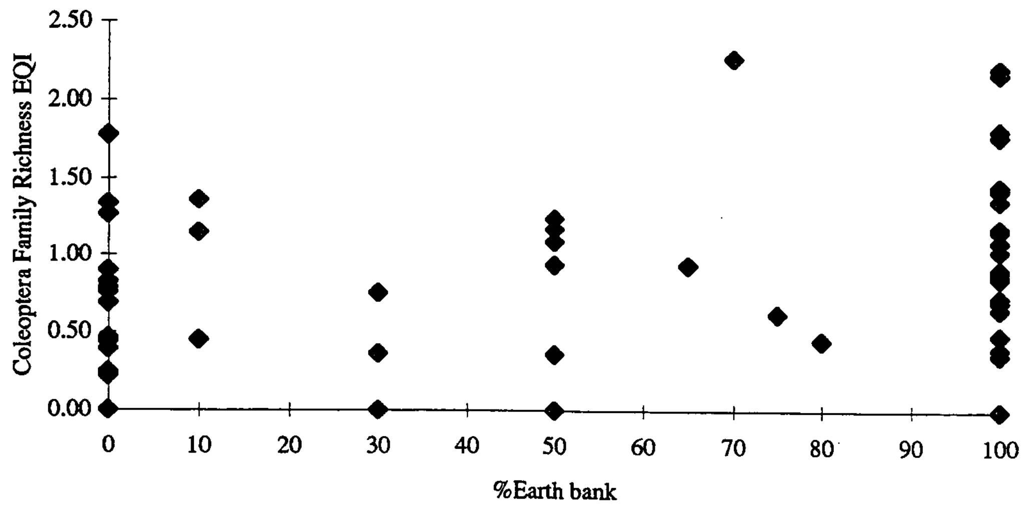


Appendix Figure 11.9. The relationship between canal EPT (Ephemeroptera + Plecoptera + Trichoptera) EQI and water quality impairment (measured as GQA chemical class). $r_s = -0.48$, $p = 0.0001$.



Appendix Figure 11.10. The relationship between canal total invertebrate family richness EQI and bank structure impairment (measured as % earth bank). $r_s = -0.66$, $p = 0.0001$.

Appendix 11 (continued). Relationships between plant and invertebrate metrics and environmental degradation.



Appendix Figure 11.11. The relationship between canal Coleoptera family richness EQI and bank structure impairment (measured as % earth bank). $r_s = -0.57$, $p = 0.0001$.

Appendix 12. Diatom field sampling protocols

The following diatom sampling protocols were developed during a one-day workshop held at University College London, organised by the Environment Agency, in April 1997 and during a pond field sampling day in Oxford in August 1997.

Pond protocol

(i) Aim

To collect representative diatom samples from all appropriate pond microhabitats (see Table A7). For each microhabitat approximately 10 sub-samples should be taken from around the pond. These are combined together in a single microhabitat sample. Ponds typically have between 3 and 8 microhabitats.

(ii) Timing

Sampling should be undertaken in summer or autumn (up to November). Spring is not ideal because of the presence of atypical species which alter abundance ratios for diatom assemblages.

(iii) Field methods

If possible, habitats should be chosen from sunlit places which will have more species and the greatest abundance of diatoms. Filamentous algae should be avoided, or if necessary, more Lugol's solution added to preserve the sample if filamentous algae is abundant. (Refer to Table A7 overleaf for detailed methodologies for each microhabitat).

Once samples have been collected and preserved from each microhabitat they should be placed in a large labelled plastic bag. All samples should be kept dark and stored in a cold room.

Canal protocol

(i) Aim

Canals are a relatively uniform habitat type in comparison with other waterbody types with regular occurrence of locks and mooring places. Hard surfaces are always available as diatom sampling substrate. Diatom sampling in canals can therefore use samples collected from a single habitat substrate / hard bank surfaces.

(iii) Field methods

Approximately 10 sub-samples should be collected from along a 5m length of stone canal bank and combined together into a single microhabitat sample. Wooden structures (e.g. lock gates) should be avoided because they have anomalous communities with high saprobic tolerance.

Equipment list

(i) General

Lugol's solution
plastic zip-close bags of different sizes
small plastic tray
toothbrush
cool box
wash bottle

(ii) Epipelon

perspex tube
pert dishes with lids
lens tissue (Whatman 105)
pasteur disposable pipettes (150mm)
30 ml and 60 ml sterilin tubes

Appendix Table 12.1. Mesohabitat field sampling methodology for diatoms

Mesohabitat	Diatom sampling methodology
Epiphyton	Diatoms should be present on permanently submerged stems and leaves of tall emergents. Older plants (including brown or decaying plants) should be sampled as they are more likely to have well developed communities. New growth should be avoided. **Submerged macrophytes** Take submerged portions of plants a few centimetres in length from various parts of the pond (approximately 10 samples). Place in a labelled zip-end plastic bag. Add a pipette full of Lugol's solution, seal bag and mix solution. **Floating plants** Floating plants, including *Lemna*, can be sampled for diatoms. Sample and preserve as above. **Tall emergents** Diatoms can be collected by brushing the plant surface with a toothbrush and collecting the material in a small plastic tray. The material should look slightly brown if diatoms are present. The sample should be transferred to a sterilin tube and 4 drops of Lugol's added.
Roots	Roots can be sampled for diatoms as long as they are growing within the water column (e.g. willow roots) and are not from the sediment. Sample and preserve as above.
Fallen leaves	Approximately 10 submerged leaves (not fresh) should be placed in a labelled zip-end plastic bag and preserved as above.
Epilithon	Rock surfaces can be sampled for diatoms by brushing with a toothbrush and preserving with a few drops of Lugol's solution. Particular attention should be paid to cracks where diatoms may be abundant (the collection of mineral matter should be avoided).
Epipsammon	Sand or gravel can be sampled for diatoms by placing in a sterilin tube and adding half a pipette full of Lugol's solution.
Epipelon	Mud from beneath the drawdown zone can be sampled for diatoms. Place thumb over the top of a 1.5m length perspex tube. Put tube into water at sediment surface. Gently ease pressure of thumb and draw tube across the sediment surface. Mud is drawn up into the sediment tube. Collect 10 sediment samples from different areas of the pond and add to a 60 ml sterilin tube. Do not add Lugol's solution. Leave to settle for 15 minutes and then pour away water. Make sure there is enough sediment to half fill a 30 ml sterilin tube. Keep samples dark and cool and return them to the laboratory for processing in the evening using the method described in Eaton & Moss (1966) as follows. (i) shake sediment tube and pour out into a petri dish. Leave for a couple of hours for the sediment to settle (ii) remove excess water using a pipette or vacuum pump. Place a square of lens tissue (double layer) over sediment, add petri lid and label sample. (iii) leave on windowsill overnight for diatoms to move up into the lens tissue. At 8.00 to 9.00 am remove lens tissue (plus diatoms) and place in a labelled sterilin tube. (iii) add Lugol's solution, put on lid and shake a little to distribute the solution (Eaton and Moss, 1966).

Appendix 13. Widespread naturalised aquatic macrophytes, fish and amphibians in the British Isles

Fish

Species	*Distribution*
Carp	Found in most parts of the southern half of the British Isles; localised in Scotland
Bitterling	Introduced in Lancashire and Cheshire, spreading via canal system; R. Cam (Cambridgeshire)
Orfe	Scattered sites
Crucian Carp	Quite common and widespread in south-east England; patchy in the north and west; rare in Scotland
Goldfish	Common in England
Danube catfish	Expanding from south-east Midlands
Zander	Expanding in eastern England; reported from R. Severn system.

Six North American fish, Rainbow Trout, Brook Charr, Largemouth Bass, Pumpkinseed and Rock Bass, have become established at very small numbers of sites.

Aquatic plants

Species	*English name*
Elodea canadensis	Canadian Pondweed
Elodea nuttallii	Nuttall's Waterweed
Azolla filiculoides	Water Fern
Lemna minuta	Least Duckweed
Lagarosiphon major	Curly Waterweed
Crassula helmsii	Australian Swamp Stone-crop
Myriophyllum aquaticum	Parrot's Feather
Hydrocotyle ranunculoides	Floating Pennywort

Examples of widely planted native species (introduction of several other common aquatic plants probably go mostly un-noticed).

Nymphoides peltata	Fringed Water-lily
Stratiotes aloides	Water Soldier

Amphibians

Edible Frog	*Rana esculenta*
Marsh Frog	*Rana ridibunda*

In addition, populations of Tree Frog (*Hyla arborea*), Alpine Newt (*Triturus alpestris*), African Clawed Toad (*Xenopus laevis*), Fire-bellied Toad (*Bombina bombina*) and Yellow-bellied Toad (*Bombina variegata*) have persisted at various times in Britain.

Sources: Maitland and Campbell (1992); Arnold (1995); Preston and Croft (1997).

Appendix 14a. Biodiversity Action Plan (BAP) species and habitats occurring in England and Wales

BAP habitats

Still or running waters	Habitat type	Distribution	Lead Partner
Still waters	Mesotrophic lakes	British Isles	SEPA
	Saline lagoons	British Isles	English Nature
Running waters	Chalk rivers	England	E. Agency

BAP species

1. Mainly or exclusively still water species (emboldening shows species for which Environment Agency is Lead Partner)

Species	Habitat	Distribution	Lead Partner
Great Crested Newt (*Triturus cristatus*)	Ponds	England, Wales, Scotland	B.Herp.Soc./Frog life/HCT
Natterjack Toad (*Bufo calamita*)	Temporary ponds	England	HCT
Vendace (*Coregonus albula*)	Lakes	Bassenthwaite Lake, Derwentwater	Environment Agency
Whirlpool Ramshorn (*Anisus vorticulus*)	Marsh drains, ponds	England	Environment Agency
Shining Ramshorn (*Segmentina nitida*)	Ditches in grazing marshes, ponds	England	Environment Agency
Glutinous Snail (*Myxas glutinosa*)	Lakes, ponds, rivers, ditches.	England	Environment Agency
Medicinal leech (*Hirudo medicinalis*)	Ponds, lakes	England, Wales, Scotland	Wildlife Trusts
Ribbon-leaved water-plantain (*Alisma graminuem*)	Lakes, ponds, ditches	2 sites in England	Environment Agency/EN
Starfruit (*Damasonium alisma*)	Ponds	About 12 sites in England	Plantlife
Floating water-plantain (*Luronium natans*)	Lakes and canals	England, Wales	British Waterways
Holly-leaved Naiad (*Najas marina*)	Lakes	Norfolk Broads	Broads Authority/ Wildlife Trusts
Three-lobed crowfoot (*Ranunculus tripartitus*)	Ponds, ditches, seasonal pools	England	Plantlife

(cont.)

Appendix 14a (continued) List of the BAP species and habitats occurring in England and Wales

2. BAP species associated with still waters and running waters

Species	Habitat	Distribution	Lead Partner
Water Vole (*Arvicola terrestris*)	Rivers, lakes, ponds, ditches	British Isles	UK Water Vole Steering Group
Otter (*Lutra lutra*)	Rivers, lakes, ponds, ditches	British Isles	Wildlife Trusts/ E.Agency
Atlantic Stream Crayfish (*Austropotamobius pallipes*)	Rivers, lakes, ponds	British Isles	Game Conservancy
Fine-lined Pea Mussel (*Pisidium tenuilineatum*)	Rivers, canals, ponds	England, Wales	Environment Agency
Depressed River Mussel (*Pseudanodonta complanata*)	Rivers, drains	England, Wales	Environment Agency

3. BAP species exclusively associated with running water

Species	Habitat	Distribution	Lead Partner
Allis Shad (*Alosa alosa*)	Estuaries	British Isles	MAFF/Environm ent Agency
Twaite Shad (*Alosa fallax*)	Estuaries	British Isles	MAFF/Environm ent Agency
Southern Damselfly (*Coenagrion mercuriale*)	Streams and runnels in fens and heaths	England, Wales	Wildlife Trusts
Freshwater Pearl Mussel (*Margaritifera margaritifera*)	Rivers	British Isles	SNH/Environmen t Agency
River Jelly Lichen (*Collema dichotomum*)	Rivers	British Isles	Environment Agency

Note: Appendix13 omits BAP species which are generally regarded as wetland species (e.g. Fen Orchid, *Liparis loeselii*, Creeping Marshwort, *Apium repens*, Black Bog Ant *Formica candida*, Bittern, *Botaurus stellaria*)

Appendix 14b. Criteria adopted by Mesotrophic Lakes Action Plan Steering Group for determining whether lakes are mesotrophic

Waterbodies which fulfil any one of the following criteria will be included on the initial scoping list for the mesotrophic lakes inventory.

1. The mean annual total phosphorus concentration is 10-35 $\mu g\, l^{-1}$.
2. The macrophyte community is classified as Type 5a or 5b Palmer's (1988) classification scheme (or the equivalent communities in the Northern Ireland lake classification scheme (Gibson *et al.*, 1995)
3. The average macrophyte Trophic Ranking Score for the whole site is between 5 &9.
4. Hindcasting studies suggest the waterbody was formerly mesotrophic.
5. The lake is described as mesotrophic in an SSSI (GB) or ASSI (NI) designation.
6. The lake has annual mean chlorophyll concentrations of 2.5 - 8 $\mu g\, l^{-1}$.
7. Inventories should initially seek to include all waterbodies for which any claim to mesotrophic status can be made, including lakes where part of the site may be mesotrophic
8. Lakes which were formerly oligotrophic but are now mesotrophic should initially be included in the inventory, although such sites will not be the subject of action under the MLAP.
9. Lakes which were formerly mesotrophic but are now eutrophic will be included in the inventory but should not be prioritised for action unless there is evidence that their mesotrophic fauna or flora can be restored (Ian Fozzard, *pers. comm.*).

Note: the group did not specify at what point in its history the lake should be regarded as mesotrophic but presumably the criteria adopted by Moss *et al.* (1994) in the Environment Agency Lakes Classification and Monitoring programme (i.e. around 1930) would be considered appropriate.

Appendix 15. Matrix analysis of diagnostic methods for biological assessment of still waters

Appendix 15a. Matrix Analysis: Diagnostic methods for Overall Biological Quality (OBQ).

Criteria	Biological Monitoring									Historical		Physical	Modelling
	phyto-plankton	peri-phyton	macro-phyte	micro-invert	macro-invert	fish	amph-ibians	birds	mam-mals	paleo-biology	bio-logy	GIS	biological
Degree to which method developed													
Scientific underpinning of the method	2	2	1	1	3	2	1	1	1	1	1	1	1
Practical application of the method	0	1	1	1	3	3	0	1	0	2	0	1	1
Method independent of temporal or spatial variability	0	0	1	1	2	2	1	1	1	2	1	3	3
Data exists to develop a metric for still waters *	0	0	1	0	1	1	0	0	0				
SCORE (% of maximum)	**20**	**30**	**40**	**30**	**90**	**80**	**20**	**30**	**20**	**56**	**22**	**56**	**56**
Application in Europe and the UK													
The method is applied throughout Europe	1	0	1	2	2	1	0	0	0	0	0	2	0
There is a UK specific method	0	0	1	0	1	0	0	0	0	0	0	0	1
SUM	**1**	**0**	**2**	**2**	**3**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**1**

*applies to Biological Monitoring methods only

Appendix 15b. Matrix Analysis: Diagnostic methods for organic pollution.

Criteria	Biological Monitoring					Biomarkers		Modelling
	phyto-plankton	peri-phyton	macro-phtye	microinvert	macroinvert	macroinvert	fish	biological
Degree to which method developed								
Scientific underpinning of the method	1	3	2	3	3	1	1	1
Practical application of the method	0	2	0	1	2	1	0	0
Method independent of temporal or spatial variability	0	0	1	1	2	3	3	3
Data exists to develop a metric for still waters *	0	0	1	0	1			
SCORE (% of maximum)	**10**	**50**	**40**	**50**	**80**	**56**	**44**	**44**
Application in Europe and the UK								
The method is applied throughout Europe	1	2	0	0	2	0	0	0
There is a UK specific method	0	0	0	0	1	0	0	1
SUM	**1**	**2**	**0**	**0**	**3**	**0**	**0**	**1**

*applies to Biological Monitoring methods only

Appendix 15c. Matrix Analysis: Diagnostic methods for acidification.

Criteria	Biological Monitoring				Biomarkers		Historical	Physical	Modelling
	peri-phyton	micro-invert	macro-invert	amphibians	macro-invert	fish	paleo-limnology	hydrology	biological
Degree to which method developed									
Scientific underpinning of the method	1	1	2	2	1	1	3	1	1
Practical application of the method	0	1	3	1	0	0	3	1	2
Method independent of temporal or spatial variability	0	1	2	1	2	2	2	2	3
Data exists to develop a metric for still waters *	0	0	1	0					
SCORE (% or maximum)	**10**	**30**	**80**	**40**	**33**	**33**	**89**	**67**	**67**
Application in Europe and the UK									
The method is applied throughout Europe	1	0	1	0	0	1	3	0	0
There is a UK specific method	0	0	0	1	0	0	1	0	1
SUM	**1**	**0**	**1**	**1**	**0**	**1**	**4**	**0**	**1**

*applies to Biological Monitoring methods only

Appendix 15d. Matrix Analysis: Diagnostic methods for eutrophication.

Criteria	Biological Monitoring				Historical	Physical	Modelling
	phyto-plankton	peri-phyton	macro-phyte	macro-invert	paleolimnology	GIS	biological
Degree to which method developed							
Scientific underpinning of the method	3	2	2	2	3	1	1
Practical application of the method	2	1	2	1	3	1	1
Method independent of temporal or spatial variability	1	1	1	2	2	3	3
Data exists to develop a metric for still waters *	0	0	1	1			
SCORE (% of maximum)	**60**	**40**	**60**	**60**	**89**	**56**	**56**
Application in Europe and the UK							
The method is applied throughout Europe	1	1	2	1	3	1	1
There is a UK specific method	0	1	1	0	1	0	1
SUM	**1**	**2**	**3**	**1**	**4**	**1**	**2**

*applies to Biological Monitoring methods only

Appendix 15e. Matrix Analysis: Diagnostic methods for metals.

Criteria	Toxicity micro-invert	Toxicity macro-invert	Biomarkers cell	Biomarkers macro-invert	Biomarkers fish	Bioaccumulation peri-phyton	Bioaccumulation macro-phyte	Bioaccumulation macro-invert
Degree to which method developed								
Scientific underpinning of the method	1	2	1	2	1	1	2	2
Practical application of the method	1	3	0	0	0	1	1	2
Method independent of temporal or spatial variability	3	3	3	3	3	1	2	1
SCORE (% of maximum)	**56**	**89**	**44**	**56**	**44**	**33**	**56**	**56**
Application in Europe and the UK								
The method is applied throughout Europe	0	0	1	0	1	0	1	1
There is a UK specific method	0	1	0	0	0	0	0	0
SUM	**0**	**1**	**1**	**0**	**1**	**0**	**1**	**1**

Appendix15f. Matrix Analysis: Diagnostic methods for organic contaminants (OCs).

Criteria	Biomarkers cell	Biomarkers macro-invert	Biomarkers birds	Bioaccumulation birds	Historical paleolimnology
Degree to which method developed					
Scientific underpinning of the method	1	1	1	1	1
Practical application of the method	0	1	1	0	1
Method independent of temporal or spatial variability	3	3	2	1	2
SCORE (% of maximum)	**44**	**56**	**44**	**22**	**44**
Application in Europe and the UK					
The method is applied throughout Europe	1	1	0	0	0
There is a UK specific method	0	0	0	0	1
SUM	**1**	**1**	**0**	**0**	**1**

Appendix 15g. Matrix Analysis: Diagnostic methods for mixed contaminants.

	Biological Monitoring	Toxicity					Biomarkers					Physical
Critera	macro-invert	phyto-plankton	macro-phyte	micro-invert	macro-invert	fish	phyto-plankton	macro-phyte	micro-invert	macro-invert	fish	hydrology
Degree to which method developed												
Scientific underpinning of the method	1	1	2	3	2	3	1	1	1	1	1	0
Practical application of the method	2	2	3	3	3	3	0	0	2	2	2	2
Method independent of temporal or spatial variability	2	2	2	2	2	2	1	2	2	2	2	2
Data exists to develop a metric for still waters *	1											
SCORE (% of maximum)	**60**	**56**	**78**	**89**	**78**	**89**	**22**	**33**	**56**	**56**	**56**	**44**
Application in Europe and the UK												
The method is applied throughout Europe	1	0	1	3	1	0	0	0	0	0	0	0
There is a UK specific method	0	0	0	1	0	0	0	0	1	0	0	1
SUM	**1**	**0**	**1**	**4**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**1**

*applies to Biological Monitoring methods only

Appendix 15h. Matrix Analysis: Diagnostic methods for effluent discharge.

	Toxicity				Biomarkers
Criteria	phyto-plankton	periphyton	macrophyte	micro-invert	fish
Degree to which method developed					
Scientific underpinning of the method	1	1	1	1	1
Practical application of the method	1	2	2	3	1
Method independent of temporal or spatial variability	3	3	3	3	2
Data exists to develop a metric for still waters *					
SCORE (% of maximum)	**56**	**67**	**67**	**78**	**44**
Application in Europe and the UK					
The method is applied throughout Europe	1	0	1	1	0
There is a UK specific method	0	0	0	0	1
SUM	**1**	**0**	**1**	**1**	**1**

Appendix 16. Summary of diagnostic methods for assessing pollution in freshwaters.

OBQ = overall biological quality, BM = biological monitoring, CCA = canonical correspondence analysis, IBI = index of biotic integrity, H = historical, P = physical, M = Modelling, fw = freshwater, OCs = organic contaminants, GIS = geographical information system, WQ = water quality.

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
Organic	Biomarker: fish	Pectoral fanning of bluegill (*Lepomis macrochirus*) (laboratory study).	Lakes	??	Fisher *et al.*1983
Organic	Biomarker: macroinvertebrate	Valve movement response in zebra mussel (*Dreissena polymorpha*)	Lakes	Netherlands	Kramer *et al.*1990
Organic	Biological survey: macroinvertebrates	Assessed 5 methods including Specific Pollution sensitivity Index (SPI) and Generic Diatom Index (GDI).	Rivers	UK	Kelly *et al.*1995
Organic	Biological survey: macroinvertebrates	Average Biological Monitoring Water Quality (a-BMWQ) score and total BMWQ (t-BMWQ)	Rivers	Iberian Pennisula	Camargo 1993
Organic	Biological survey: macroinvertebrates	Chironomid community index used to assess impact of effluents from wine and cheese industries.	Rivers	Italy	Ferrarese and Bertocco 1990
Organic	Biological survey: macroinvertebrates	Diversity, biotic and similarity parameters used to assess inputs from a trout farm	Streams	Spain	Camargo 1994
Organic	Biological survey: macroinvertebrates	Index of Lake Quality (IMOL) using presence/absence data and generic criteria	Lakes	France	Mouthon 1993
Organic	Biological survey: macroinvertebrates	Modification of Chessman's SIGNAL-95 biotic indices	Rivers	New South Wales	Chessman *et al.*1997
Organic	Biological survey: macroinvertebrates	Oligocheata as indicator organisms	Rivers	Yugoslavia	Djukic *et al.*1996
Organic	Biological survey: macroinvertebrates	Rapid bioassessment - comparison of the UK and US approach	Rivers	Australia	Resh *et al.*1995
Organic	Biological survey: macroinvertebrates	Scale of sensitivity of mussels to organic pollution	Rivers	France	Mouthon 1996
Organic	Biological survey: macroinvertebrates	Temporal and spatial variability in standard biotic index values; computation of additional biotic metrics from same data is possible	Streams	USA	Lillie and Schlesser 1994
Organic	Biological survey: macroinvertebrates, microinvertebrates	Integrated assessment using chemical, physical, biological data: Belgian Biotic Index and Sladecek Index	Rivers	Belgium	Marneffe *et al.*1996
Organic	Biological survey: macroinvertebrates, P	Tropho-saprobic status of 7 lakes attributed to lake mean depth and outside biogenic load	Lakes	Russia	Oksiyuk *et al.*1997
Organic	Biological assemblage: macrophyte	Stress index approach: chlorophyll to phaeophytin ratio as an index of physiological stress in bryophytes, regressed using canonical correspondence analysis.	Rivers	Spain	Lopez *et al.*1997
Organic	Biological assemblage: macrophyte	Macrophyte indices for water quality	Streams	France	Haury *et al.*1996
Organic	Biological assemblage: microbiology	Ciliated protozoa abundance used as part of a saprobic evaluation	Rivers	Italy	Madoni 1993
Organic	Biological assemblage: microbiology	Use of epizoic ciliates (Protista) of *Gammarus* as bioindicators	Rivers	Germany	Rustige and Mannesmann 1993
Organic	Biological assemblage: microinvert	Microbiological indicators: Kohl catagorization, phophatase activity index (PAI), T bacteria to heterotroph ratio (T/H index), oligotrophs to heterotroph ratio (O/H	Rivers	Yugoslovia	Petrovic *et al.*1996

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
		index)			
Organic	Biological assemblage: microinvert	Presence, frequency and abundance of epizoic ciliate species of *Gammarus pulex*	Rivers	Germany	Mannesmann and Rustige 1994
Organic	Biological assemblage (phytoplankton, macrophyte, microinvertebrate, macroinvertebrate	Sladecek's Indicator List and ecological scope (species occurrence x total number of individuals)	Rivers	Latvia	Cimdins 1995; Cimdins *et al.*1995
Organic	Biological assemblage: periphyton	Review of 6 diatom indices - all assess organic pollution, only Specific Pollution Specificity Index (SPI), Generic Diatom Index (DI) and the Commission of Economical Community Index (CEC) showed correlation with ionic strength and eutrophication	Rivers, canals	France	Prygiel and Coste 1993
Organic	Biological assemblage: periphyton	Ostracods	Rivers	France	Milhau *et al.*1997
Organic	Biological assemblage: periphyton	Periphyton community dynamics from glass-slide colonies	Rivers	Germans	Steege *et al.*1996
Organic	Biological assemblage: periphyton	Practical Diatom Index	Canals, Rivers, Lakes	France	Prygiel *et al.*1996
Organic	Biological assemblage: periphyton	Saprobic index	Rivers	Romania	Rasiga *et al.*1994
Organic	BM- macroinvert	Abundance and biomass, saprobic used to assess inputs from a trout farm	Streams	Czech Republic	Adamek and Sukop 1996
Organic	M - biology	Modelled macroinvert community changes along a pollution gradient - based on Chandler-ASPT	Rivers	UK	Cao *et al.*1997
Acidification	Biomarker: fish	11 paired meristic and morphometric characteristics in field-collected perch scored for fluctuating assymetry. This is proposed as an indicator of environmental stress in an acidic lake	Lakes	Norway	Oxnevad *et al.*1995
Acidification	Biomarker: macroinvertebrate	Ionoregulatory responses in transplanted fw floater mussel, Anodonta grandis grandis - field study	Lakes	Canada	Malley *et al.*1988
Acidification	Biomarker: macroinvertebrate	Lab bioassay - ionoregulatory and morphological changes in stonefly nymphs, Pteronarcys dorsata, P. proteus, and Tallaperla maria	Rivers	USA	Lechleitner *et al.*1985
Acidification	Biomarker: macroinvertebrate	Lab bioassay - respiratory rates in the dragonfly (Libellula julia) in response to changes in pH and Al concentration	Rivers	USA	Rockwood *et al.*1990
Acidification	Biological assemblage: amphibians	Amphibian (Ambystoma maculatum) embryonic survival should only be used as a measure of acidification with long-term population monitoring of amphibians	Temporary Ponds	USA	Portnoy 1990
Acidification	Biological assemblage: amphibians	Biological indicator - growth and feeding behaviour of smooth and palmate newts (Triturus vulgaris and Triturus helveticus)	Amphibian habitat	UK	Brady and Griffiths 1995
Acidification	Biological assemblage: amphibians	Integrated assessment: 1) chemical analysis 2) census of annual egg-mass deposition, assessment of embryonic mortality 3) sampling of larval success	Temporary Ponds	USA	Freda *et al.*1991
Acidification	Biological survey: macroinvertebrates	Norwegian invertebrate acidification monitoring program based on the acidification index - derived from acid-	Lakes, Rivers	Norway	Fjellheim and Raddum 1990; Fjellheim and Raddum 1992;

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
		sensitive inverts and acidification tolerance limits of inverts			Raddum and Fjellheim 1995
Acidification	Biological survey: macroinvertebrates	Sequential sampling of amphipod abundance - recommends incorporation of amphipod (Hyallela) abundance as a metric for assessing biological integrity of acid-sensitive waters	Lakes	Canada	France 1992
Acidification	Biological assemblage: microinvert	Recommended response variables: 1) crustacean and rotifer community composition plotted in abundance ordination space, 2) crustacean and rotifer species richness, 3) relative abundance of acid tolerant spp. More detailed monitoring would include crustacean biomass, rotifer biomass and/or overall community size spectra	Lakes	Canada	Marmorek and Korman 1993
Acidification	Biological assemblage: periphyton	Use of changes in diatom community structure to assess biotic integrity of rehabilitated artificial wetlands	Fw wetlands	Australia	John 1993
Acidification, metals - Al, Ni	Palaeolimnology	Chrysophyte and diatom-inferred transfer functions to assess changes in lake pH, Ni and Al	Lakes	Canada	Dixit *et al.*1992b; Dixit *et al.*1992a; Dixit *et al.*1993
Acidification	Palaeolimnology	Chrysophyte distribution correlated with changes in pH - CCA clusters groups along a pH gradient as a tool to infer pH changes	Lakes	USA	Dixit *et al.*1990; Smol and Dixit 1990
Acidification	Palaeolimnology	Dating, diatoms, and fly-ash particle analysis used to record timing, rate, and cause of acidification	Lakes	UK	Battarbee 1984; Flower *et al.*1987; Flower *et al.*1988; Battarbee *et al.*1989; Battarbee 1992
Acidification	Palaeolimnology	Diatom analysis, spheroidal carbonaceous particles (SCP) present in sediments as a result of fossil-fuel combustion provide a history of atmospheric pollution	Lakes	UK, Ireland	Flower *et al.*1994; Rose *et al.*1995
Acidification	Palaeolimnology	Diatom-inferred pH reconstruction using CCA	Lakes	UK	Stevenson *et al.*1989
Acidification	Palaeolimnology	Fossil pollen analysis used to reconstruct changes in terrestrial vegetation; changes in diatom and chrysophyte assemblages used to determine water quality	Lakes	Canada	Dixit *et al.*1989; Dixit *et al.*1996a; Dixit *et al.*1996b
Acidification	Palaeolimnology	Historical records determined from diatom, chrysophyte and pigment ratios	Lakes	Italy	Guilizzoni *et al.*1996
Acidification	Palaeolimnology	Mandibles of chaoborus larvae, diatom valves and chyrsophyte scales used to assess fish communities and infer historical changes in pH	Lakes	Canada	Uutala *et al.*1994; Uutala and Smol 1996
Acidification	Palaeolimnology	Paleological Investigation in to Recent Lake Acidification (PIRLA) project: sedimentary chrysophytes, chlorphylls and carotenoids, pollen, plant macrofossils, and metals analysis	Lakes	USA	Whitehead *et al.*1989; Whitehead *et al.*1990; Siver and Smol 1993
Acidification	Palaeolimnology	Planktonic and benthic diatom biomass and abundance	Lakes	Sweden	Anderson *et al.*1997
Acidification, eutrophication	Palaeolimnology	Spheroidal carbonaceous particles (SCP) and artificial radionuclides used to determine environmental changes	Lakes	UK	Jones *et al.*1997

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
Acidification	Palaeolimnology	Surface Waters Acidification Program (SWAP) - diatom-inferred chemistry for DOC, pH, Al	Lakes, Streams	Norway, Sweden, UK	Renberg and Battarbee 1990; Battarbee 1994
Acidification	P - hydrology	Ground water hydrology as a function of basin stratigraphy and minerology	Lakes	Canada	Craig and Johnston 1988
Eutrophication, salinity	Biological assemblage: macrophyte, periphyton, microinvert	Integrated study: land-use changes, macrophyte, microinvert spp biomass and community dynamics	Brackish Lake	UK	Bales *et al.*1993
Eutrophication	Biological assemblage: periphyton	Abundance of silica-scaled Chyrsophyceae examined with a transmission electron microscope	Lakes	New Zealand	Wujek and O'Kelly 1992
Eutrophication	Biological assemblage: periphyton	Diatom community analysis used to infer lakewater TP levels	Lakes	Canada	Hall and Smol 1992
Eutrophication	Biological assemblage: periphyton	Sediment diatom assemblages used to assess ecological state and eutrophication	Lakes	Finland	Ollikainen *et al.*1993
Eutrophication	Biological assemblage: periphyton, phytoplankton	Species diversity and abundance	Lakes	Bandladesh	Khondker and Rahim 1993
Eutrophication	Biological assemblage: periphyton, Toxicity - algae	Integrated assessment - chemical analysis, biological. Algal bioassays, periphyton biomass accumulation and taxanomic distribution on artificial substrates	Wetlands	USA	McCormick *et al.*1996
Eutrophication, Organic	BM - phytoplankton	Eutrophication index, diversity index, saprobic index and saprobic quotient	Lakes	Egypt	El Naggar *et al.*1997
Eutrophication	BM - macroalgae	Filamentous green algal biomass and species composition	Ditches, Ponds	The Netherlands	Simons 1994
Eutrophication	BM - phytoplankton	Phytoplankton species composition used to differentiate 3 types of lakes	Shallow Lakes	The Netherlands	Roijackers and Joosten 1996
Eutrophication	BM- macrophyte, phytoplankton, fish	Biomass, presence/absence	Ponds	UK	Balls *et al.*1989
Eutrophication, OBQ	H - GIS	Submerged macrophytes mapped using GIS and aerial photography over a 30 yr period	Lakes	Germany	Schmieder 1995
Eutrophication	Palaeolimnology	% and abundance of diatoms and chironomids in sediment cores	Lakes	UK	Battarbee and Carter 1993
Eutrophication	Palaeolimnology	Diatom based transfer function to infer past TP water concentrations	Lakes	Canada	Reavie *et al.*1995b; Reavie *et al.*1995a
Eutrophication	Palaeolimnology	Diatom frustules	Lakes	Finland	Liukkonen *et al.*1993
Eutrophication	Palaeolimnology	Diatom frustules from sediment cores and archival areal photographs used to demonstrate historical reed decline as a result of eutrophication	Lakes	Germany	Kubin and Melzer 1997
Eutrophication	Palaeolimnology	Diatom-inferred TP concentrations	Lakes	Denmark	Anderson and Odgaard 1994
Eutrophication	Palaeolimnology	Diatom-P transfer function	Pond	UK	Bennion 1994
Eutrophication, acidification, salinity	Palaeolimnology	General discussion on the use of sedimentary record to address environmental changes	Lakes	UK	Anderson and Battarbee 1994
Eutrophication	Palaeolimnology	Use of fungal remains to infer environmental changes	Lakes	USA	Sherwood-Pike 1988
Eutrophication	Palaeolimnology, P- catchment area and slope	Diatom-inferred TP concentrations, magnitude of limnological responses related to catchment area and slope	Lakes	Canada	Hall and Smol 1993
Eutrophication	Palaeolimnology, sediment mapping	Chironomid and diatom community dynamics; sediment	Lakes	Finland	Salonen *et al.*1993

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
		mapping revealed influence of wind pattern on nutrient cycling in lake			
Eutrophication	M - biology, chemistry	DELWQ-BLOOM-SWITCH - nutrients, algal biomass and composition, water transparency	Lakes	The Netherlands	Van Der Molen *et al.*1994
Eutrophication	M - biology, physical	Modelling of nutrients in wetlands - hydrological and biological submodels	Fw wetlands	Germany	Dorge 1994
Eutrophication, OBQ	P - GIS	Satellite optical remote sensing used to monitor trophic status of lake	Lakes	Italy	Zilioli and Brivio 1997
Metals - Cd, Zn	Bioaccumulation - , Biomarker - macrophyte	Correlation between Cd, Zn levels in aquatic moss (Fontinalis antipyretica) tissue and water quality. Induction of thiol-containing peptides investigated as a biomarker in field collected moss	Rivers	Germany	Bruns *et al.*1997
Metals	Bioaccumulation - , BM - Toxicity - macroinvert	Integrated field and lab methods: metal levels, chronic toxicity, metal bioaccumulation by benthos, benthic community structure	Rivers	USA	Clements and Kiffney 1994
Metals - Hg	Bioaccumulation - macroalgae	Accumulation of Hg and methyl Hg in filamentous green algae grown in acid lakes - levels correlated positively with Hg levels in fish	Lakes	Canada	Stokes *et al.*1983
Metals	Bioaccumulation - macroinvert	Bioaccumulation of sediment-bound by macroinverts does not correlate with total metal concentrations	Lakes	Canada	Krantzberg and Sherman 1995
Metals - Cd, Cu, Mg, Mn, Ni	Bioaccumulation - macroinvert	Feasibility of crayfish (Cambarus bartoni) as an indicators of metal uptake is debatable (field and lab)	Lakes	Canada	Alikhan *et al.*1990
Metals - Cd, Cu, Pb, Zn	Bioaccumulation - macroinvert	Few isopods (Asellus aquaticus) could be used to assess bioavailablity and bioaccumulation of sediment-bound metals	Sediments	The Netherlands	Van Hattum *et al.*1993
Metals - Cu, Zn	Bioaccumulation - macroinvert	Accumulation of metals in 3 fw amphipods	Rivers	France	Plenet 1995
Metals - methyl Hg	Bioaccumulation - macroinvert	Levels of methyl-Hg monitored in caged Pyganodon grandis in experimentally flooded ponds/wetland	Ponds	Canada	Malley *et al.*1996
Metals - Cd, Cu	Bioaccumulation - macroinvert, macrophtye	Potential for use of Zebra mussel (Dreissena polymorpha) and fw moss (Rhynchostegium riparioides) as indicators of metal pollution - lab study	Lakes	USA	Mersch *et al.*1993
Metals - Cu	Bioaccumulation - macrophyte	Uptake of Cu monitored in aquatic moss Rhynchosegium riparioides for use as a biomonitoring tool to assess accidental metal discharges - lab	Rivers	France	Claveri *et al.*1994
Metals - Cu, Hg, Pb, Ni,	Bioaccumulation - macrophyte	Vascular plants - laboratory uptake experiments	Rivers	Canada	Mortimer 1985
Metals - Hg, Se, Zn	Bioaccumulation - macrophyte, Biological survey: macroinvertebrates.	Integrated assessment, water chemistry and biology. Se and Hg bioaccumulation in bryophytes. Macroinvert indices assessed general degredation	Rivers	USA	Nelson and Campbell 1995
Metals - Hg	Bioaccumulation - periphyton	Methyl-Hg bioaccumulation in filamentous green algae from acid-stressed lakes	Lakes	Canada	Stokes *et al.*1983
Metals - Ag, Cd, Cu, Hg, Ni, Pb, Zn	Biomarker - cellular	Cytotoxicity of cultured R1 cells from rainbow trout (Oncorhynchus mykiss) assessed by neutral red uptake	Fw	Germany	Segner *et al.*1994

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
		inhibition test. Correlations between cytotoxicity and fish LC50s varied for cationic metals (Ag, Hg, Cd, Zn, Cu, Ni, Pb).			
Metals - Hg	Biomarker: fish	Metallothionein (MT) expression as a biomarker of mercury exposure in field-collected large mouth bass (Micropterus salmoides)	Lakes	USA	Schlenk *et al.*1995
Metals - Cd	Biomarker: macroinvertebrate	Metallothionein production in body tissue of the fw mussel Anodonta grandis grandis exposed to Cd, field and lab exposure compared	Lakes	Canada	Malley *et al.*1993
Metals - Cu	Biomarker: macroinvertebrate	Lab bioassay - juvenile mussel (Villosa iris and Anodonta grandis) response, measured as visual examination of valve closure and vital staining with neutral red	Fw	USA	Jacobson *et al.*1993
Metals - Zn	Biomarker- macroinvert	Cellulolytic changes in asiatic clams (Corbicula fluminia) and snails (Mudalia dilatata)	Streams	USA	Farris *et al.*1994
Metals	Toxicity - macroinvert	Gammarus pulex feeding rates - interpopulation differences in response to contaminated and non-contaminated sites detected in field but not lab	Fw	UK	Maltby and Crane 1994
Metals - Cu	Toxicity - macroinvert	Cu effect on Asiatic clam tissue and shell growth in artificial streams	Streams	USA	Belanger *et al.*1990
Metals - Zn	Toxicity - macrophtyes	Linear relationship between apical growth in an aquatic moss and intracellular Zn concentrations	Fw	UK	Sidhu and Brown 1996
Metals	Toxicity - microinvert	Life-cycle sediment toxicity test using the ostracod (Cyprinotus incongruens)	Streams	USA	Havel and Talbott 1995
Metals	Toxicity - sediment	Sediment porewater extraction method	Sediment	USA	Ankley and Schubauer Berigan 1994
OCs - pentachlorophenol	Bioaccumulation - birds	Growth and bioaccumulation effects of pentachlorophenol in mallard duckling	Fw	USA	Nebeker *et al.*1994
OCs - PAHs, PCBs, dioxins, furans	Biomarker - , BM - birds	Great Blue heron (Ardea herodias) used as bioindicators. Measured EROD activity; incidence of chick edema; body weight; reproductive success from field collections as measures of temporal changes in contaminant levels	Fw	Canada	Sanderson *et al.*1994
OCs - PCBs, planar chlorinated hydrocarbons	Biomarker - , BM - birds	Hatchling success, hatchling survivorship, deformed hatchlings correlated with levels of OCs in eggs and EROD activity in rat hepotoma cells	Fw	USA	Larson *et al.*1996
OCs - chorophenols	Biomarker - cellular	Submitochondrial particles response to xenobiotics - results correlated with other toxicity tests for aquatic organisms	Fw	Italy	Argese *et al.*1995
OCs - pentachlorophenol	Biomarker: macroinvertebrate	Valve movement response in fw mussel Dreissinia polymorpha - field and lab tested	Rivers	Germany	Borcherding and Jantz 1997
OCs - pesticides	Palaeolimnology	Cladoceran remains, diatom, and mollusc presence/absence in sediment cores, and OC analysis of sediments	Lakes	UK	Stansfield *et al.*1989
OCs - PCBs, dioxins,	Toxicity - mammals	Both additive model of toxicity (TEQs) and toxic	Fw	USA	Tillitt *et al.*1996

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
furans		equivalent factors (TCDD-EQ) indicate sensitivity of mink to the reproductive toxicity of TCDD and related compounds			
OCs, PAHs	Toxicity - microinvert	Amex and Mutatox assays	Sediment	USA	Hoke *et al.*1994
OCs - herbicide Velpar	Toxicity - periphyton, macroinvert	Outdoor stream channels used to assess response to herbicide: periphyton chl-a productivity 80% reduced, periphyton biomass, macroinvert biomass, density, length and drift not affected by herbicide	Streams	USA	Schneider *et al.*1995
Mixed contaminants metals - Cd, Hg, Zn, OCs - pentachlorophenol, lindane	Bioaccumulation - macrophyte	Bioaccumulation of metals and OCs in fw mosses indicate that scales of quality based on aquatic moss are useful tools for assessing potential degradation - field study	River	France	Mouvet *et al.*1993
Mixed contaminants	Biomarker - phytoplankton	Microscopic analysis of the impact of contaminants on individual cells/organelles - field tested	Lakes	USA	Munawar *et al.*1991
Mixed contaminants	Biomarker: fish	Allele and genotype frequency of field collected fish (Campostoma anomalum) - results compared with IBI and Invertebrate Community Index showing little correlation	Rivers	USA	Fore *et al.*1995
Mixed contaminants	Biomarker: macroinvertebrate	4 in vitro bioassays in field-collected mussel hemocytes: i) typan blue exclusion assay, indicative of cell viability, ii) zymosan phaygocytosis, indicative of phaygocytosis activity iii) DAB-Mn2+ oxidation assay for estimating reactive oxygen intermediate production iv) neutral red (NR) uptake assay, indicative of endocytic ability	Estuarine	USA	Cajaraville *et al.*1996
Mixed contaminants metals - Cd, Cr, Cu, Mn, Se, OCs - sulfometruon methyl (Oust) anthracene,	Biomarker - macrophyte	Lab study - use of peroxidase (POD) activity in macrophyte Hydrilla verticillata as an indicator of exposure to OCs and metals	Rivers, Lakes	USA	Byl *et al.*1994
Mixed contaminants	Biomarker - microinvert	Reduction of enzyme activity in laboratory-reared fw rotifer (Brachionus calcyciflorus) in response to 10 compounds representing a variety of toxicant classes - part of a Rapid Assessment Approach for water quality assessment	Freshwater	USA	Burbank and Snell 1994
Mixed contaminants	Biological survey: macroinvertebrates	7 biological indices: BIOTIC-index most sensitive to chemical pollution, reservoirs classified as unpolluted, slightly, or moderately polluted	Reservoir	Poland	Fleituch 1992
Mixed contaminants	Toxicity - fish, inverts, phytoplankton	Distinguishes between effluent (how toxic is the effluent?) and ambient (is the water toxic?) testing. Recomm. for ambient testing1) frequent testing with 1 spp, rather than infrequent with > 1. 2) >5 test sites, >2 ref sites 3) 4-6 test periods annually 4) diagnostic testing used to supplement	Fw	USA	Stewart 1996

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
		ambient-testing			
Mixed contaminants	Toxicity - fish, mayflies, amphipods, midges, cladoceran, rotifer, macrophyte, algae, bacteria	Review of sediment toxicity test methods in fw - elutriate and whole sediment tests	Sediment	USA	Burton, Jr. *et al.*1996a
Mixed contaminants	Toxicity - macroinvert	Chironomus tentans life-cycle test	Sediment	USA	Benoit *et al.*1997
Mixed contaminants	Toxicity - macroinvert	Oligocheate (Lumbriculus variegatus) as a test organisms for degraded fw sediments	Sediment	USA	Phipps *et al.*1993
Mixed contaminants	Toxicity - macroinvert	Sediment toxicity test methods: Chironomid tentans and Hyalella azteca	Sediment	USA	Burton, Jr. *et al.*1996b
Mixed contaminants	Toxicity - macrophytes	Review of use of plants in BM and assessment. Phytotoxicty can be required in US, Canadian statutes such as: Federal Insecticide, Fungicide, and Rodenticide Act; Toxic Substance Control Act; Water Quality Act; Canadian Pest Control Products Act; CEPA	Fw	USA, Canada	Wang and Freemark 1995
Mixed contaminants metals - Cu, OCs - pentachlorophenol, dichloroanaline, lindane	Toxicity - microinvert	2 cyst-based bioassays with rotifer Brachionus calyciflorus : i) 4-day Life Table test and ii) 3-day Population Growth test	Fw	USA	Janssen *et al.*1994
Mixed contaminants	Toxicity - microinvert	Chemosensory response bioassay of ciliates (Tetrahymena thermophylia) to xenobiotics (43 compounds from the European Inventory of Existing Chemicals). lab study, compared results with standard tox tests	Fw	Germany	Pauli *et al.*1994
Mixed contaminants	Toxicity - microinvert	Cyst-based tests using fw Anostracans (Streptocephalus rubricaudatus and S. texanus)	Shallow Lakes and temporary Ponds	Switzerland	Crisinel *et al.*1994
Mixed contaminants metals - Cu, OCs -pentachlorphenol, 3,4-dichloroaniline, lindane	Toxicity - microinvert	Cyst-based toxicity testing round-robin analytical exercise in Europe, USA, Canada. 4 TOXKITS: with fw rotifer Brachionus calyciflorus, fw anostracan crustacean Streptocephalus proboscideus, and 2 marine kits	Fw	Europe, USA, Canada	Persoone *et al.*1992
Mixed contaminants	Toxicity - microinvert	Hydra attenuata assay developed, responded well when exposed to industrial and agriculturally contaminated waters	fw	USA	Fu *et al.*1991
Mixed contaminants	Toxicity - microinvert	Reproductive behaviour of Gammarus pulex and response to pollution assessed under lab and field conditions	Fw	UK	Pascoe *et al.*1994
Mixed contaminants, effluent discharge	Toxicity - microinvert	Review of microbiological test methods: bacteria, protozoans, microalgae, small inverts, fish cell lines,	Fw, marine	Canada	Blaise 1991
Mixed contaminants	Toxicity - microinvert	Suitablilty of Ceriodapnia for use in acute and chronic toxicity testing	Fw	USA	Versteeg *et al.*1997
Mixed contaminants	Toxicity - microinvert, fish	Review of methods for assessing soil, sediment, water quality. Recommended for water: 72-h Selenastrum capricornutum growth inhibition, 48-h Daphnia spp	Fw	Canada	Keddy *et al.*1995

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
		survival, 5 and 15 min Photobacterium phosphoreum bioluminescence, 7-day Ceriopdaphnia dubia, 7-day fathead minnow larval survival, 96-hr rainbow trout survival			
Mixed contaminants	Toxicity - microinvert, macroinvert	Review of spp used in fw and marine benthic sediment bioassays. 30 spp of fw benthic metazoans used in sediment bioassays. Common endpoints include: mortality, development, growth, behavioural. Others to consider: genetic, biochemical, physiological, and pathological	sediment	Germany	Traunspurger and Drews 1996
Effluents - industrial	Biomarker: fish, Bioaccumulation - fish	Bioindicators of health in the redbreast sunfish (Lepomis auritus) include: growth, enzyme activity, bioaccumulation of PCBs in fish muscle	Rivers	USA	Ham *et al.*1997
Effluents - domestic	Biomarker -fish	Estrogenic effects measured in trout (Onchorhynchus mykiss) caged downstream from sewage treatment works	Rivers	UK	Harries *et al.*1996; Harries *et al.*1997
Effluents - receiving water impacts	BM - aq. macrophytes, terr. plants, bacteria	Lemna minor (aq. plant), Brassica rapa and Lepidium sativam (terr. plant), Photobacterium phosphoreum (bacteria)		Germany	Devare and Bahadir 1994
Effluents - receiving water impacts	BM - microbiology	Optical properties, biochemically active components, receiving water impacts - pond effluent character seemed to be influenced by sunlight and wind via affects on lagoon solids (algal biomass and detritus)	lagoons/Ponds	New Zealand	Davies-Colley *et al.*1995
Effluents - boat wash	BM - microbiology	Receiving water fecal coliform densities	Lakes	Canada	Palmer *et al.*1993
Effluents - landfill leachate	M - physical	Groundwater flow, dilution, and adsorption capacity of the organic soil used to model contaminant movement	Fw wetland	Canada	Fernandes *et al.*1996
Effluents - receiving water impacts	P - flood control structures	Ponds act as sediment traps that remove urban sediment and suspended particulate matter with contaminants	Rivers, Lakes, Ponds, Canals, ditches	Canada	Dutka *et al.*1994
Effluents - landfill leachate	Toxicity - macrophyte	Duckweed (Spirodela polyrhiza) toxicity tests using frond number endpoint to calculate EC50, compared toxicity to a variety of effluent exposure	Fw	Germany	Sallenave and Fomin 1997
Effluents - industrial and domestic	Toxicity - microinvert	Daphnia magna bioassay, Rotoxkit F with fw rotifer Brachionus calyciflorus, Streptoxkit F and Thamnotoxkit F with fw fairy shrimps Streptocephalus proboscideus and Thamnocephalus platyurus, respectively	Fw	Austria	Muna *et al.*1995
Effluents	Toxicity - microinvert	Variability in toxicity test results and implications to UK 'Toxicity-Based Consents' (TBC). Reviews acute Daphnia test	Fw	UK	Whitehouse *et al.*1996
Effluents	Toxicity - periphyton	Periphyton photosynthesis (14C-uptake) in response to effluent exposure - sensitivity of results compared with invertebrate and fish toxicity tests	Fw	USA	Lewis 1992
Effluents - leachate	Toxicity - periphyton, macrophytes	Review of methods for fw green algae, duckweed, blue-	Lakes,	USA	Lewis 1995

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
(phytoplankton), nutrients (macrophytes)		green algae, diatoms and rooted macrophytes	wetlands, Rivers		
Effluents - industrial	Toxicity - phytoplankton, microinvert	Scenedesmus subspicatus chlorophyll fluorescence test and Photobacterium phosphoreum bioluminescence - poor correlation in exposure tests	Fw	Germany	Peter *et al.*1995
Land-use changes and effects on WQ*:	Palaeolimnology	Diatom-based methods	Lakes, canal	Canada	Christie and Smol 1996
Land-use changes and effects on WQ*:	Palaeolimnology	Pollen analysis, diatom productivity, sediment characteristics (grain size)	Reservoir	USA	Bradbury and Van Metre 1997
Land-use changes and effects on WQ:	Palaeolimnology	Integrated study: geochemical data, pollen and magnetic records, historical land-use patterns	Lakes	Sweden	Olsson *et al.*1997
Physical habitat damage	BM - fish	Indices of Biotic Integrity (IBI) used to assess p-h damage in warmwater streams	Streams	USA	Shields, Jr. *et al.*1995
Physical habitat damage	H- paleolimnology, M -biology	Diatom-inferred DIC and DOC weighted average models (WA) used to provide evidence for changes in water chemistry as a result of historical vegetational shifts in the treeline	Lakes	Canada	Pientiz and Smol 1993
Salinity	Palaeolimnology	Environmental indicator - ostracod fauna indicates changes since Holocene	Brackish	Aral Sea, Asia	Boomer *et al.*1996
Salinity	Palaeolimnology	Holocene sediments:14C and 210Pb dating, diatom abundance, sand/silt/clay ratios, organic carbon, P, Cu levels	Lakes	Australia	Barnett 1994
Salinity	Palaeolimnology	Diatom, pollen, and geochemical evidence for historical lake salinity	Lakes	USA	Radle *et al.*1989
Salinity	Palaeolimnology	Chrysophyte stomatocysts inferred-salinity	Lakes	Canada, USA	Zeeb and Smol 1993; Zeeb and Smol 1995
Salinity	Palaeolimnology	CCA and distribution of diatoms correlated with changes in ionic gradients.	Lakes	Canada	Fritz *et al.*1993
Salinity	M - biology	Models of expected macrobenthic community structure as a function of salinity developed for: biomass; number of individuals; species richness; % biomass of deep-dwelling spp, equilibrium spp, and opportunistic spp	Estuaries	USA	Dauer 1993
Water level changes	H - macrophytes, P - water levels	Historical records use to asses changes in macrophyte abundance and compared with annual and seasonal water level changes	Lakes	USA	Kahl 1993
Water level changes	Palaeolimnology	Geological, geochemical, palynological, diatom analysis	Lakes	Switzerland	Straub 1993
Water level changes, salinity	Palaeolimnology	Bedding features and lamination types of Holocene age in saline and hyper saline lakes can be used to interpret history of brine chemistry fluctuations which may be used to infer past changes in hydrologic budget and groundwater inflow	Hypersaline Lakes	Canada	Last and Vance 1997
Water level changes,	H- paleolimnology	Analysis of Holocene lake sediments gives information on	Hypersaline	Canada	Sack and Last 1994

Pollution Type	Diagnostic Method	Method Description	Waterbody	Country	Reference
salinity		fluctuating water levels and salinity over 2 000 year period	Lakes		
Climate change	Palaeolimnology	Predictive statistical model to infer lake surface water temperature based on correlation between diatom community assemblages and measured water temperature	Lakes	Canada	Pientiz *et al.*1995
Climate change	Palaeolimnology	Recent shifts in diatom assemblages in high-Arctic lakes may be a result of climate change	Lakes	Canada	Douglas *et al.*1994
Climate change - salinity	Palaeolimnology	Diatom-salinity transfer functions used to construct salinity changes in lake since Holocene	Lakes	Canada	Wilson *et al.*1997
Climate change - salinity	Palaeolimnology	Climate and Salinity Project (CASPIA) - use of fossil diatom assemblages in lake sediments to infer salinity gradients	Lakes	UK	Juggins *et al.*1994
Climate change - salinity	Palaeolimnology	Diatom valves, chyrsophyte scales and cysts, chironomid head capsules - weighted average calibration functions to infer salinity and temperature	Lakes	Canada	Walker *et al.*1991; Wilson *et al.*1994; Smol *et al.*1995; Walker *et al.*1995
Climate change - salinity	Palaeolimnology	Diatom-based salinity models that can be used with other paleolimnological information	Lakes	Canada	Cumming and Smol 1993
Climate change - water level changes	Palaeolimnology	Lacustrine and marsh sediment record from Holocene indicative of changes in hydrological regime and climate	Lakes	USA	Mason *et al.*1997

* nutrients, increased sediment loading (turbidity), acidification, water level changes