Biological Techniques of Still Water Quality Assessment

Phase 3. Method Development

R&D Technical Report E110

J Biggs, P Williams, M Whitfield, G Fox, P Nicolet

Research Contractor:
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Publishing Organisation

Environment Agency
Rio House
Waterside Drive
Aztec West
Almondsbury
Bristol BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
ISBN : 1 85705 332 X

Dissemination status
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Statement of Use
This report describes the development of a biological assessment method for still waters, particularly canals and ponds. The information on the methodology will be of use to Agency staff involved in monitoring ecological quality and state of the environment assessment. The information will allow active involvement in progression of the development of PSYM both in the provision of data for testing the system and providing a practical insight into the priorities for method development.

Research Contractor
This document was produced under R&D Project E1-062 by:
Pond Action
c/o School of Biological and Molecular Sciences
Oxford Brookes University
Gipsy Lane Campus
Headington
Oxford OX3 0BP

Tel : 01865 483249 **Fax :** 01865 483282

Environment Agency Project Manager
The Environment Agency's Project Manager for R&D Project E1-062 was Shelley Howard – (Midlands Region).

ACKNOWLEDGEMENTS

We would like to thank the members of the Project Board for their inputs and assistance in the project: S. Howard (Project Leader), E. Fisher, D.Jowett, J. Stansfield, R. Sweeting (Freshwater Biological Association), G. Newman (British Waterways) and K. Ferguson (British Waterways).

We are also grateful to all those people who provided valuable assistance in the course of the project (Environment Agency, unless stated otherwise): J. Adams, C. Adams, M. Aprhamian, R. Battarbee (University College London), H. Bennion (University College London), P. Bentham (British Waterways), D. Bligh (British Waterways), R. Bradney, B. Brierley, N. Bromwich, R. Burroughs, L. Carvalho (University College London), N. Cameron (University College London), S. Chadd, E. Clegg, E. Cox (Natural History Museum), R. Dines, S. Downie (Scottish Natural Heritage), M. Drake (English Nature), I. Fozzard (Scottish Environmental Protection Agency), A. Frake, G. Fretwell, C. Furguson (British Waterways), S. Garwood (British Waterways), P. Gilliland (English Nature), B. Goldsmith (University College London), P. Hale (Industrial Research and Technology Unit), R. Handford, E. Haworth (IFE), A. Heaton, B. Hemsley-Flint, P. Hickley, E. Howarth, J. Hunt, F. Jones, G. Jones, J. Karr (University of Washington), M. Kelly (University of Durham), D. Lawson (SEPA), A. Lewis, P. Lidgett, P. Logan, I. Marmont (British Waterways), G. Millar (British Waterways), J. Murray-Bligh, C. Reeds, K. Rouen, J. Sansbury, P. Sibley, S. Tebbutt (British Waterways), A. Tubb, H. Webb, D. Willis.

The Natural Environmental Research Council funded collection of much of the variably degraded pond data used in the project, through the Realising Our Potential Award (ROPA) scheme.

CONTENTS

APPENDICES

TABLES

FIGURES

GLOSSARY

Agency: Environment Agency.

Al: Aluminium.

AQ: Aquatic plant.

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

Assemblage: A group of plants or animals recorded together. The term is used in preference to 'community' because the latter implies an interaction between species.

ASPT: Average Score per Taxon (see BMWP).

Biological Monitoring Working Party: The Biological Monitoring Working Party score system is a macroinvertebrate-based biological index widely used in UK for diagnosing organic pollution (Armitage *et al.*, 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.

CCW: Countryside Council for Wales.

Ca: Calcium.

Cd: Cadmium.

cf: Compare.

Ch: Chapter.

Cu: Copper.

DECORANA: DEtrended CORrespondence ANAlysis**.**

Distribution status: Distribution status (Common, local, etc.). See also SRI.

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

Diatoms: Unicellular algae with a siliceous and often highly sculptured cell wall (see Appendix 12).

EM: Emergent plants.

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 measure based on numbers of species or families in these three Orders.

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

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

ETO: Ephemeroptera, Trichoptera, Odonata. A measure based on numbers of species or 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.

Ha: Hectare.

IBI: Index of Biotic Integrity**.**

IFE: Institute of Freshwater Ecology.

ITE: Institute of Terrestrial Ecology.

km: Kilometres.

m: Metres.

Macroinvertebrate: Larger invertebrate animals, easily visible with the naked eye, such as snails, beetles, dragonflies. A list of the macroinvertebrate groups surveyed in the project is given in Table 2.1.

Macrophyte: Larger wetland plant species. In the context of the current report includes vascular wetland plants, aquatic mosses and liverworts. Charophytes, but not other algae, are also included.

MDA: Multiple Discriminant Analysis.

Metric: A feature, usually a biological attribute (such as number of species or species rarity), which changes predictably with anthropogenic degradation. Such attributes can, therefore, be used to measure degradation.

Mg: Magnesium.

n: Number.

Na: Sodium.

NERC: Natural Environment Research Council.

NFAM: Number of families.

NPS: National Pond Survey.

NUS: The number of uncommon plant or invertebrate species recorded from a site, where an ‘uncommon species’ is any species which has a rarity score of two or more (see SRI below).

OM: Odonata and Megaloptera.

p: Page.

PA: Pond Action.

PC: Personal computer.

pH: Measure of acidity or alkalinity of a substance based on the number of hydrogen ions in a litre of solution. pH 7 represents neutrality, smaller values become progressively more acid, larger values more alkaline.

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.

ROPA: Realising Our Potential Award (a government-funded research grant scheme).

$\mathbf{r_s}$: Spearman's coefficient of rank correlation.

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

SRI: Species Rarity Index. A numerical assessment which indicates the average species rarity value of a biotic assemblage. The process of SRI derivation is outlined below.

1. Each species of plant or animal recorded at a site is given a numerical rarity weighting (value) using the following criteria:

Status[1]	**Value**	**Definition**
Common	1	Recorded from >700 10x10 km grid squares in Britain
Local	2	Recorded from between 101 and 700 grid squares in Britain
Nationally Scarce	4	Nationally Scarce. Recorded from 15-100 grid squares in Britain
RDB3	8	Red Data Book: Category 3 (rare)
RDB2	16	Red Data Book: Category 2 (vulnerable)
RDB1	32	Red Data Book: Category 1 (endangered)

2. The rarity values of the plant or animal species recorded at a site are summed. This gives a Species Rarity Score for each site.
3. To calculate the SRI, the SRS is divided by the number of plant or animal species present at the site to give the average rarity value of plants or animals at a site.

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

SUB: Submerged plants.

TRS: Trophic Ranking Score. A biotic measure of water body nutrient status, or more correctly, an indication of plant community response to waterbody nutrient levels. Trophic Ranking Scores are calculated using the following method:

1. A numerical value is given to each plant species which describes the extent to which it is associated with nutrient enrichment. The scores may differ in different waterbody types e.g. lakes and rivers. The Trophic Ranking Scores used in the present study were based on work undertaken on lakes by Palmer *et al.* (1992). Plant scores in this system vary between 2.5 (dystrophic i.e. very nutrient poor conditions) and 10 (eutrophic, i.e. nutrient rich conditions).

[1] The rarity status values for Scarce and RDB species are based on existing definitions derived from the Red Data Books and other authorities. The definition of 'local' has been used to define species which are not uniformly common and widespread in Britain: with plants this refers specifically to species recorded from between 101 and 700 10 x 10 km squares (approximately 25% of all 10 km in England, Wales and Scotland).

2. The values from all plant species at a site are summed.
3. The summed score is divided by the number of plant species present at the site to give the average nutrient enrichment value for plants at the site.

TWINSPAN: Two-Way INdicator SPecies ANalysis. A multivariate statistical technique for classifying biological data.

UK: United Kingdom.

Water Framework Directive: European Union legislation, currently in draft.

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 (see Appendix 5).

Zn: Zinc.

EXECUTIVE SUMMARY

The aim of this project was to develop a biological method for assessing the quality of still waters (ponds, lakes, canals, temporary waters, ditches and brackish lagoons) in England and Wales.

This report summarises the results of the third and final phase of the project.

In Phase 1, the project's multimetric methodological approach was defined and the preferred biotic assemblages to be used for assessment identified (macrophytes, macroinvertebrates, diatoms and fish). As the range of work required for complete development of the method was extensive a multi-track approach was adopted to method development which could simultaneously progress significant sections of the project at different rates.

In Phase 2 initial development and testing of the method were undertaken in ponds and canals, in a trial area covering 30% of England and Wales, using two of the preferred assemblages (macroinvertebrates and macrophytes) ('Track 1'). The use of diatom and fish assemblages in multimetric assessment was evaluated ('Track 2') and a desk-study of diagnostic methods for identifying the causes of environmental degradation was undertaken ('Track 3').

In the current phase (Phase 3) the assessment method for canals and small lentic waterbodies (ponds and lakes up to 5 ha) was extended to cover the whole of England and Wales.

Background: the biological assessment method developed for the project
The biological assessment method which has been developed for the project is called PSYM (the Predictive SYstem for Multimetrics).

The method enables a surveyor to assess the overall quality of a waterbody using a number of aquatic plant and invertebrate measures (metrics)[2], which are combined together to give an overall waterbody quality value. Using the method involves the following steps:

1. Simple environmental data are gathered for each waterbody from map or field evidence (area, grid reference, geology etc.).
2. Biological surveys of the plant and animal communities are undertaken and samples processed.
3. The biological and environmental data are entered into a computer programme which:
   (i) uses the environmental data to predict which plants and animals should be present in the waterbody if it is not degraded,
   (ii) uses the observed plant and animal lists to calculate a number of metrics[2].

Finally the computer programme compares the predicted plant and animal metrics with the real survey metrics to see how similar they are (i.e. how near the waterbody currently is to its ideal/undegraded state).

The metric scores are then combined to provide a single value which summarises the overall ecological quality of the waterbody.

[2] Metrics are measures such as taxon richness which can be used to assess the extent of damage to a waterbody's community.

Where appropriate, individual metric scores can also be examined to help diagnose the causes of any observed degradation (e.g. eutrophication, metal contamination).

The aim of the current report

The aim of the current project phase has been to extend the PSYM method so that it can be applied to ponds and canals across England and Wales. The main questions that the report seeks to address are:

(i) Which are the best environmental variables for predicting the plant and animal communities that occur in minimally impaired ponds and canals?

(ii) Which biological measures are the best metrics? i.e. which measures (species richness, diversity etc.) are most strongly related to environmental degradation and can, therefore, be used to measure the extent of degradation in ponds and canals?

(iii) How well do the methods perform in practice? This included a preliminary assessment of sources of variability within the datasets.

(iv) Can the pond PSYM methodology be extended to include larger lentic waterbodies up to about 5 ha in area?

Three data sets were used to undertake this method development (i) a data set of 398 ponds less than 2 ha (ii) the pond data set plus 15 small lakes, 2 ha - 10 ha in area (iii) a data set of 113 canals.

Results of PSYM development

The results of *Pond PSYM* method development showed the following:

(i) The most effective environmental variables for predicting the plant and animal communities that occur in minimally impaired ponds were: pH, location and geology. Factors such as shade and vegetation cover were also useful predictors.

(ii) The most effective metrics for measuring environmental degradation were:

Plants:
- Number of submerged and marginal plant species (SM_NTX)
- Trophic ranking score for aquatic and marginal plants (TRS_ALL)
- Number of uncommon plant species (PL_NUS)

Invertebrates
- Average Score per Taxon (ASPT)
- Number of dragonfly and alderfly families (F_OM)
- Number of beetle families (F_COL)

(iii) Reanalysis of the project data sets to investigate the effectiveness of Pond PSYM showed that the method could effectively distinguish high quality from degraded sites.

(iv) Further development of PSYM to include small lakes up to c. 5 ha indicated that the method was viable, but tended to under-predict plant richness variables. This was mainly due to a richness/area relationship within some TWINSPAN end groups (i.e. some end-groups had ponds which, although supporting similar types of plant assemblage, varied in their species-richness according to their size). It may be possible to remove this relationship by further analysis.

The results of *Canal PSYM* method development showed the following:

(i) The most effective environmental variables for predicting the plant and animal communities that occur in 'minimally impaired' canals were location and boat traffic. Factors such as alkalinity and substrate were also useful predictors.

(ii) The most effective metrics for measuring environmental degradation were:
- Average Score per Taxon (ASPT)
- Number of Ephemeroptera, Plecoptera and Trichoptera families (EPT)
- Total number of invertebrate families (NFAM)
- Number of beetle families (FCOL)

(iii) Reanalysis of the project data sets to investigate the effectiveness of Canal PSYM showed that the method could effectively distinguish high quality from degraded sites.

(iv) Comparison of replicate canal samples from locations with both reinforced banks and natural banks showed that the metrics ASPT and EPT could be used to assess water quality in canals regardless of bank type. However, ASPT results were shown to be rather variable at sites where very few taxa were recorded.

Number of beetle families and total number of invertebrate families were good predictors of bank habitat quality regardless of water quality.

Preliminary investigation of Pond PSYM variability

The results of a preliminary investigation of the variability of pond *data collection* showed that the variability of most measures was low (< c.5%). However a number of measures had higher variability (13%-28%). These included substrate type, plant and tree cover. The most variable biotic metrics were: number of beetle families and number of Odonata and Megaloptera families. The variability of both metrics was due to the relatively small number of taxa included in these groups.

Metric EQIs variability was investigated by looking at the frequency distribution of EQI values for each predicted metric using reference site data. The results suggest that biotic indices (e.g. ASPT, TRS) were generally predicted more accurately than metrics based on number of taxa. The metrics which were least well predicted were number of Odonata and Megaloptera families and number of rare plant species. The results of these analyses were used to redefine banding categories for each metric so that divisions between bands currently reflect the natural variability of each metric at high quality sites.

Conclusions and further work

Pond and Canal PSYM can now be used to provide a single season biological assessment of pond and canal quality in Environment Agency regions across England and Wales.

In future, the effectiveness of the methods for ponds and canals could be further optimised by: (i) collection of data from additional seasons (ii) collection of data from additional sites (iii) refinement of existing metrics.

A strategy for developing a Pond PSYM monitoring programme in England and Wales is proposed.

Key Words

Biological monitoring, water quality, canal, pond, lake, metric, prediction, PSYM.

1. INTRODUCTION

1.1 About the project

This report describes the results of the third phase 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 waters,
- Phase 2 (1997-1998): during which the project's assessment method, PSYM[3], was developed using regional trials for two still waterbody types (canals and ponds)[4] and two biotic assemblages (macroinvertebrates and aquatic macrophytes),
- Phase 3 (1998-1999): national development of the PSYM method for ponds and canals.

The outcomes of Phases 1 and 2 of the project are summarised in more detail in Section 1.3 below. Definitions of the "still waters" included in the project are given in Table 1.

1.2 The aim of the current project phase

The aim of Phase 3 of the project was to extend the scope of PSYM, from a regional trial to national application for canals and small lentic waterbodies (ponds[5] and lakes under 5 ha in area).

This report describes:

(i) describes the most effective environmental variables for predicting the plant and animal assemblages of 'minimally impaired' ponds and canals,

(ii) evaluates the most effective measures (metrics)[6] for describing environmental degradation,

(iii) assesses whether the Pond PSYM method can be extended to cover larger waterbodies than the current upper limit of 2 ha, particularly waterbodies in the 2 ha - 5 ha range,

(iv) identifies how well the methods perform in practice,

(v) provides a preliminary assessment of sources of variability within the pond dataset,

(vi) summarises the results of training sessions with Agency staff to enable them to use PSYM.

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[3] PSYM - Predictive SYstem for Multimetrics.

[4] Phase 2 did not include developement of a method for assessing lake quality. This was because considerable sampling method investigation would be required before data could be collected for Lake PSYM development and this was outside the scope of the current project.

[5] Ponds are defined as waterbodies under 2 ha in area.

[6] Metrics - biological measures (such as species richness, diversity etc.) which can trace anthropogenic degradation, or as defined by Karr (1995): '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'

Table 1.1 Definitions of still waterbodies used for the project

Lake	Waterbodies greater than 2 ha in area (Johnes *et al.*, 1994). Includes reservoirs, gravel pits, meres and broads.
Permanent and semi permanent ponds	Waterbodies between $1m^2$ and 2 ha in area which usually retain water throughout the year (Collinson *et al,*. 1994). 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 mg/l sodium chloride (Allaby, 1985).
Canals	Artificial channels originally constructed for navigation purposes.
Ditches	Man-made drainage channels, including drains and rhines.

1.3 Summary of the results from previous phases

A brief summary of the results from Phases 1 and 2 of the project is given below. More detailed information describing the results from these phases is given in the reports:

Biological techniques of still water quality assessment: Phase 1 Scoping Study, Environment Agency R&D Technical Report E7 (Williams *et al.* 1996).

Biological techniques of still water quality assessment: *2. Method development.* Environment Agency R&D Technical Report E56 (Williams *et al.* 1998).

1.3.1 Phase 1 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[7] with the multimetric-based methods used for ecological quality assessment in the United States.

The multimetric approach assesses overall waterbody integrity using multiple parameters (metrics) each related to degradation. In multimetric assessments, the values from individual metrics are combined to give a single measure[8], which aims to represent the overall ecological quality of the waterbody.

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

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

[8] Usually called an Index of Biotic Integrity (IBI).

(i) predicting the biota which should occur at a site, if it were minimally impaired, using physico-chemical variables alone,

(ii) assessing the extent to which the biota observed at a site deviates from the minimally impaired state using a number of metrics (e.g. taxon richness, percentage of 'sensitive' groups, functional feeding groups),

(iii) simple scoring of the individual metrics on four point scale e.g. 0, 1, 2, 3, where 0 represents poor quality, and 3 represents good quality (i.e. no significant deviation from baseline),

(iv) combining individual metric scores to give an overall site integrity score. This score aims to provide an overall measure of biological water quality enabling sites to be ranked according to their degree of ecological impairment.

A more detailed overview of the steps involved in PSYM method development is given in Chapter 3 and Appendix 1.

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

- the scheme is flexible and the principles can be applied to any waterbody type in any area,
- a wide range of variables (metrics) are used to assess water quality: this gives a broad-based assessment of quality,
- 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 Quality Objectives,
- the method can be used to address both the Agency's pollution monitoring responsibilities and can be used to aid its conservation duties and role in protecting biodiversity,
- the method can be developed so as to be appropriate to existing levels of skill amongst Agency staff,
- the methodology parallels the approach defined in the EU water policy framework directive. This includes requirements for (i) comparisons with minimally impacted baseline conditions, and (ii) for 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, attempt to diagnose the cause, or causes, of degradation. Indeed it is considered inappropriate for a general quality assessment method to be biased towards the 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 Phase 1 suggested that the biotic assemblages most appropriate for use as the basis for multimetric assessments varied between different still waterbody types. However, the reliability and validity of assessments are 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 still waterbody type considered by the project 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)	

It was clear at the Scoping Study stage that the potential to develop multimetric methods based on any one of these biotic assemblages varied considerably. Thus macroinvertebrates are a well tried and tested biotic monitoring assemblage with sampling methodologies which could be easily applied to any waterbody type. In contrast, a diatom or fish based assessment would require a prolonged set-up period during which field sampling methods were agreed and the potential of the group was more fully evaluated.

Based on these findings the Scoping Study recommended a multi-track approach to Phase 2 development, which could simultaneously progress significant sections of the project at different rates.

1.3.2 Phase 2 results

Phase 2 development of the PSYM methodology included the first field trials of the method and the results of a series of desk-studies to develop other aspects of the multimetric system.

Three main tracks were followed:

Track 1: 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 of the preferred biotic assemblages identified by matrix analysis. These were aquatic macroinvertebrates in canals and both macroinvertebrates and aquatic macrophytes in ponds. These two assemblages were available for immediate field testing as both have well-developed field survey techniques. In contrast the two other preferred assemblages (diatoms and fish) do not have well defined field survey techniques for ponds and canals. The method was trialled in areas covering approximately 30% of England and Wales.

The results showed the following:

- the flora and fauna of minimally impaired ponds and canals could be predicted successfully using physical environmental variables alone. In ponds the main predictors were location,

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

size and underlying geology. In canals, the predictive variables were associated with location, sediment depth and bank characteristics,

- identification of multiple metrics to assess degradation in ponds and canals was straightforward. There were strongly significant correlations between a number of biotic attributes (taxon richness etc.) and independent measures of physical and chemical degradation (water and sediment chemistry, land-use intensity, bank structure etc.),
- for ponds the most effective plant metrics were based on species richness and rarity attributes. In both ponds and canals, the most effective invertebrate metrics were based on family richness and attributes of pollution-sensitive taxa.

Five trials were undertaken using sites from the data set. Overall, the results successfully demonstrated the key features of the method. Specifically:

1. the method clearly differentiated minimally impaired and degraded sites in both ponds and canals.
2. the overall quality score, produced by combining the metrics, was more effective than the individual metrics for assessing the ecological quality of waterbodies.
3. family-level invertebrate metrics were as effective as species-level metrics for assessing overall waterbody quality indicating that, for the invertebrate component of PSYM, it will be possible to use relatively rapid family level survey methodologies.
4. in canals, it was possible to identify specific invertebrate metrics which could independently assess both water quality and habitat quality.

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

Track 2: Desk study evaluation of multimetric assemblages and applications

Track 2 sought (i) to evaluate the application of fish and diatoms as promising biotic assemblages for multimetric assessment and (ii) to undertake a desk study to evaluate the potential use of PSYM for biodiversity monitoring.

The Phase 1 scoping study suggested that fish were potentially a useful assemblage for monitoring the quality of lakes. The Phase 2 desk study indicated that suitable fish metrics could be derived from standard Environment Agency fisheries survey data. Fisheries data already held by the Agency, particularly a database of about 200 Fenland drains in the Anglian Region, could be used to undertake a cost effective preliminary trial of fish-based multimetric methods.

To evaluate 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 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 ecological quality monitoring.

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

The Scoping Study identified quality assessment as a 2 stage process: (i) the assessment of general ecosystem quality (progressed in this project in Tracks 1 and 2) and (ii) the *diagnosis* of problems identified by general ecosystem assessments. The 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 for still waters 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, micro-organic pollution and habitat quality, however, biological methods have been relatively little developed and applied.

There appears to be considerable potential for information gathered for PSYM assessments 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. The recommended techniques could then be used as confirmatory tests.

2. METHODOLOGY USED TO DEVELOP THE PREDICTIVE MULTIMETRIC APPROACH

2.1 Introduction

This chapter provides background information about the methods used to develop PSYM for (i) ponds alone (ii) ponds and small lakes and (iii) canals.

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.

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

Summaries of the field protocols used to survey the ponds and canals are given in Appendices 5 and 6 respectively.

2.2 Survey sites and samples

2.2.1 Data sets

Pond data sets

In the current phase, the PSYM method was developed using a pond data set of 298 sites. Just over half of these ponds (n=152) were minimally impacted reference sites which were used for classification and prediction purposes (cf. RIVPACS). The remaining sites (146 ponds) had been exposed to a variety of potentially degrading influences (e.g. agricultural or urban runoff, intensive fish stocking). The full data set, combining both the degraded and reference ponds, was used in correlation analysis to identify which metrics would be most effective as measures of anthropogenic degradation.

The 298 pond data set was derived from the following sources:

- 144 minimally impaired ponds derived from Pond Action's National Pond Survey (NPS) database,
- 130 variably degraded ponds derived from Pond Action research work funded by NERC's ROPA (Realising Our Potential Award) scheme,
- 20 Environment Agency ponds specifically surveyed for Phase 2 of the current project in summer 1997. These sites were strategically located so as to fill existing gaps in the database. Full data from these ponds is given in the Phase 2 R&D Project Record E1/012/1 (Pond Action, 1998),
- 4 ponds from Pinkhill Meadow in Oxfordshire which were monitored by Pond Action as part of Environment Agency R&D Project 383 (Pond Action, 1997).

Canal data sets

For canals, which are more physically and chemically uniform than ponds, fewer sites were surveyed. In total the data set comprised macroinvertebrate species composition and relative abundance, vegetation cover and physico-chemical data collected from 94 canal sites (70 sites in 1997, 24 in 1999). To enhance the potential to identify bank-structure effects, replicate invertebrate samples and environmental data were gathered from an additional 20% of the canal sites (n=19), particularly focusing on sampling well-vegetated banks vs. bare, vertical reinforced bank sections. In total, therefore, 113 samples were collected: 83 in 1997 and 30 in 1999.

The majority of invertebrate samples were taken from the towpath bank of the canal. 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.

2.2.2 Selection of reference and degraded sites

Selection of pond sites

The 152 reference ponds were all located in areas of minimally impaired, semi-natural land across England and Wales (e.g. unimproved grasslands, semi-natural woodland, lowland heathland, moorland). Sites were selected in these areas to ensure representative coverage of land classes within the Institute of Terrestrial Ecology (ITE) Land Classification system.

The variably degraded ponds were located in more intensively managed landscapes exposed to a variety of anthropogenic impacts. The initial selection of these sites was made objectively 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. 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. Sites were also chosen to attempt to minimise correlation between land use type and pollutant impacts. This included selection of ponds from organic farming areas. A list of the project survey ponds is given in Appendix 2.

Selection of lake sites

In order to investigate the potential to extend the PSYM method to larger waterbodies, a number of additional small lakes (n=15) were combined with the pond data set. The 15 lakes were all 'reference sites' located, as far as possible, in areas of semi-natural land use. The size of the lakes ranged from 2 ha to 10 ha in area. A list of the survey lakes is given in Appendix 3.

Selection of canal 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 (i) 1995 Environment Agency chemical water quality data and (ii) English Nature data listing canal SSSIs. In addition an effort was made to ensure good geographic coverage of the canal network in England and Wales. This included sampling the Lancaster Canal, one of the most northerly canals, even though its GQA Chemical Class was only C. In practice, it proved difficult to find sufficient good quality canals to use as reference sites.

The final choice of minimally impaired baseline sites used in analysis was based on ranking of *actual* data gathered from the sites. This included: (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: Ashby, Basingstoke, Bridgewater and Taunton, Cannock Extension, Grantham, Huddersfield Narrow, Kennet and Avon, Lancaster, Leeds-Liverpool, Llangollen, Leven, Monmouthshire and Brecon, Montgomery, Newport, Oxford, Pocklington, Ripon and Shropshire Union.

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

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

2.3 Biological data collection

Collection of invertebrate and plant data from ponds and lakes

PSYM was developed for both ponds and small lakes using two biotic assemblages: aquatic macrophytes and macroinvertebrates.

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, see Appendix 5). 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 original RIVPACS sampling methods, whilst allowing for differences between river and pond habitat types (see Phase 2 report).

NPS samples were collected by allocating time equally between all the major mesohabitat types present in the waterbody (i.e. if six main habitat types were identified time was divided equally amongst these). The 3 minute survey subsamples were taken from around the entire pond. Deep water areas were sampled with a hand net using chest waders or from a boat.

Samples were laboratory-sorted using live (as opposed to preserved) samples. Sorting was exhaustive, although very abundant taxa were subsampled where appropriate. Sorting took an average of 8 hours per pond (range; 3 - 25 hours). Macroinvertebrates were identified to the levels shown in Table 2.1 and enumerated.

A more detailed description of pond survey and sorting methods is given in Appendix 5.

Collection of invertebrate data from canals

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.

The sampling technique used to collect invertebrate samples was developed as 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 recommended for sampling deep rivers. The method will also be used by IFE in future canal surveys (Wright *et al.*, 1999).

The method comprises:

1. A one-minute search.
2. A two-minute semi-continuous hand-net sampling of the canal margin, shallows and any emergent plant habitats present. This sample typically covers a bank length of 5m to 15m.
3. Four net hauls from deeper bottom sediments along a canal length of approximately 10 m, elutriated on site to wash out the bulk of muds and fine sands. These should be taken at c. 3m intervals along the canal sampling length.

Two directly compatible field techniques can be employed to gather the four bottom sediment sample hauls from deeper areas, the choice depending on canal depth and accessibility:

(i) where canals are shallow enough to wade, bottom samples can be collected using a hand-net haul (c.3m length) taken perpendicular to the bank, (ii) where canals are too deep to use a hand net, bottom samples are collected using a Naturalist's dredge with a hand net sub-sample filling ca. one quarter of the pond net then taken from this dredged material. It is recommended that the bank and bottom samples are kept separate, since this makes the samples easier to sort in the laboratory.

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.

Table 2.1 Macroinvertebrate taxa included in 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 Physical and chemical data collection

2.4.1 Introduction

Physical and chemical data from the ponds were collected in order 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 derived from desk study information (e.g. geology, altitude).

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

   These data were specifically related to gradients of anthropogenic degradation (i.e. elevated heavy metal concentrations, inputs of treated sewage effluents, nutrient concentrations, bank degradation, intensive surrounding land uses). The parameters will not, however, be used in routine Environment Agency field assessments and 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. Details of the pond and canal field survey methods, together with a copies of the field survey pro-formas used are given in Appendices 5 and 6 respectively.

2.4.2 Pond physical and chemical data

A range of physico-chemical data were collected from each site. A summary of the variables described is given in Table 2.2. A full list is shown in the NPS field survey recording sheet (Appendix 5).

Water samples from the ponds were taken in spring or summer. Two water chemistry samples (filtered[9] and unfiltered water) were collected at each site. Water quality determinands which required immediate analysis (e.g. pH) 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.

2.4.3 Canal physical and chemical data

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

Chemical data used in analysis were 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.

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 protocol used for collecting pond samples.

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 for samples collected in spring 1997 and average values for 1998 for samples collected in spring 1999.

Sediment data were provided by British Waterways 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 British Waterways sediment sample.

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[9] Water was filtered, using a hand pump, through a Whatman glass microfiber filter GF/C, pore size 1.2 μm.

Table 2.2 Physico-chemical data gathered from water bodies

Location	Water chemistry:
Altitude	pH
Water depth	Conductivity
Lithology	Suspended solids
Drawdown	Total alkalinity
Catchment size	Total phosphorus
Pond area	Soluble reactive phosphorus
Shade	Total nitrogen
Fish	Total oxidised nitrogen
Mesohabitats	Chloride
Sediment depth and type	Calcium
Permanence	Magnesium
Water source and inflows	Sodium
Margin complexity	Potassium
Age	Iron
Grazing and trampling	Zinc
Vegetation cover	Copper
Surrounding land use	Nickel
Adjacent wetlands	Aluminium

2.5 Selection of potential metrics

Metrics are biological tracers: measures (such as taxa richness) which vary uniformly with anthropogenic degradation and can, therefore, be used to measure the extent of ecosystem degradation (Karr, 1995). 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 to identify possible metrics which might be able to track degradation in a given waterbody type. In principle, the list of test metrics should initially be wide and should aim to include both structural measures (such as family richness and Ephemeroptera, Plecoptera, Trichoptera richness [EPT]) 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).

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, scavengers) • Ratio and number of trophic specialists/generalists
Occurrence of sensitive taxa	• Presence of intolerant species (e.g. nutrient pollution sensitive Gastropoda, pesticide sensitive Malacostraca) • Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa • Ephemeroptera, Trichoptera, Odonata (ETO) taxa
Organic pollution indices	• BMWP score, ASPT
Rarity value	• Number of uncommon species and species rarity index based on numeric values i.e. 1=common, 2=local, 4=Nationally Scarce, 8=RDB3, 16=RDB2, 32=RDB1.
Abundance	• Abundance of families • Abundance of sensitive species • Abundance of insects/non-insects
Plant metrics	
Species richness	Based on number of: • submerged species[2] • floating species • free-floating species • emergent species • all wetland species
Plant abundance	Abundance of plants in the categories above
Species rarity	Number of uncommon species and species rarity index
Sensitive species	Trophic Ranking Score for submerged, emergent and all species
Exotic species	Based on the number, percentage and cover of exotic species (i.e. species which have only been recorded in Britain in the last 100 years, and have typically been imported by aquarists).
Key species	The occurrence of key species and families: i.e. charophytes, *Potamogeton*, *Lemna*.

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

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 that were evaluated is given in Appendix 7.

2.6 Data handling 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.

2.6.1 Development of fauna/flora baseline prediction techniques

TWINSPAN (Two-way Indicator Species Analysis) (Hill, 1994) was used to classify ponds on the basis of each biotic assemblage. Invertebrate classifications were based on species-level data (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:

$$p_i = \Sigma\, G_j S_{ij}$$ Clarke *et al.* (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.

2.6.2 Development of metrics

Relationships between trial metrics calculated from plant and invertebrate assemblage data and environmental degradation (Chapter 3) were investigated using non-parametric correlation analysis (Spearman's coefficient of rank correlation). Due to the large number of variables analysed, only correlates which were significant at probability levels of $P \leq 0.001$ were usually considered as viable.

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

For each biotic assemblage used in pond assessment, two or three viable metrics were identified.

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) were compared. Sites which are minimally impaired should show no significant deviations from the baseline values.

Metrics were transformed to a four point scale (0, 1, 2, 3, 4) to enable them to be combined, and summed to give an Index of Biotic Integrity (IBI) which is presented as a percentage of the maximum score, and 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 (i) ponds alone (ii) ponds and a small number of lakes (iii) canals.

Method development for each waterbody type 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 (i) pond invertebrate assemblages (ii) pond macrophyte assemblages (iii) lake+pond macrophyte (iv) lake+pond invertebrate assemblages and (v) canal invertebrate assemblages.

3.2 Site classification: results of the TWINSPAN analysis

Classification of minimally impaired sites was undertaken for each biological assemblage using the multivariate classification package, TWINSPAN (Hill, 1994). The pond classifications were based on data from 152 sites. The lake+pond analysis combined the 152 pond data set with 15 small lakes. The canal classification was based on data from 46 sites.

3.2.1 Pond classifications

The TWINSPAN classifications grouped both the plant and invertebrate pond data into seven viable end-groups, with 5 - 44 sites included in each end-group. This pattern is similar to that seen in the initial 268 site river TWINSPAN classifications of the RIVPACS team who grouped sites in end-groups with 1 – 56 sites (Wright et al., 1987). Summary information for each of the four TWINSPAN analyses undertaken is shown in Table 3.1. TWINSPAN classification diagrams for each data set are shown in Appendix 9.

Correlation analysis of the relationships between end-groups and environmental variables suggested that, in both data sets, the main environmental gradient shaping the classification was acidity/alkalinity, followed by waterbody permanence/depth.

3.2.2 Pond and lake classifications

The main purpose of the lake+pond analysis was to undertake a preliminary investigation of the potential to extend the pond PSYM method to larger lentic waterbodies.

The addition of 15 lakes to the pond data set produced only a partial re-arrangement of the pond TWINSPANs. In general, the lakes spread across the classification end groups, and although they tended to group with other larger ponds (for both plant and invertebrate assemblages), this was not always the case (Appendix 9).

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

Assemblage	*Number of end-groups used from each TWINSPAN*	*Maximum and minimum no. of sites within the end-groups*
Pond invertebrates	7	5 - 44
Pond macrophytes	7	4 - 36
Lake and pond invertebrates	6	15 - 48
Lake and pond macrophytes	6	10 - 42

In the invertebrate classification, the 15 lakes were spread amongst three of the six end groups, three of which were alkaline groups and one acid. Only one of these groups (Group 3) comprised predominantly large sites.

In the plant classification, the lakes again classified into four of the six pond end groups (three alkaline, one acid). None of these was dominated by large sites.

Overall, therefore, the lake communities classified along similar pH gradients to the ponds, and their biotic assemblages were sufficiently similar to the ponds that they did not form independent end-groups.

3.2.3 Canal invertebrate data classification

The TWINSPAN classification of canal invertebrate data was cut off after the third split (giving eight end-groups) and since end group number 8 comprised only two sites it was combined with group seven. The final seven end groups each had between 4 and 11 sites (see Appendix 9).

Correlation analysis of the relationships between end-groups and environmental variables suggested that, in both data sets, the main environmental gradients shaping the classification were locational (easting, northing, altitude). However, water turbidity (linked to boat traffic), water chemistry and bottom substrate were also important correlates with some groups.

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

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.125 for ponds and c.100 for canals (see Appendix 8). However, where possible, this number was reduced by omitting land-use and other variables which would, themselves, be likely to change as a result of anthropogenic degradation.

3.3.1 Pond MDAs

Multiple Discriminant Analysis was used to (i) identify which physical variables were the best predictors of biological assemblage composition, and (ii) to identify the proportion of sites which could be placed in their correct TWINSPAN end-group with different numbers of physical variables.

Table 3.2 Pond dataset: summary data showing proportion of sites predicted to the correct TWINSPAN end-group using MDA with different numbers of physical variables.

(a) Macroinvertebrate assemblage					
Number of variables used in prediction	14	13*	9	7	5
Number of discriminant functions used	6	6	6	6	6
Percent of sites assigned to the correct classification group	74%	69%	67%	63%	61%
(b) Plant assemblage					
Number of variables used in prediction	9	8*	6	5	4
Number of discriminant functions used	6	6	6	6	6
Percent of sites assigned to the correct classification group	67%	66%	64%	58%	50%

*Model used for final PSYM predictions.

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 10 for full tables of environmental variables). For invertebrates, 59% of the sites could be placed in the correct TWINSPAN end-group using five physico-chemical variables. Using 14 variables, 74% of sites were correctly placed. Plant predictions showed similar success rates (50% correctly placed with 4 variables, 67% with 9 variables).

Best predictor variables for ponds

The most important variables for predicting pond invertebrate end-group membership were associated with pond location, pH and pond area. The addition of other significant environmental factors such as shade, grazing and pond base geology increased the probability of sites being correctly classified by about another 20%.

The most important variables for predicting pond plant end-group membership were associated with pond location, pH and geology. Addition of shade increased the number of sites being correctly classified by another 15%.

The final choice of variables for the prediction was based on 13 variables for invertebrate assemblages and 8 for plants. Using these variables 69% and 66% of sites were placed in the correct TWINSPAN end-group for invertebrate and plant assemblages, respectively. There was a high degree of overlap in the variables used for the plant and invertebrate predictions, suggesting that similar factors influenced both faunal and floral communities. Table 3.3 summarises the variables used. A full list of the variables is given in Appendix 11.

In terms of the implications for Environment Agency data collection, the variables used for prediction fall into 8 major categories (e.g. location, size, water chemistry etc.). Of these, three are relatively invariant (e.g. location, base geology, isolation) which need only be assessed once. The remaining five categories of variable require on-site field measurement when each assessment is made. These are water depth, pH, shade, grazing and vegetation cover (Table 3.3).

Examples of predicted pond plant and macroinvertebrate taxa lists, compared to the observed flora and fauna, are given in Table 3.4.

Table 3.3 Summary of pond variable categories[1]

Categories	*Invertebrate variables*	*Plant variables*
Location	Easting, northing, altitude	Easting, northing
Size	Pond area	-
Water chemistry	pH	pH
Inflows	Presence of an inflow (Yes/No)	-
Shade	Pond area shaded (%)	Pond area shaded (%)
Pond base geology	Proportion of: • Clay • Sand/gravel/pebbles • Rock • Peat	Proportion of: • Clay • Sand/gravel/pebbles • Rock • Peat
Vegetation	Margin grazed by livestock (%)	-
	Emergent plant cover (%)	-

[1]A full list of variables is given in Appendix 11.

Table 3.4 Examples of predicted and observed taxa lists for pond plants and macroinvertebrates

Predicted and observed scores for Asham Meads field pond, Oxfordshire.

Species	Predicted (probability of occurrence)	Observed	Species	Predicted (probability of occurrence)	Observed
Wetland plants			*Macroinvertebrates*		
Agrostis stolonifera	0.76	4	Lymnaeidae	1.00	4
Juncus effusus	0.75	4	Planorbidae	1.00	4
Epilobium hirsutum	0.66	4	Glossiphoniidae	1.00	4
Solanum dulcamara	0.64	4	Coenagrionidae	1.00	
Juncus articulatus	0.61	4	Corixidae	1.00	4
Alisma plantago-aquatica	0.58	4	Haliplidae	1.00	4
Glyceria fluitans	0.54	4	Dytiscidae	1.00	4
Typha latifolia	0.52		Hydrophilidae	1.00	4
Lycopus europaeus	0.52		Notonectidae	0.80	4
Mentha aquatica	0.50	4	Baetidae	0.78	4
Juncus inflexus	0.48	4	Asellidae	0.76	4
Galium palustre	0.43	4	Libellulidae	0.75	
Sparganium erectum	0.42		Gerridae	0.64	4
Eloeocharis palustris	0.39	4	Leptoceridae	0.61	
Deschampsia caespitosa	0.38	4	Sialidae	0.61	
Myosotis scorpioides	0.30		Hydraenidae	0.58	4
			Limnephilidae	0.56	4
Aquatic plants			Aeshnidae	0.53	
Lemna minor	0.67	4	Crangonyctidae	0.49	4
Callitriche spp.	0.52	4	Caenidae	0.45	4
Chara spp.	0.44		Planariidae	0.42	
Potamogeton natans	0.32	4	Erpobdellidae	0.39	
			Hydrobiidae	0.32	

Lists show all taxa predicted to occur with 30%, or greater, probability of occurrence.

3.3.2 Lake and pond data set MDAs

The physical factors that were most useful in predicting the membership of sites in TWINSPAN end-groups in the pond+lake data set were similar to those for pond-only data. In the predictions of invertebrate assemblages, the main change was the inclusion of the proportion of limestone rock in the catchment of the pond or lake. For plants no additional variables were needed (see Appendix 11). Using these predictive measures 75% plant and 64% of invertebrate sites were placed in the correct lake+pond TWINSPAN end-group.

3.3.3 Canal MDAs

Table 3.5 summaries the relationship between the number of physico-chemical variables used to predict correct membership of canal invertebrate TWINSPAN end-groups and the percentage of sites that are correctly predicted. Appendix 8 lists the environmental variables used in these analyses.

The results show that 75% of the sites could be placed in the correct invertebrate TWINSPAN end-group using 7 physico-chemical variables. Using 4 variables, 45% of sites were correctly placed.

Table 3.5 Canal macroinvertebrate dataset: summary data showing proportion of sites predicted to the correct TWINSPAN end-group using MDA with different numbers of physical variables.

Number of variables used in prediction	7	6	5	4
Number of discriminant functions used	6	6	6	6
Percent of sites assigned to the correct classification group	75%	70%	57%	45%

Best predictor variables for canals

The most important variables for predicting invertebrate end-group membership were associated with canal location, boat traffic, water chemistry and bottom substrate. The addition of data describing canal vegetation abundance increased the success of prediction by an additional 5%.

The final choice of predictive variables used seven variables in four major categories: location, water chemistry, boat traffic and substrate type. Of these, location (i.e. easting, northing and altitude) are invariant and need only be assessed once. Boat traffic data are annual figures derived from British Waterways or other canal companies. They are also relatively invarient and need only be reassessed once every five years or so unless conditions change significantly (e.g. major canal refurbishment). The two remaining categories of variable require on-site field measurement when each assessment is made. These are alkalinity and bottom substrate composition. Table 3.6 summarises the variables used. A full list of the variables is given in Appendix 11.

Table 3.6 Summary of canal variable categories[1]

Categories	*Invertebrate variables*
Location	Northing, easting, altitude
Water chemistry	Alkalinity
Substrate	% Sand
Boat traffic	Number of boats per annum (in thousands)

[1]A full list of variables is given in Appendix 11.

3.4 Identification of metrics

Biological attributes (e.g. taxa richness, proportion of detritivores) which could potentially be useful as metrics for tracking waterbody degradation were calculated from the pond data set. In total, 140 potential invertebrate metrics and 48 potential plant metrics were calculated. Lakes were assessed using pond-based metrics. For canals, only the invertebrate metrics were calculated. The general categories of metrics are listed in Table 2.3, and a full list is given in Appendix 7.

Relationships between biotic variables (potential metrics) and physico-chemical variables associated with environmental degradation were investigated by correlation analysis.

Degradation was assessed using three main groups of criteria:

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

(ii) measured concentrations of chemical water pollutants (e.g. phosphate, nitrate, heavy metals),

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

3.4.1 Result of metric correlations

Tables 3.7 to 3.9 list potential metrics which were significantly correlated with degradation factors at P=0.001 (Spearman's coefficient of rank correlation) in ponds and canals. The tables also include physico-chemical variables (e.g. water depth, area) which were correlated with 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 for ponds, acid/alkaline correlates, and to some extent pond area, are likely to be acceptable co-correlates of degradation. In canals: location, alkalinity, bottom substrate and boat traffic (together with turbidity and aquatic plant cover which are linked to boat usage) are acceptable co-correlates. A full list of correlations between the ecological variables is given in the Project Record.

Pond aquatic macrophytes

The correlation results suggest a range of plant richness and rarity parameters which could be viable metrics in that they showed (i) strong correlations with degradation indicators but (ii) relatively few correlations with other physico-chemical variables.

The plant attributes which showed the strongest correlations with environmental degradation were:

- emergent plant richness,
- submerged plant richness,
- abundance of emergent plants,
- abundance of submerged plants,
- number of uncommon plant species,
- species rarity index,
- trophic ranking score.

Plant richness

Emergent and submerged plant richness showed similar correlations. Both were strongly correlated with degradation variables including overall pollution index, and a range of water chemistry variables, including phosphate. The main disadvantage with the use of emergent and submerged plant richness as metrics is that both show a strong species-richness/area relationship. The current TWINSPAN community classification largely splits sites into acid-alkaline groups and only partially removes this effect.

In contrast to aquatic and emergent plant species, free-floating plants such as *Lemna* spp. typically showed increases in richness with increasing landscape degradation. This finding suggests that it could be advantageous to omit free-floating plant species from total plant species-richness metrics, since they are likely to dilute the strength of the metric.

Plant abundance (% cover)

As with species richness, the abundance (i.e. % cover) of emergent and abundance of submerged plants appeared to be potentially good metrics. Both were negatively correlated with pollution indices and intensive land use. Of the two, submerged plant abundance appeared to be the better metric for assessing water quality since there were strong correlations between aquatic cover and water chemistry variables such as potassium, suspended solids and phosphate. This metric also had few other *non*-degradation co-correlates. Emergent plant abundance had the disadvantage of a number of correlations with natural factors, particularly water depth, area and marginal shade. However, emergent cover was also relatively unusual in showing strong correlations with bank quality (i.e. there was significantly less emergent cover where banks were steep or reinforced).

Total plant cover was strongly correlated with overall pollution index. There were particularly strong negative relationships with the proximity of urban surrounds. This may be a direct result of the effects of urban runoff. However the relationship may also be an indirect relationship which reflects the increased management of ponds (and hence reduced plant cover) in areas to which people have easy access. This is a relationship which has been observed elsewhere (Williams *et al.* 1998). Total plant cover was also significantly lower in ponds which have intensive fish or duck use, a factor likely to have been related to similar relationships with turbidity.

Overall, therefore, both submerged and emergent plants might be good metrics. Aquatic cover has an advantage in being relatively free from non-degradation co-correlates. Marginal plants, however, have the potential to help describes poor bank structure. In principle it might be possible to use the cover of free-floating plants as part of an enrichment metric, but there would be a number of disadvantages in this because (i) there are relatively few free-floating species, so the metric would often be unusable, (ii) the cover of free-floating species can change very rapidly during the summer months (e.g. increases in *Lemna minor* from 1% to 100% pond cover in six weeks, *pers. obs.*).

Plant rarity

Plant rarity was calculated in terms of: (i) the number of uncommon plant species (NUS), (ii) a species rarity index (SRI)[10].

NUS and SRI metrics generally showed highly significant relationships with degradation measures. Both submerged and marginal plant NUS and SRI declined significantly as pollution indices increased. Correlations with non-degradation variables were largely limited to area. Floating-leaved plant NUS and SRI showed few relationships with environmental variables, either degradational or natural.

In principle, therefore, NUS and SRI could provide useful measures of degradation. The main disadvantage of these metrics is that, by definition, relatively few plant species are uncommon; typically only one to two species per pond. Metrics based on these indices would, therefore, be likely to be highly variable.

Number of exotic species

The number of exotic plant species was generally a poor metric. There were few strongly significant correlations between environmental degradation and the number of *emergent* exotic plant species, and positive correlations with non-degradation factors such as water depth and permanence. The most interesting correlation was a strong relationship between the number of aquatic exotics and public access and disturbance by people - suggesting that many alien plants are deliberately introduced into ponds by people rather than spread through naturalisation.

Abundance of exotic plant species

In contrast to exotic species richness, the *cover* of specific groups of exotic plants (i.e. submerged, floating, emergent) was moderately well correlated with a number of degradation variables. The relationship was not, however, the expected one. Exotic species are generally held to increase in richness and abundance with increasing degradation (Williams *et al.* 1998 and references therein). The present analysis showed, in contrast, greater cover of exotics in semi-natural areas than in degraded areas. The reason is likely to be because most common pond aliens are aquatic species (Williams *et al.* 1998), and although more tolerant of

[10] SRIs are a measure of the average rarity value of species at a site. For definitions of SRI and NUS see the Glossary.

degradation and pollution than some native taxa, they still appear to be intolerant of very polluted waters.

Trophic Ranking Score

Trophic ranking scores (TRS)[11] were calculated based on Palmer's TRS values for (i) submergent and floating species (ii) emergent species (Palmer, 1989).

Correlation analysis indicated that both aquatic and emergent trophic ranking scores were highly correlated with factors related to nutrient enrichment, acidification and overall pollution. This included water chemistry variables (e.g. pH, conductivity, calcium, TON and SRP) as well as landuse variables (such as the extent of anthropogenic urban or agricultural influence in the surrounds).

Overall, *submerged* TRS appeared to be a slightly more sensitive metric than emergent TRS (i.e. stronger correlations with degradation variables). However, as noted in the Phase 2 report, there are many aquatic plant species which have not yet been given still-water trophic ranking scores, and some survey ponds had few, or no, aquatic plants, making it difficult to assign a reliable TRS score.

A combined TRS score using both aquatic and emergent trophic values was also correlated with environmental degradation and appeared to give a good compromise: the metric gave similar correlation significance levels to aquatic trophic ranking scores, and yet almost all ponds had scoring species.

Pond invertebrates

Three major categories of invertebrate metrics were calculated (i) species richness (ii) family richness (iii) taxon abundance.

Overall, for each major taxonomic group, the correlations between metrics and environmental factors showed similar relationships12. So, for example, the three metrics: dragonfly species richness, dragonfly family richness and dragonfly abundance, were significantly correlated with similar environmental factors at relatively similar significance levels. Typically, however, species-level metrics were slightly better correlated with degradation variables (i.e. correlated at slightly higher probability levels) than family-level metrics. Abundance metrics were generally better correlated with degradation than both.

Together these findings suggests that (i) overall, the metrics are likely to be robust (ii) that family-level taxonomy will be adequate for pond integrity assessments and (iii) that abundance-based predictions are likely to be more effective than presence/absence predictions. Since family level invertebrate metrics are generally preferable to species level metrics in an Agency operational methodology, further analysis focused on use of family level invertebrate metrics. There is little suggestion from the correlations that use of mixed-level taxonomy would improve the predictive ability.

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[11] Trophic Ranking Score (TRS): the average nutrient status score for the wetland plant species present at a site. See Glossary for further information.

[12] Correlations between all variables are given in the appendices.

General quality assessment invertebrate metrics

Correlation between the invertebrate metrics and environmental variables revealed a wide range of associations (see Table 3.9). The most significant of these are discussed below.The invertebrate attributes which showed the strongest correlations with environmental degradation were: (i) Average Score per Taxon (ASPT) (ii) OM (Odonata + Megaloptera) number of families and abundance.

ASPT appeared to be a particularly effective metric: it showed strongly significant relationships with all major pollutant indices (overall, urban, agricultural) and landuse degradation variables. It was correlated with a moderate number of physical variables, particularly water depth and shade. However these were factors which were important in shaping the TWINSPAN classification suggesting that physical variability within ponds will be partly factored-out during the prediction process (see Section 3.4.1). BMWP score, in contrast, showed few correlations with degradation (as well as relatively strong relationships with physical factors such as pond area and permanence) suggesting it would be likely to be a relatively poor metric.

Significant relationships between degradation and EMO (Ephemeroptera, Megaloptera, Odonata), OM (Odonata + Megaloptera) and Odonata alone were all evident at family level and, particularly, in terms of abundance (see Table 3.6). The most effective of these metrics was F_OM (Odonata + Megaloptera family richness). The main drawback of the F_OM metric was that it correlated with a number of natural environmental variables, particularly water depth. Fortunately, however, most of these variables were major community predictors and their effect would be, at least partially, taken out by site classification.

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

Potential metric	Environmental factors correlated with potential metric
Total plant richness	Overall pollution index; intensive land use (both urban and agricultural); semi-natural surrounds, particularly heathland and unimproved grassland; grazing; area; fish; bank naturalness; margin complexity; spring and groundwater source; surrounding waters and waterbody isolation; turbidity; suspended solids; potassium; phosphate.
Emergent plant richness	Overall pollution index including agricultural and urban runoff; intensive land use (both urban and agricultural); semi-natural surrounds, particularly unimproved grassland; area; fish; pond marginal complexity; surrounding waterbodies and waterbody isolation; bank naturalness; turbidity; phosphate.
Floating plant richness	Presence of fish.
Free-floating plant richness	Semi-natural surrounds (especially heath, bog and grassland); fish; clay catchment; calcium; conductivity; alkalinity; potassium.
Potamogeton richness	Sediment type; limestone catchment; wetland surrounds; fish; pH.
Submerged plant species richness	Overall pollution index; semi-natural surrounds particularly (heathland and unimproved grassland); grazing; area; pond marginal complexity; shade; clay geology; spring and groundwater source; surrounding waterbodies and waterbody isolation; turbidity; alkalinity; potassium; phosphate.
Total plant species rarity index	Overall pollution index; urban pollution index; intensive land use (particularly agricultural); semi-natural surrounds particularly heathland; grazing; area; shade; surrounding waterbodies and waterbody isolation; phosphate;
Aquatic plant species rarity index	Overall pollution index; intensive land use; semi-natural surrounds particularly grassland; grazing; surrounding waterbodies and waterbody isolation; turbidity; suspended solids; phosphate.
Marginal plant species rarity index	Overall pollution index; urban pollution index; marginal complexity; shade; waterbody isolation; heathland surrounds; grazing.
Floating plant species rarity index	(None)
Submerged plant species rarity index	Overall pollution index; intensive land use, especially agricultural; surrounding waterbodies and waterbody isolation; semi-natural surrounds, especially unimproved grassland; turbidity; suspended solids; phosphate.
Total plant number of uncommon species	Overall pollution index; intensive land use (both urban and agricultural); semi-natural surrounds, especially heathland; area; margin complexity; shade; surrounding waterbodies and waterbody isolation; grazing; turbidity; phosphate.
Marginal plant number of uncommon species	Overall pollution index, particularly urban; intensive land use; semi-natural surrounds, especially heathland; area; margin complexity; surrounding waterbodies and waterbody isolation; grazing.
Floating plant number of uncommon species	Watersource: flooding.

(Continued)

Table 3.7 (continued) Examples of pond macrophyte metrics which have significant relationships with environmental degradation[1]

Potential metric	Environmental factors correlated with potential metric
Submerged plant number of uncommon species	Overall pollution index; urban and agricultural pollution indices; intensive land use, particularly agriculture; semi-natural surrounds, especially heathland and grassland; area; margin complexity; surrounding waterbodies and waterbody isolation; grazing; turbidity; potassium; phosphate.
% total plant cover	Overall pollution index; intensive landuse, particularly urban; intensive fish and duck use; drawdown; semi-natural vegetation on margins; marsh; grazing; turbidity.
% cover of emergent plants	Overall pollution index; urban pollution index; intensive land use (both agricultural and urban areas); area; drawdown area; depth; permanence; margin shade; marsh; grazing; intensive fish and duck use; semi-natural vegetation on margins; bank steepness and reinforcement.
% floating plant cover	(None)
% free-floating plant cover	Shade; clay catchment; buildings and intensive agriculture; grassland; heathland and bog surrounds; alkalinity; calcium; conductivity; potassium; phosphate.
% submerged plant cover	Overall pollution index (especially agriculture); intensive land use (especially agriculture); semi-natural surrounds (especially heathlands and grassland); groundwater or spring water source; other wetlands in the surrounds; turbidity; suspended solids; iron; potassium; phosphate.
Number of exotic species	Urban pollution index; depth; permanence; area; fish; human disturbance; pH.
% exotic plant cover	Overall pollution index; intensive land use (especially agriculture); other wetlands near-by; semi-natural surrounds, especially woodland and grassland.
Trophic Ranking Score	Intensive landuse (urban and agricultural); semi-natural surrounds; easting; shade; drawdown; catchment geology; peat base and bog; heathland surrounds; grazing; turbidity; pH; alkalinity; conductivity; calcium; potassium; phosphate; nitrate.
Submerged/floating spp.	(None)
Free floating / submerged species	Shade; heathland surrounds; calcium; conductivity; potassium.

[1]All correlations significant at $P \leq 0.001$.

Ephemeroptera and Trichoptera were both generally poorly related to degradation in terms of richness. As a result, the common river index, EPT (Ephemeroptera, Plecoptera, Trichoptera), showed very poor relationships with pond degradation. In contrast, Ephemeroptera and Trichoptera *abundance* was related to overall pollution levels, but their relationship with other degradation variables was generally weak. Consequently, their addition to OM abundance to give an OMET abundance metric typically reduced the significance of relationships with degradation.

Species and family richness appeared to have a moderate potential as invertebrate metrics. There were correlations with a wide range of degradation factors at significance levels less than $P<0.001$. However, the most significant correlations were related to physico-chemical factors such as pH and area. Interestingly, order richness was often inversely related to semi-natural landuse and degradation variables, largely because there were fewer orders associated with ponds on naturally acid landuse types such as heath and bog.

The invertebrate species rarity metrics (i) number of uncommon species (NUS) and (ii) species rarity index (SRI)[13], were significantly correlated with the intensity of land use around a pond and could potentially make effective metrics. However, the calculation of these indices requires species-level identification of invertebrates. In practice, therefore, they are unlikely to be a cost-effective metrics to utilise, and are unlikely to give information about sites which could not be derived from other, family-level, metrics.

True bugs (Hemiptera) showed no evident relationships to degradation in terms of either richness or abundance. Similarly, there were few statistically significant correlations between attributes such as broad functional feeding groups (e.g. detritivores, predators) and degradation measures.

Diagnostic invertebrate metrics

A variety of other groups showed specific correlations which might prove useful as diagnostic metrics.

Snail richness and abundance were both strongly associated with factors related to acidity and calcium levels as well as to landuse types (such as bog and heath). Snail abundance was, in particular, highly correlated with acidity, but little influenced either by other natural factors (such as pond area) or by other forms of degradation. A second metric, the abundance of insects/non-insects, had a similarly strong relationship with acidity and alkalinity

The richness of Malacostraca (shrimps, slaters and crayfish) was notable for being highly correlated with a wide range of metals (aluminium, lead, copper, iron, zinc). The group might, therefore, provide a valuable metric for assessing high metal contaminant levels in small waterbodies.

Water beetles richness and abundance were correlated with a wide range of natural factors and, to a lesser extent, with degradation. The group was unusual, however, in that richness and abundance metrics were also related to the quality of the bank structure.

[13] See Glossary for further definitions of SRI and NUS.

Table 3.8 Examples of pond invertebrate metrics which have significant relationships with environmental degradation

Potential metric	Environmental factors correlated with potential metric
Species richness	Urban pollution index; water depth and permanence; sandstone catchment; isolation from other waters; fish; pH; aluminium; iron; phosphate; zinc; suspended solids.
Family richness	Area; age; depth; permanence; drawdown; sediment; isolation from other waters; fish; pH; zinc. Less significant relationships with overall pollution index and semi-natural surrounds.
Order richness	Water area; depth and permanence; drawdown; peatland; heath and bogs; grassland; inflows; intensive land-use; agriculture; grazing; urban areas; all-semi-natural surrounds; flood water source; fish; pH; alkalinity; calcium; conductivity; nitrogen.
Snail family richness	Overall pollution index; agricultural pollution index; altitude; area; depth; shade; water source; bog, heath, marsh or traditional wetlands in the area; fish; pH; alkalinity; calcium; conductivity; aluminium; iron; sodium.
Snail abundance	Bog or heath land use; fish; stream; pH; alkalinity; conductivity; calcium.
Shrimp and slater (Malacostraca) family richness	Urban landuse; permanence; depth; shade; sediment; geology; bog; floodplain; woodland; heath; grazing; fish; pH; calcium; conductivity; aluminium; copper; iron; lead; zinc.
Shrimp and slater (Malacostraca) abundance	Shade; geology; bog; isolation; woodland; fish; pH; alkalinity; conductivity; calcium; aluminium; copper; iron.
Malacostraca + Gastropod family richness	Age; depth; permanence; water source; surrounding waters and isolation woodland; heath; grassland; fish; pH; alkalinity; conductivity; calcium; aluminium; copper; iron; nickel.
Leech + flatworm family richness *and* abundance	Intensive landuse; semi-natural land use, especially heath and bog (richness only); area, depth; permanence; fish; intensive duck use (richness only); pH; alkalinity; calcium.
Dragonfly and damselfly family richness *and* abundance	Overall pollution index; intensive land use, particularly agriculture; semi-natural land use particularly heathland; water area (richness only); depth; permanence; age (abundance only); isolation from other waters; alkalinity; calcium; potassium; phosphate; suspended solids (abundance only).
Beetle family richness	Intensive land use; steep banks; bank degradation index; isolation; semi-natural grassland surrounds; suspended solids.
Beetle abundance	Intensive land use, particularly urban; steep banks; semi-natural surrounds, particularly grassland; grazing; northing; water source; isolation; phosphate.
Bug *and* predatory bug family richness	Depth; permanence; age; fish; pH.
Bug abundance	Area; depth; permanence; age; conifer woodland surrounds; fish.
Alderfly species richness	Age; drawdown; depth; permanence; fish; wetland surrounds and isolation from other waters; phosphate.

(Continued)

Table 3.8 (continued) Examples of pond invertebrate metrics which have significant relationships with environmental degradation (continued).

Potential metric	Environmental factors correlated with potential metric
Alderfly abundance	Overall pollution index; urban land use; semi-natural grassland; age; drawdown; depth; permanence; water source; wetland surrounds and isolation from other waters; fish; phosphate.
Caddis-fly family richness	Area; drawdown; depth; permanence; wetland surrounds and isolation; fish; pH phosphate.
Caddis-fly abundance	Overall pollution index; area; drawdown; depth; permanence; sediment; water source; wetland surrounds and isolation; fish; pH; phosphate.
Mayfly family richness	Drawdown; water depth; area; permanence; water source; fish; pH; calcium; iron.
Mayfly abundance	Overall pollution index; area; drawdown; water depth; permanence; water source; fish; intensive duck use pH; iron.
Number of Ephemer-optera, Plecoptera, Trichoptera family richness	Area; water depth; drawdown; permanence; age; adjacent wetlands and isolation; fish; pH; iron; phosphate.
Ephemeroptera, Trich-optera, Megaloptera, Odonata) family richness	Intensive agricultural surrounds; adjacent wetlands and isolation from other waters; area; water depth; drawdown; permanence; age; sediment; fish; pH; suspended solids; phosphate; iron.
Odonata + Megaloptera number of families richness and abundance (OM)	Overall Pollution index; intensive surrounds both urban and agricultural; semi-natural surrounds, particularly heathland; area; water depth; drawdown; permanence; age; shade (abundance only); adjacent wetlands and isolation from other waters; fish; suspended solids (richness only); alkalinity; potassium; phosphate.
Abundance of non-insects	Overall pollution index; agricultural pollution index; clay catchment; isolation from other waters; bog and heath surrounds; fish; pH; conductivity; calcium; sodium; aluminium; iron.
Abundance of insects	Overall pollution index; agricultural pollution index; Urban pollution index; intensive surrounds, particularly urban; intensive duck use; semi-natural areas, particularly unimproved grassland; water area; sediment; water source; isolation from other waters; potassium; phosphate.
Abundance of non-insects/insects	Shade; water source; woodland surrounds; acid landscape surrounds (e.g. bog, heath); pH; alkalinity; calcium; conductivity; sodium.
BMWP score	Area; age; drawdown; permanence; shade; water source; isolation; fish; pH; suspended solids; aluminium; iron; phosphate.
ASPT score	Overall pollution index; urban pollution index; agricultural pollution index; intensive surrounds (both agricultural and urban); semi-natural land-use; drawdown; depth; permanence; shade; geology; wetland surrounds; isolation; woodland; heath; pH; conductivity; calcium; sodium; potassium; phosphate.
Rare Species Score (RSS)	Intensive surrounds, particularly agricultural; semi-natural surrounds, particularly heathland; margin complexity; shade; water source; isolation; copper; nitrogen; phosphate.

(Continued)

Table 3.8 (continued) Examples of pond invertebrate metrics which have significant relationships with environmental degradation (continued).

Potential metric	Environmental factors correlated with potential metric
Number of uncommon species (NUS)	Overall pollution index; urban pollution index; intensive land use, especially agricultural; semi-natural surrounds; water area; shade; sediment; water source; isolation from other waters; nitrogen; phosphate.
Species Rarity Score (SRS)	Intensive surrounds; semi-natural surrounds; water area; sediment; water source; fish; isolation; aluminium; iron; copper; zinc; pH; phosphate; suspended solids.
Species rarity index (SRI)	Intensive landuse, including both agriculture and urban surrounds; semi-natural surrounds especially heathland; permanence; sediment; inflow; alkalinity; nitrogen.

[1]All correlations significant at $P \leq 0.001$.

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 3.9).

ASPT score correlated strongly with a variety of water quality parameters, including heavy metals, suspended solids and chemical water quality (the overall chemical quality class based on suspended solids, BOD and ammonia concentrations) but showed few strong relationships with bank degradation. BMWP showed relationships with water quality class but also with bank degradation measures.

EPT attributes (EPT species and family richness) showed similar relationships to 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 bank, boat traffic and some water quality 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 or family richness could be combined into the final quality index.

Table 3.9 Examples of canal metrics which have significant relationships with environmental degradation

Potential metric	Environmental factors correlated with potential metrics
Invertebrate species richness and SRS	Bank composition; bank angle; vegetation abundance; boat traffic; turbidity; suspended solids.
Invertebrate family richness	Altitude; bank composition; bank angle; vegetation cover; boat traffic; turbidity; suspended solids; Environment Agency chemical water quality class.
Snail species and family richness	Bank composition; bank angle; vegetation cover; turbidity.
Planorbidae species richness	Northing; bank composition; fine sediment; vegetation cover; turbidity; boat traffic.
Leech species & family richness	Vegetation cover; metals.
Crustacean+molluscan spp. richness	Bank composition; vegetation cover; bank angle; bank shade;
Dragonfly spp. richness	Vegetation cover; turbidity; boat traffic.
Dragonfly family richness	Vegetation cover.
Coenagrionidae species richness	Vegetation; turbidity; sediment type and depth; boat traffic; suspended solids
Mayfly species *and* family richness	Northing; boat traffic; turbidity; suspended solids; sediment; phenols; Environment Agency chemical water quality class.
Baetidae species richness	Vegetation; boat traffic; turbidity; Environment Agency chemical water quality class.
Bug species richness and family richness	Altitude; bank composition; bank angle; vegetation cover; boat traffic; turbidity; suspended solids.
Beetle species richness	Bank composition; bank angle; vegetation cover; turbidity; Environment Agency chemical water quality class.
Haliplidae species richness	Bank composition; fine sediment; vegetation cover; boat traffic; turbidity; sediment phenols; Environment Agency chemical water quality class.
Hydrophilidae species richness	Bank composition; bank angle; water depth at edge; coarse sediment; vegetation cover; boat traffic.
Beetle family richness	Bank composition; bank angle; vegetation cover; turbidity; Environment Agency chemical water quality.
Alderfly richness	Bank composition; vegetation cover; boat traffic; turbidity; suspended solids; phenols; suspended solids.
Caddisfly species richness	Northing; edge composition; boat traffic; turbidity; ammonia; chloride; potassium; sodium; phenols; Environment Agency chemical water quality class. (continued)

Table 3.9 (continued) Examples of canal metrics which have significant relationships with environmental degradation[1]

Potential metric	Environmental factors correlated with potential metrics
Caddisfly family richness	Boat traffic; turbidity; potassium; sodium; phenols; Environment Agency chemical water quality class.
Leptoceridae richness	Northing; bank composition; vegetation cover; boat traffic; turbidity; ammonia; choride; sodium; potassium; suspended solids; Environment Agency chemical water quality class.
Limnephilidae richness	Bank composition; bank angle; vegetation cover; water depth at edge; boat traffic; sodium; potassium; suspended solids; Environment Agency chemical water quality class.
Moth species *and* family richness	Sediment composition; vegetation cover; boat traffic; turbidity; suspended solids; TON.
BMWP score	Bank composition; bank angle; vegetation; boat traffic; turbidity; phenols; suspended solids; Agency chemical water quality class.
ASPT	Water quality class; salts; magnesium; ammonia; chloride; phenols; BOD; Agency chemical water quality class.
EPT species richness	Northing; bank composition; boat traffic; turbidity; ammonia; salts; phenols; suspended solids; Agency chemical water quality class.
EPT family richness	Northing; turbidity; boat traffic; phenols; suspended solids; ammonia; salts.
ETO species richness	Bank composition; vegetation; boat traffic; turbidity; ammonia; phenols; suspended solids; Agency chemical water quality class.
ETO family richness	Northing; bank composition; vegetation; boat traffic; turbidity; ammonia; phenols; salts; suspended solids; Agency chemical water quality class.
OM family richness	Bank composition; vegetation; boat traffic; turbidity; phenols.
EMO family richness	Bank composition; vegetation; boat traffic; turbidity; phenols; suspended sediment; Agency chemical water quality class.

[1]All correlations significant at $p<0.001$.

3.4.3 Final choice of viable metrics

Further rationalisation to choose the most effective 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:

(i) Metrics were prioritised where they showed strong monotonic relationships to a wide range of degradation gradients and, in addition, had relatively few correlations with 'natural' physico-chemical variables, particularly those not 'taken out' by the TWINSPAN classification.

(ii) 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.*).

Using this rationalisation the following biotic attributes were prioritised as *possible* metrics:

<u>Ponds</u>

- SM_NTX Number of submerged + marginal plant species
- TRS_ALL Trophic Ranking Score for aquatic + marginal plants
- PL_NUS Number of uncommon plant species
- %SUB_PLT Cover of submerged plant species
- ASPT Average Score Per Taxon
- F_OM Number of Odonata and Megaloptera families
- F_COL Number of Coleoptera families
- AB_EPMO Abundance of Ephemeroptera + Plecoptera + Megaloptera + Odonata

<u>Canals</u>

- ASPT Average Score Per Taxon
- F_EPT Number of Ephemeroptera + Plecoptera + Trichoptera families
- F_COL Number of Coleoptera families
- INV_NFA Total number of invertebrate families

3.5 Developing and testing the multimetric approach

3.5.1 Comparison of observed and predicted values

Using the full data set of 298 minimally impaired and degraded sites, MDA predictions were made for both pond and pond+lake biotic assemblages.

Predicted values for each of the possible metrics 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 metrics, the predicted EQIs of each metric was correlated with measures of environmental degradation for all sites. Environmental degradation was described in terms of overall exposure of sites to point source and diffuse pollutants based on a 1 to 10 ranked scale (overall pollution index)[14].

Appendix 12 gives scatter diagrams showing the relationships between metrics and this degradation measure. Ideally, good metrics will show a strong linear relationship with degradation factors and moderate or low variability.

In general, metrics based on indices (such as ASPT) showed less variability than those based on taxonomic richness. For some of the family richness EQIs maximum values of up to 2.5 are seen (e.g. marginal and submerged plant species richness, number of Coleoptera families). 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 small, semi-permanent ponds.

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

3.5.2 Pond metrics highly correlated with environmental degradation

Marginal and submerged plant species richness EQI

In ponds, submerged plant species richness EQI was strongly negatively correlated with overall pollution (Appendix Figure 12.1; note that in these figures the x-axis shows an *increasing* degree of pollution i.e. ponds scoring 10 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.

Number of uncommon plant species EQI

Number of uncommon plant species EQI (NUS) was also highly correlated with the risk of exposure to point and non-point source pollution (Appendix Figure 12.2). EQIs showed a moderate level of variation with most values below 1.3.

Trophic ranking score EQI

Although Trophic Ranking Score is primarily a measure of waterbody enrichment, analysis showed this metric was correlated with a wide range of degradation factors (Appendix Figure 12.3). In terms of its predicted EQI values the metric was strongly correlated with exposure to point and non-point source pollution. As an index it showed moderate variability with some EQIs up to 1.4.

Cover of submerged plants EQI

The percentage cover of submerged plant species was strongly correlated with the risk of exposure to point and non-point source pollution (Appendix Figure 12.4). However, this

[14] Overall pollution index was assessed in terms of exposure to pollution inputs from the pond's surface water catchment (e.g. occurrence of intensive land-use around the pond, runoff from road drains, farmyards or urban catchments etc.) and ranked in the field on a 1-10 scale. To minimise subjectivity, all assessments were made by a single surveyor (PW).

metric was also rather variable, with EQIs up to 2.5, and has not, at present, been used in trials of the IBI.

Average Score per Taxon EQI

ASPT EQI was strongly 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 species richness with few values above 1.2.

Odonata and Megaloptera family richness EQI

As in Phase 2 analysis, Odonata and Megaloptera family richness EQI was highly correlated with risk of exposure to pollutants (Appendix Figure 12.6). The metric was, however, rather variable, with occasional EQI values up to 1.9.

Number of Coleoptera families

The number of Coleoptera families was highly correlated with risk of exposure to pollutants (Appendix Figure 12.7). In regression analysis, this variable added little to the explained variation in pollution index.

Abundance of Ephemeroptera + Plecoptera + Megaloptera + Odonata (EPMO) EQI

The abundance of EPMO was highly correlated with risk of exposure to pollutants (Appendix Figure 12.8). However, this was a highly variable metric with maximum EQIs of 3.0. The metric also added nothing to the explained variation in overall pollution index in regression analysis.

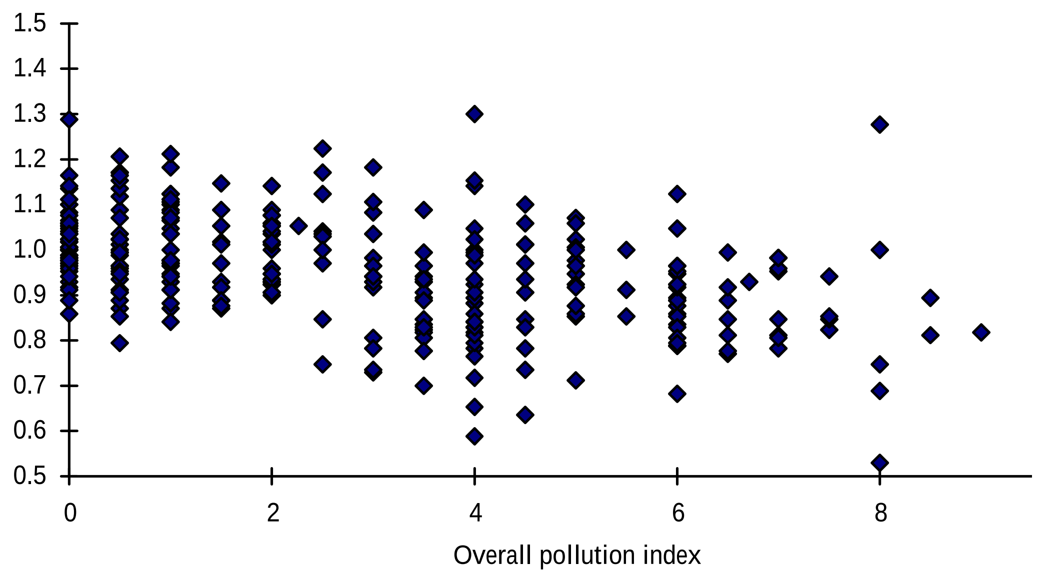

Figure 3.1 The relationship between pond average score per taxon (ASPT) EQI and risk of exposure to point and non-point source pollution.

3.5.3 Comparison of the proportion of degradation explained using single metrics and multiple metrics

To test the effectiveness of the combined metrics in the present study, the pond metric results derived from EQI predictions for all ponds in the data set were investigated to compare the relative proportion of degradation explained by single and multiple metrics.

The results (Table 3.10) show that the IBI (where all metric values were summed), explained about twice as much of the variation in overall pollution index compared to any one metric. Note that the absolute magnitude of correlations in this analysis is less important than their relative magnitude. Overall pollution index is a relatively broad measure of ecosystem degradation and would not be expected to show strong correlations with individual metrics.

Table 3.10 Comparison of the proportion of pond degradation explained using single metrics and multiple metrics

Metric	*Proportion of pond overall pollution index[15] variation explained (r^2)*
IBI (all 6 metrics combined)	0.34
F_OM EQI	0.16
SM_NTX EQI	0.18
TRS_ALL EQI	0.09
ASPT EQI	0.10
PL_NUS EQI	0.10
F_COL EQI	0.10

3.5.4 Canal predicted metrics

The performance of each of the possible canal metrics is reviewed briefly below. Scatter diagrams showing relationships between metric EQIs and water chemistry impairment are given in Appendix 13. The water chemistry impairment measure used in this comparison is Environment Agency water chemistry category. Note that, although useful as broad-based measure for comparative purposes, this measure is not ideal. This is because dissolved oxygen is an important contributory variable in defining water chemistry category and, in canals where DO may be naturally rather low, this can lead to canals being placed in a lower water chemistry category than is appropriate.

ASPT EQI

ASPT EQI was highly correlated with water quality impairment (Appendix Figure 13.1). There were no significant correlations between ASPT EQI and canal bank structure.

[15]See footnote on p32 for explanation of overall pollution index.

EPT (Ephemeroptera, Plecoptera, Trichoptera) family richness EQI

EPT EQI showed a similar trend to ASPT, although there was greater variation in values (Appendix Figure 13.2). This pattern was typical of all metrics involving taxonomic richness.

Family richness EQI

Family richness EQI was strongly correlated with bank structure (Appendix Figure 13.3). The variability of family richness EQI was similar to that for other taxonomic richness metrics. There was, however, also a rather weakly significant correlation with water chemistry ($P>0.1$)

Coleoptera family richness EQI

Coleoptera family richness EQI was the most strongly correlated metric of those tested with bank structure (Appendix Figure 13.4). There was, however, also a correlation between water chemistry and Coleoptera family richness ($p = 0.008$).

3.5.5 Final choice of metrics

Based on the performance of each of the possible metrics in EQI comparisons the final choice of metrics was:

<u>Ponds</u>

- SM_NTX Number of submerged + marginal plant species
- TRS_ALL Trophic Ranking Score for aquatic + marginal plants
- PL_NUS Number of uncommon plant species
- ASPT Average Score per Taxon
- F_OM Number of Odonata and Megaloptera families
- F_COL Number of Coleoptera families

The metric 'abundance of Ephemeroptera + Plecoptera + Megaloptera + Odonata' was omitted from the final choice of metrics because it was highly variable and, in a multiple regression analysis, added nothing to the variation explained in overall pollution index values. Similarly 'cover of submerged plant species' was too variable to function as a viable metric at this stage.

Although the number of Coleoptera families also explained little extra variation in overall pollution index (i.e. it was a redundant variable for measuring water pollution), the metric was retained since beetle family richness can be used, in part, as a measure of pond margin habitat quality and can, therefore, be used to help assess the physical quality of the pond environment.

<u>Canals</u>

- ASPT Average Score per Taxon
- F_EPT Number of Ephemeroptera + Plecoptera + Trichoptera families
- F_COL Number of Coleoptera families
- INV_NFA Total number of invertebrate families

3.5.6 Metric normalisation

Metric normalisation was undertaken to convert the metrics EQIs to a standard 0 to 3 scale. As in Phase 2, in this initial analysis, a simple categorisation was created by dividing the EQI range equally into four bands (0 = 0-0.24, 1 = 0.25-0.49, 2 = 0.50-0.74, 3 = 0.75 and above). New category boundaries developed in the current phase following further investigation of PSYM variability (see Section 5.4) were not applied to the present examples.

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 is presented as a percentage of the maximum (i.e. the undisturbed state).

3.5.7 Case studies

In order to give an indication of the type of results produced using Pond and Canal PSYM, four 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 lake IBIs based on plant and macroinvertebrate assemblages
3. Use of canal invertebrate IBIs to describe the ecological integrity of canals.
4. Use of canal metrics to distinguish the effects of water quality and bank structure.

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, seriously degraded and minimally impaired ponds. The total number of sites used was 298 (152 minimally impaired and 146 variably degraded). Seriously degraded ponds were all those in the dataset with Overall Pollution Index (OPI) values of 7.0 or more (7 sites). A similar number of minimally impaired ponds (OPI values = 0) were selected at random from the minimally impaired dataset.

To create a Pond PSYM IBI scores the three priority invertebrate and plant metrics listed in Section 3.5.4 were combined in the trial. The results of the comparison are shown in Table 3.11.

Overall, the analysis showed that the eight trial seriously degraded sites had IBIs that ranged from 28% to 56% of the possible maximum. The minimally impaired sites in the trial all had IBI score that were 70% or more of the maximum possible, (with two interesting exceptions, Malvern Quarry [site code: MAQU] and Ullswater Pond [site code ULPO]). This generally reflected the low exposure of these sites to potential water pollution stresses and location in areas of high quality, semi-natural habitat.

Malvern Quarry was of interest in that it had low scores that were clearly attributable to its physical structure. The site was located on the edge of the Malvern Hills and had a semi-natural woodland and grassland catchment. However it was a steep-sided pond created by quarrying and had partly reinforced stone banks. The hard sides of the site meant that it supported less than half the expected number of marginal plant species giving low SM_NTX EQI values and had low numbers of Coleoptera families.

The other relatively low-scoring site was Ullswater Pond (ULPO), a small, semi-seasonal pool above Ullswater in the Lake District. This site may well have been too temporary to be adequately characterised by the present version of PSYM and work presently in progress to add a specific temporary pond component to PSYM to address this issue.

Table 3.11 Trial IBI (Index of Biotic Integrity) index for seriously degraded and minimally impaired ponds

'Seriously degraded'

Site code	Overall pollution index	SM NTX EQI	Score	PL NUS EQI	Score	TRS ALL EQI	Score	ASPT EQI	Score	F_OM EQI	Score	F_COL EQI	Score	**IBI score**	**IBI % of unimp'd score**
BEDW	7.00	0.31	1	0.00	0	1.04	3	0.96	3	0.00	0	0.61	2	**9**	**50**
STAN	7.00	0.41	1	0.13	0	0.93	2	0.73	2	0.00	0	0.81	3	**8**	**44**
ACLA	7.50	0.47	1	0.25	1	0.89	3	0.91	3	0.31	1	0.26	1	**7**	**39**
BEGO	7.50	0.37	1	0.13	0	0.87	1	0.77	2	0.00	0	0.26	1	**5**	**28**
TODU	7.50	0.05	0	0.00	0	0.85	1	0.83	2	0.00	0	0.50	2	**5**	**28**
HAFA	8.00	0.14	0	0.00	0	0.87	1	0.97	3	0.00	0	0.27	1	**5**	**28**
THCH	8.00	0.54	2	0.00	0	0.78	1	0.51	1	0.00	0	1.14	3	**5**	**28**
TIMK	8.00	0.41	1	0.12	0	1.01	3	1.26	3	1.12	3	0.00	0	**10**	**56**

'Minimally impaired'

Site code	Overall pollution index	SM NTX EQI	Score	PL NUS EQI	Score	TRS ALL EQI	Score	ASPT EQI	Score	F_OM EQI	Score	F_COL EQI	Score	**IBI score**	**IBI % of unimp'd score**
MAQU	0	0.37	1	0.46	1	0.97	3	0.86	3	0.59	2	0.51	2	**12**	**67**
PIGR	0	2.07	3	0.82	3	0.99	3	0.91	3	0.84	3	1.25	3	**18**	**100**
RUPO	0	0.83	3	0.74	2	0.90	1	1.00	3	0.63	2	1.80	3	**14**	**78**
TCP1	0	1.85	3	2.72	3	0.92	2	0.80	2	0.53	2	1.73	3	**15**	**83**
THCO	0	0.85	3	1.00	3	0.48	0	1.12	3	1.53	3	0.57	2	**15**	**83**
WIDU	0	0.69	2	0.68	2	0.80	0	1.06	3	1.32	3	1.20	3	**13**	**72**
VEMO	0	1.69	3	1.32	3	1.12	2	1.04	3	2.07	3	1.44	3	**17**	**94**
UPTP	0	1.37	3	1.00	3	1.10	2	0.96	3	0.40	1	1.14	3	**15**	**83**
ULPO	0	1.22	3	0.58	2	0.87	1	0.99	3	0.00	0	1.04	3	**12**	**67**

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

Case study 2. Lake IBIs based on plant and macroinvertebrate assemblages

For the small sample of 15 lakes in the Phase 3 data set, an IBI score was calculated using an extension of Pond PSYM (Table 3.12). As with the ponds, plant and macroinvertebrate metrics were combined to produce a six metric IBI.

IBI index values ranged from 14 (out of 18) for Llyn Morwynion in Wales to 18 (the maximum) for the exceptionally rich Hatchet Pond (New Forest), Westhay Moor lake (Somerset Levels), Mytchett Lake (on the Basingstoke Canal) and Upton Broad (the cleanest of the Norfolk Broads). The lowest score (14) was for Llyn Morwynion; this was undoubtedly real since this lake, although located in a semi-natural landscape, was a pumped-storage reservoir with a water quality which appeared visibly degraded.

Inspection of the lake predictions suggested that PSYM typically under-predicted the species richness based metrics in lowland lakes, particularly for plants, leading to very high SM_NTX EQI values at some sites (e.g. HATC). Note, however, that several of the sites included in the survey are, indeed, exceptionally rich locations. For example, Hatchet Pond is one of the top three sites surveyed in Britain by Pond Action, in terms of its wetland plant species richness.

Table 3.12 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 index	SM NTX EQI		TRS ALL EQI		PL NUS EQI		F_OM EQI		ASPT EQI		F_COL EQI		**IBI score**	**IBI % of unimp'd score**
ACRE	0.00	1.24	3	0.95	3	0.53	2	0.58	2	1.02	3	1.32	3	**16**	**89**
BAVI	1.50	1.40	3	1.11	3	0.48	1	0.77	3	1.05	3	0.73	2	**15**	**83**
BURT	1.00	1.75	3	1.02	3	1.29	3	0.69	2	0.94	3	0.41	1	**15**	**83**
DUNG	0.50	1.85	3	0.92	3	1.81	3	0.68	2	0.95	3	1.58	3	**17**	**94**
HATC	4.00	2.48	3	1.20	3	2.57	3	0.80	3	1.00	3	1.48	3	**18**	**100**
HOFE	1.00	0.97	3	0.95	3	0.60	2	1.32	3	1.07	3	1.04	3	**17**	**94**
LGOR	0.00	1.11	3	1.27	3	0.42	1	1.14	3	1.14	3	0.56	2	**15**	**83**
LHIR	1.00	1.43	3	1.23	3	0.54	2	0.69	2	0.98	3	1.30	3	**16**	**89**
LMOR	2.00	1.05	3	1.31	3	0.75	2	0.46	1	1.06	3	0.56	2	**14**	**78**
MYTC	4.00	1.94	3	0.96	3	1.47	3	0.80	3	1.14	3	1.22	3	**18**	**100**
NARE	0.00	0.89	3	1.57	3	0.46	1	0.87	3	1.11	3	0.99	3	**16**	**89**
TEWE	0.00	1.75	3	1.10	3	0.97	3	0.46	1	0.89	3	1.32	3	**16**	**89**
UPTO	0.00	1.69	3	0.98	3	0.90	3	0.92	3	1.06	3	1.29	3	**18**	**100**
WEST	1.00	2.05	3	0.92	3	1.11	3	1.02	3	1.03	3	1.93	3	**18**	**100**
WHEL	0.00	1.20	3	0.92	3	0.27	1	1.13	3	1.04	3	1.26	3	**16**	**89**

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

Table 3.13 Trial IBI (Index of Biotic Integrity) for impaired and minimally impaired canals

'Impaired'

Site no.	Canal	ASPT EQI		EPT EQI		NCOL EQI		NFAM EQI		**IBI score**	**IBI % of un-impaired score**
43	Birmingham	0.56	1	0	0	0	0	0.22	0	**1**	**13%**
39	Birmingham	0.56	1	0	0	0	0	0.35	1	**2**	**19%**
38	Birmingham	0.67	2	0	0	0	0	0.27	1	**3**	**25%**
40	Birmingham	0.69	2	0	0	0	0	0.31	1	**3**	**25%**
19	Grand Union	0.75	3	0	0	0	0	0.24	0	**3**	**25%**

'Minimally impaired'

		ASPT EQI		EPT EQI		NCOL EQI		NFAM EQI		**IBI score**	**IBI % of un-impaired score**
48	Basingstoke	0.97	3	0.87	3	1.16	3	1.01	3	**12**	**100%**
50	Basingstoke	0.92	3	0.80	3	0.84	3	0.83	3	**12**	**100%**
51	Basingstoke	1.04	3	1.07	3	0.89	3	1.16	3	**12**	**100%**
86	Chesterfield	0.93	3	1.06	3	0.56	2	0.62	2	**10**	**83%**
113	Leven	1.03	3	1.28	3	1.10	3	1.07	3	**12**	**100%**

Case study 3. Use of canal invertebrate IBIs to describe the ecological integrity of canals.

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. Canals were assessed on the basis of the four priority invertebrate metrics i.e.: ASPT EQI, EPT EQI, number of Coleoptera families EQI (NCOL) and number of families EQI (NFAM) (Table 3.13).

The five degraded canals were located in the West Midlands and Hertfordshire and were all classified by the Environment Agency as having a chemical water quality of E or F. The IBI of these sites ranged from 1 to 3 (out of a total of 12) i.e. between 13% and 25% of the score which would be expected from a minimally impaired site.

The high quality sites were from the Basingstoke, Chesterfield and Leven Canals and were all classified as either chemical Class A or B. These sites had IBI scores which ranged from ranging from 10 to 12 i.e. scores between 83% and 100% of the total which would be expected from a minimally impaired canal.

Case study 4. 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. This gave pairs of samples which were collected under the same chemical quality conditions, but which had contrasting levels of bank structure impairment.

Water quality metrics

The four canal invertebrate metric EQIs were calculated for each pair of sites (ASPT EQI, EPT EQI, number of Coleoptera families EQI (NCOL) and number of families EQI (NFAM) (Table 3.14). At these sites ASPT and EPT EQIs were generally similar regardless or bank type, showing that ASPT values typically reflected water quality rather than habitat structure. There were however a small number of anomalies where ASPT values were lower than might be expected e.g. replicate sites 42 and 43. Sites 85/86 did not follow the general pattern owing to an abundance of filamentous algae on the reinforced bank providing habitat for a rich fauna (with more taxa than the 'natural' bank).

Further analysis suggested that this was largely an effect caused by low taxon richness at some sites. As Figure 3.2 shows, sites with fewer than approximately 8 families (left of dotted line in Figure 3.2) had ASPT values that were relatively unpredictable. This is, because, in taxa poor sites, the occurrence a small number of high (or low) BMWP scoring taxa will exert a considerable effect on ASPT values.

This finding suggest that where canals have low taxon richness (due to poor water quality and/or poor bank structure) water quality may be relatively poorly predicted. Clearly, further work is needed in this area. However, it is likely that the collection and aggregation of two or three seasons of invertebrate data would be likely to solve this problem by providing more comprehensive species lists for each site.

Bank quality metrics

Number of coleoptera families EQI and number of families EQI generally responded, as predicted, to bank quality rather than water quality. However, there were a small number of exceptions where reinforced and vegetated banks had rather similar NCOL and NFAM EQIs (e.g. Sites 101&102, 111&112). In practice, these all proved to be sites where the reinforced banks supported dense stand of filamentous algae. This, presumably, provided an effective alternative habitat to macrophyte stands for many invertebrate families.

Table 3.14 Comparison of IBI scores from 'replicate' canal sites with natural and reinforced banks

Site no.	Canal	Bank type*	Water Quality Scores: ASPT EQI	EPT EQI	**Total water quality**	Bank Quality Scores: NCOL EQI	NFAM EQI	**Total Bank Quality**	**Index of Biotic Integrity: IBI score**	**IBI % of unimpaired score**
12	Oxford	Re	3	3	**6**	1	2	**3**	**9**	**75%**
13		Nat	3	3	**6**	3	3	**6**	**12**	**100%**
17	Grand Union	Re	3	2	**5**	0	1	**2**	**7**	**58%**
18		Nat	2	3	**5**	3	3	**6**	**11**	**92%**
33	Wyrley & Essington	Re	3	2	**5**	1	2	**3**	**8**	**67%**
34		Nat	3	3	**6**	3	2	**5**	**11**	**94%**
43	Birmingham	Re	0	0	**1**	0	0	**1**	**2**	**17%**
42		Nat	2	0	**4**	2	3	**5**	**9**	**75%**
51	Birmingham	Re	3	3	**6**	2	2	**4**	**10**	**83%**
50		Nat	3	3	**6**	3	3	**6**	**12**	**100%**
66	Shropshire Union	Re	3	3	**6**	0	1	**2**	**8**	**67%**
65		Nat	3	2	**5**	2	2	**4**	**9**	**75%**
77	Trent and Mersey	Re	2	2	**4**	1	1	**4**	**8**	**67%**
76		Nat	3	1	**4**	2	3	**5**	**9**	**75%**
82	Basingstoke	Re	3	3	**6**	1	3	**4**	**10**	**83%**
83		Nat	3	3	**6**	3	3	**6**	**12**	**100%**
86	Chesterfield	Re	3	3	**6**	2	2	**4**	**10**	**83%**
85		Nat	3	2	**5**	1	2	**3**	**8**	**67%**
96	Peak Forest	Re	3	1	**4**	0	0	**1**	**5**	**42%**
97		Nat	3	1	**4**	1	2	**3**	**7**	**58%**
101	Lancaster	Re	3	3	**6**	3	3	**6**	**12**	**100%**
102		Nat	3	3	**6**	3	3	**6**	**12**	**100%**
105	Ashby	Re	3	2	**5**	1	2	**3**	**8**	**67%**
104		Nat	3	2	**5**	2	3	**5**	**10**	**83%**
107	Leeds-Liverpool	Re	3	3	**6**	1	3	**4**	**10**	**83%**
108		Nat	3	3	**6**	3	3	**6**	**12**	**100%**
111	Pocklington	Re	3	3	**6**	2	3	**5**	**11**	**92%**
112		Nat	3	3	**6**	3	3	**6**	**12**	**100%**

Bank types*: Re = Reinforced; Nat = Natural

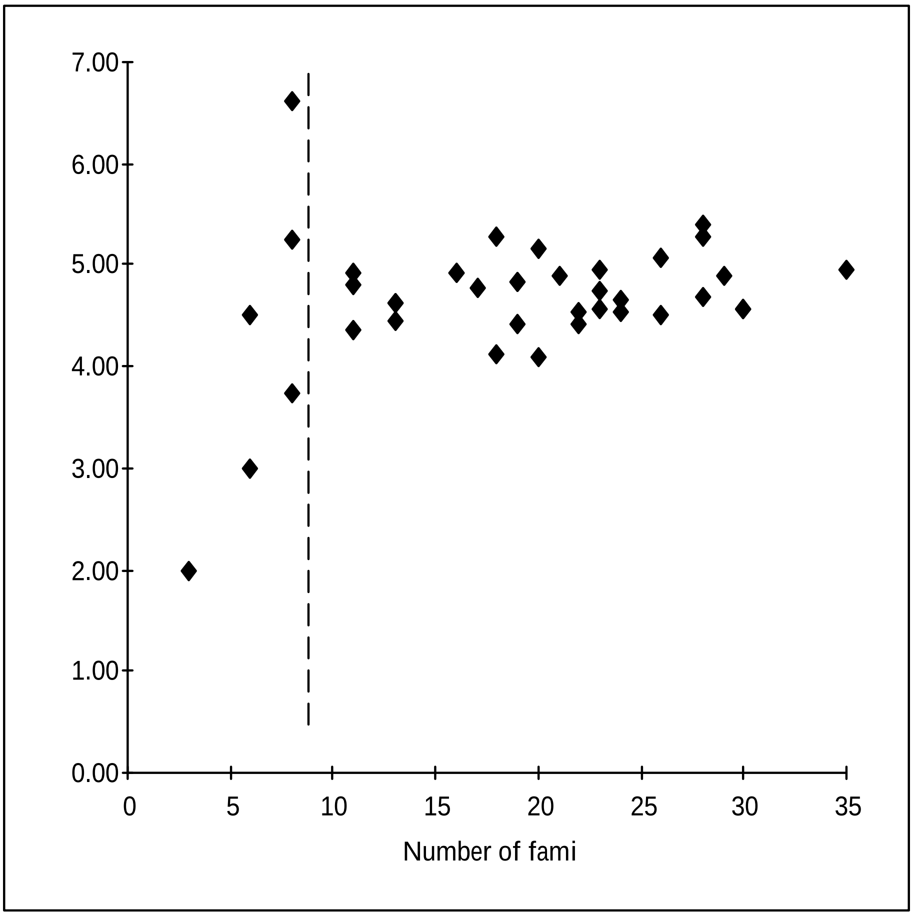

Figure 3.2. Relationship between ASPT and number of invertebrate families in canals from which duplicate samples were taken.

3.6 Running models of the method

Using the predictive equations and metric evaluations developed in this chapter, simple working models of both Pond PSYM and Canal PSYM, have been developed using Excel spreadsheets.

4. PRELIMINARY VARIABILITY STUDY

4.1 Background

A recommendation from the Phase 2 Project was that further work should be undertaken to describe *Pond* PSYM variability including sample, metric and EQI category variation.

It was recognised in the Phase 2 report that a full variability study would be beyond the scope of the Phase 3 project. However, it was suggested a trial assessment of sources of variability in the pond dataset would be possible and worthwhile in that it would give an initial impression of areas that should be of greatest concern.

To this end a small-scale pilot variability study was undertaken in the current phase. The results were used to:

1. Investigate the magnitude of field survey data variability.
2. Evaluate the variability of EQIs and reappraise the banding of EQI categories in the light of metric variability.

The results of these studies are discussed below.

4.2 Field survey data variability

4.2.1 Methods

An initial assessment of the variability of invertebrate, plant and environmental data was made. For this study five ponds were resurveyed including:

- collection of a second invertebrate sample on the same day by the same operator
- a repeat botanical survey at least 1 week later (by the same operator) without reference to the first plant survey records
- a repeat environmental data survey at least 1 week later (by the same operator) without reference to the first survey sheet.

Variability of measurements was assessed in terms of the percentage coefficient of variation (%CV)[16]. This statistic enables the variability of measures of widely differing magnitude to be compared. The %CV was calculated by assessing the mean and standard deviation of the each of the PSYM environmental variables and metrics from the replicate samples. The mean %CV was then calculated for each value for the five sites.

4.2.2 Results

<u>*Environmental data variability*</u>

Altitude, easting, northing, pond area, pH and percentage of the pond margin grazed showed low variability, all having coefficients of variation (CV) less than 4% (see Table 4.1).

[16] The %CV is the standard deviation divided by the mean, with the results expressed as a percentage.

Shade and marginal plant cover showed intermediate levels of variability with CVs of up to 20%. This is in part due to real variation within season, caused by repeat visits which were up to two months apart. It is likely that within season and surveyor variability would be reduced by categorisation of percentages on a 0-4 scale. Preliminary investigation of the MDA predictions suggests that this could be achieved with relatively little loss of predictive ability. Substrate measurements showed greatest variability in the trial but this was largely due to variation at just one site.

Table 4.1 Preliminary assessment of variability of PSYM environmental data: mean %CV of 5 sites which were resurveyed

Environmental variable	Description	Percentage coefficient of variation (%CV)
ALTITUDE	Altitude (m)	1.37%
EASTING	Easting	0.00%
NORTHING	Northing	0.00%
PAREA	Area of pond (m^2)	3.90%
PH_SITE	Water quality: average pH	2.76%
PSHADE_%	% pond overhung	13.70%
INFLOW	Inflow present	0.00%
%MGRAZ	% of margin grazed	3.14%
%MAR_PLT	% cover marginal plants	18.09%
CLAY/SILT	Pond base (clay/silt)	28.28%
SAND/GRAVEL/COBBLES	Pond base (sand/gravel/cobbles)	0.00%
PEAT	Pond base (peat)	0.00%
BEDROCK	Pond base (bedrock)	28.28%
OTHER	Pond base (other)	0.00%

Note that the *relative* importance of different sources of error cannot be assessed from the present, preliminary, study i.e. how much of the variability was due to observations made by the same observer (i.e. the inherent variability of the measurement) and how much variability was due to seasonal variation.

Metric variability

Plant metrics showed low variability, with CVs of approximately 6%, or less (Table 4.2).

ASPT showed low variability, with a CV of approximately 3% (Table 4.2). The two other invertebrate metrics, number of Odonata and Megaloptera families (F_OM) and number of Coleoptera families (F_COL), showed greater variability with CVs of 19% -28%. This reflected the fact that small differences in the numbers of families recorded have a relatively large effect on the metric because the range of possible values for each of these metrics is quite small.

OM can vary from zero to a maximum of six[17]; F_COL varies from zero to eight. This small range of values makes these metrics rather variable: if one more or less family is recorded these metrics will inevitably vary by about 15% - 20%. Further operational experience of these metrics will probably be necessary before it becomes clear whether they should be retained.

Table 4.2 Preliminary assessment of variability of PSYM metrics: mean %CV of 5 sites which were resurveyed at one week intervals

Metric	Description	Percentage coefficient of variation (%CV)
Plants:		
NO.SUB+MARG	No. of submerged and marginal species	2.76%
ALL_TRS	All plant Trophic Ranking Score	0.82%
PL_NUS	No. of uncommon plant species (all plant species)	5.93%
Macroinvertebrates:		
ASPT	Average Score per Taxon	2.91%
F_COL	No. beetle families	18.86%
F_OM	No. of Odonata + Megaloptera families	28.28%

4.3 Variability of EQIs

4.3.1 Method

In Phase 2 of the project a simple system was adopted for the banding of EQIs. This system was also used in the trials described in Chapter 3. However, in the current project phase refinements to EQI banding were also further investigated by reviewing the variability of EQIs for all sites in the minimally impaired database.

Since sites in the database should, by definition, be good quality, the ratio of the predicted to observed values should be close to one. The distribution of EQIs around a mean value of 1.00 can be used as a criterion for setting of band limits: particularly the lower limit of the upper, 'minimally impaired' band.

4.3.2 Results

Plots of the frequency distribution of each metric EQI are shown in Figures 4.1 to 4.6. Each plot is discussed briefly below. Table 4.3 summarises recommendations for the new band widths.

[17] Ponds can support 1 Megaloptera family and up to 5 families of Odonata.

Number of submerged and marginal plants. Number of submerged and marginal plants was moderately well predicted using the current data. The data show that 80% of minimally impaired sites have EQIs above 0.75 and this has provisionally been adopted as the lower band of the 'undamaged' group. Lower bands are set at intervals of 0.25 EQI units.

Trophic ranking score. Trophic ranking score is predicted slightly more accurately than either of the other two plant metrics (which are both based on numbers of taxa). At present, about 90% of sites have EQIs above 0.8 and below 1.2. Using these data, together with empirical evidence, bands have been set at 0.5 TRS units above or below the predicted value. Note that TRS is an unusual metric in that variation must be accounted for both above and below the predicted values: TRS EQIs which are higher than predicted suggests evidence of eutrophication; lower values suggest acidification.

Figure 4.2, showing TRS EQI variability, has a frequency distribution slightly skewed to the left suggesting less accurate prediction of acid sites. Evidence from practical testing of the PSYM database (see Appendix 14) confirms that acid lowland sites in particular are relatively poorly predicted at present. This is largely because insufficient ponds located on sandstone lithologies in Southern England have been included in the database. The addition of further sites to the database will be needed to reduce the variability of this metric.

Number of uncommon and rare plant species. The number of rare and uncommon plant species is at present one of the least satisfactory of the metrics in terms of its variability. As Figure 4.3 shows, numbers of uncommon species are poorly predicted at many sites, leading to a severely skewed distribution of EQI values. Prediction is particularly poor for those sites which have no, or only 1, rare plant species.

This metric is potentially a good one since it is highly correlated with landscape intensification and pond degradation. However, currently, its omission from the metrics needs to be considered until its performance can be improved. Two factors could be influential in this (i) incorporation of additional pond sites into the database which should improve the predictability of this measure within end-groups (ii) the forthcoming publication of the results of the Atlas 2000 project, a new national botanical atlas funded by DETR, which will provide more accurate plant distribution statistics. The latter will allow creation of a greater number of plant rarity categories which will, in turn, reduce the number of sites with low rarity scores.

ASPT. ASPT shows the least variability of the metrics tested to date. 90% of sites have EQIs greater than 0.85 and this value has been set as the lower limit of the upper 'minimally impaired' band.

Number of Coleoptera families. Number of Coleoptera families shows moderate variability. Approximately 90% of sites have EQI values above 0.75; consequently the lower limit of the 'minimally impaired' band has been set at this value. Other bands have been set at equal width to the upper band.

Number of Odonata and Megaloptera families. Number of Odonata and Megaloptera families is not well predicted at present and this metric show considerable EQI variability. This primarily reflects the fact that sites with few of these taxa are not well predicted. It is possible that, although this metric is strongly correlated with water quality impairment, it will prove to be too variable for routine use.

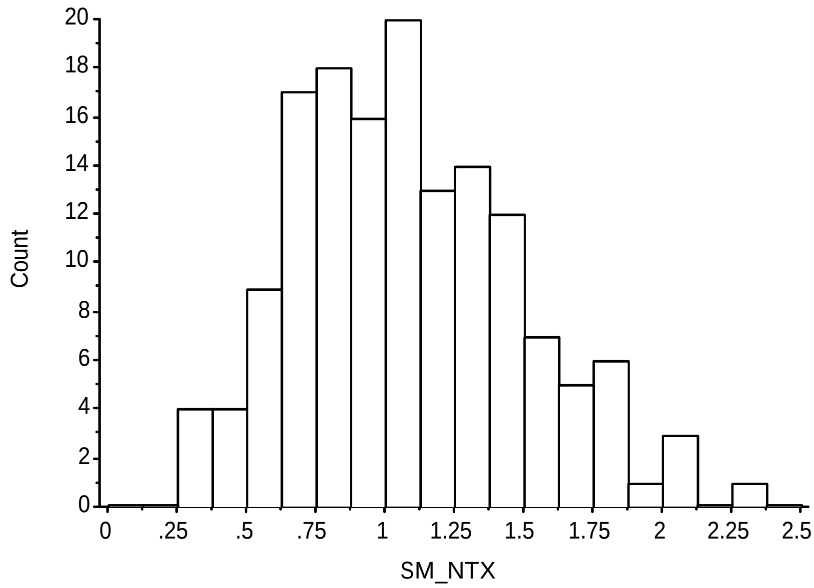

Figure 4.1. Frequency distribution of the number of submerged and marginal plants (SM_NTX) metric EQI for 150 NPS sites

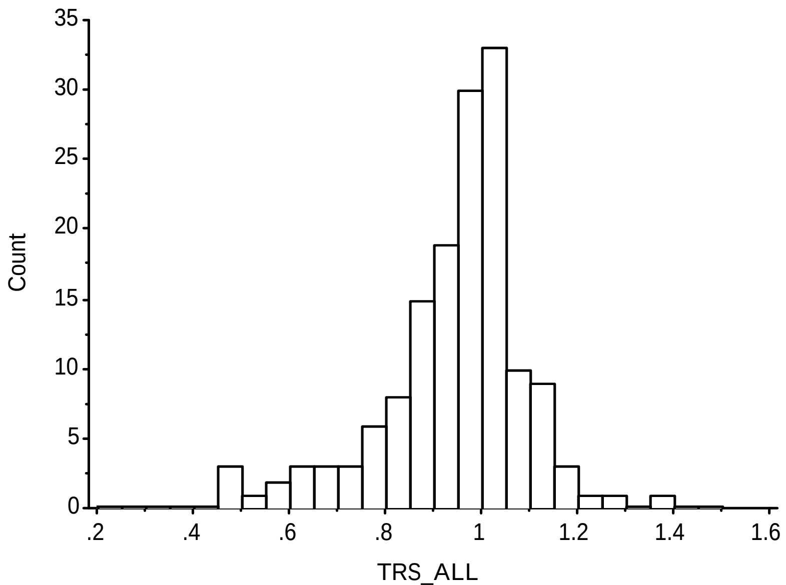

Figure 4.2. Frequency distribution of the Trophic Ranking Score (TRS_ALL) metric EQI for 150 NPS sites

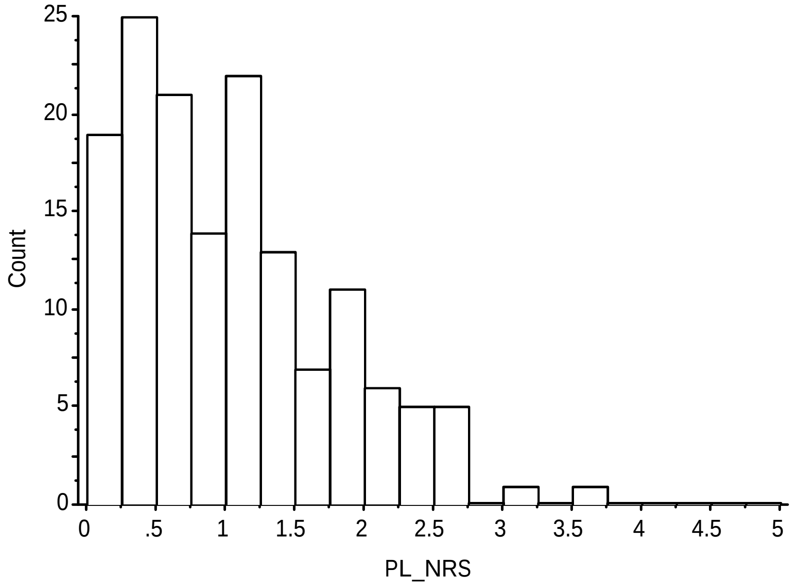

Figure 4.3. Frequency distribution of the number of rare and uncommon plant species (PL_NUS) metric EQI for 150 NPS sites

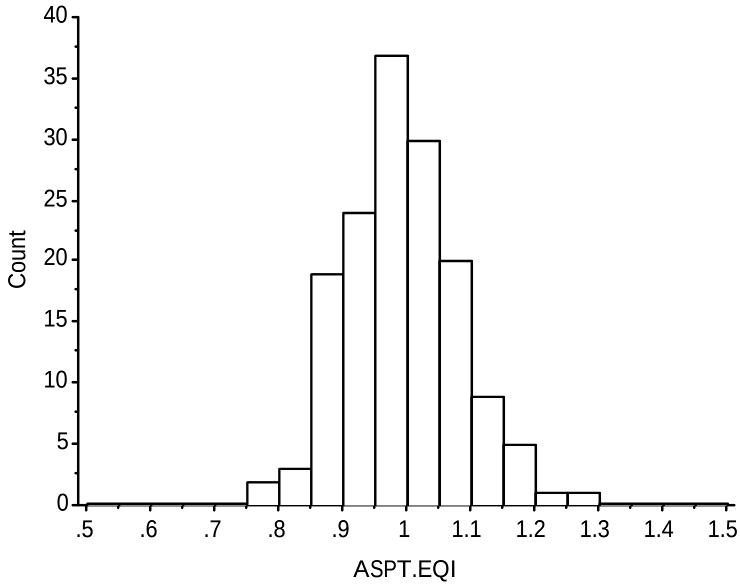

Figure 4.4. Frequency distribution of the Average Score per Taxon (ASPT) metric EQI for 150 NPS sites

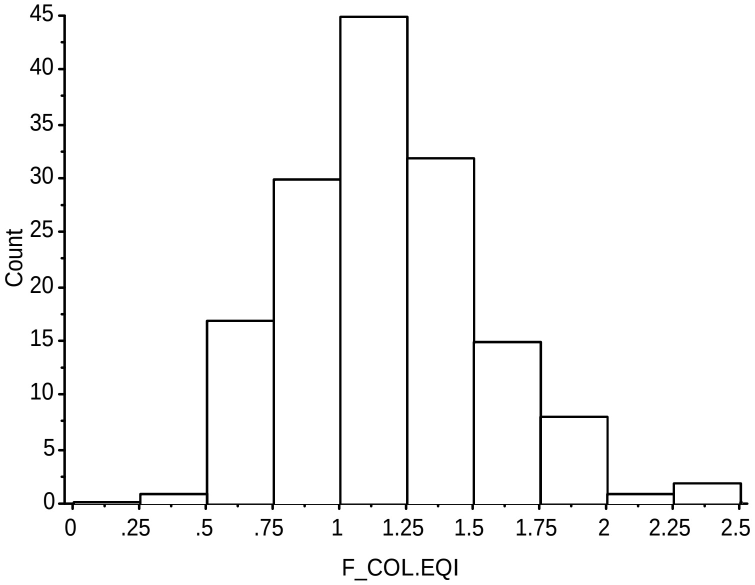

Figure 4.5. Frequency distribution of the number of Coleoptera families (F_COL) metric EQI for 150 NPS sites

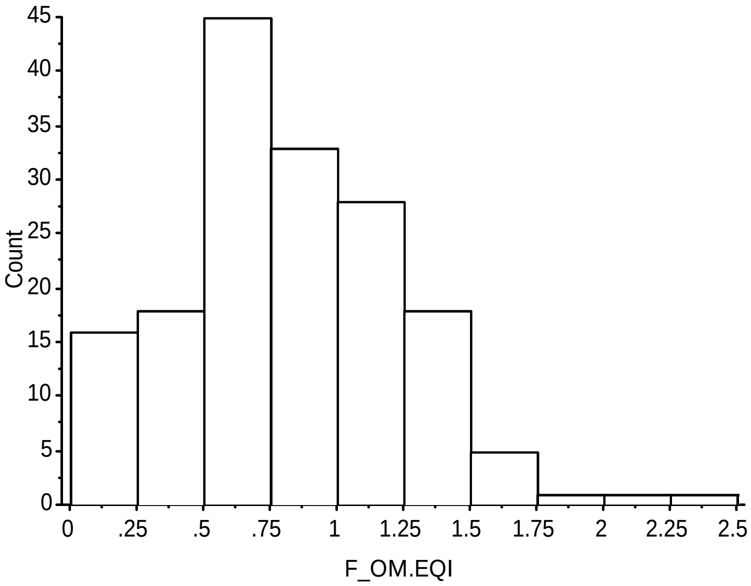

Figure 4.6. Frequency distribution of the number of Odonata and Megaloptera (OM) metric EQI for 150 NPS sites

4.3.3 Revised bandings

The revised quality bands for each metric are summarised in Table 4.3. The table includes number of uncommon plant species (PL_NUS) and number of families of Odonata and Megaloptera (OM), although in practice, neither of these metrics are currently predicted with good reliability.

Discussion of strategies for further metric development are given below (see Section 4.4).

Table 4.3 Revised bandings of the six metrics currently being developed in the PSYM system

Band	NO.SUB+ MARG	ALL_TRS*	PL_NUS	ASPT	F_COL	OM
1 Good	=0.75	0.95-1.05	=0.75	=0.85	=0.75	=0.75
2 Moderate	0.50-0.74	0.90-0.94 1.06-1.10	0.50-0.74	0.70-0.84	0.50-0.74	0.50-0.74
3 Low	0.25-0.49	0.80-0.89 1.11-1.15	0.25-0.49	0.50-0.69	0.25-0.49	0.25-0.49
4 Poor	<0.25	<0.80 >1.15	<0.25	<0.50	<0.25	<0.25

* NB two TRS values are given: one for values that are lower than predicted (i.e. more acid), one for higher (i.e. more eutrophic) values.

4.4 Further development of metrics

Further refinement of the metrics has two broad components:

- improving predictability of metrics (i.e. reducing EQI variability)
- selecting metrics which can be predicted more accurately, leading to better EQI predictions.

4.4.1 Improving predictability of metrics.

Prediction of most of the metrics currently being used is likely to be improved with a larger site database. At present, with only 150 baseline sites in the database, it is clear that some pond types are classifying into TWINSPAN end-groups composed of rather dissimilar sites.

Collection of a greater number of sites is likely to make differences in community types rather clearer. Metrics which would be likely to particularly improve with an expanded data set are: number of submerged and marginal plants (SM_NTX), Trophic Ranking Score (ALL_TRS), Average Score per Taxon (ASPT) and number of Coleoptera families (F_COL) . It is less clear whether number of uncommon plant species (PL_NUS) and number of Odonata and Megaloptera (F_OM) families will be improved equally since these currently have other flaws (see below).

Observation of end group membership in the plant TWINSPAN suggests that it would be particularly useful to have additional sites with the following characteristics:

(i) acid heathland sites in southern Britain,
(ii) very small ponds with limited numbers of species,
(iii) exceptionally species-rich sites.

Invertebrate assemblage types which are not well predicted and would benefit from further site data include:

(i) sites supporting relatively few water beetle families, including shallow acid pools in southern England and Wales,
(ii) ponds with shaded or little vegetated margins (again producing relatively species-poor faunas),
(iii) sites of exceptional species richness.

In addition, the inclusion of three seasons of invertebrate data would undoubtedly improve the predictability of invertebrate metrics. In RIVPACS for example predictions based on the single season database are 30-40% more variable than those based on three seasons.

4.4.2 Options for modifying existing metrics

Some of the metrics used in the PSYM analysis could undoubtedly be improved. This is particularly true of metrics which currently have a small range of possible values (e.g. number of OM families), so that small differences in the number of taxa collected inevitably producing large differences in EQI.

With invertebrate metrics, a number of options are possible including:

1. Replacing numbers of Odonata and Megaloptera families with a metric based on the number of *genera* in these groups. This would double the range of possible values the metric could take. However, the additional taxonomic expertise required would be considerable, particularly in dividing damselflies such as *Ischnura* and *Coenagrion*.
2. Replacing number of Odonata and Megaloptera families (OM) with another metric. Total number of invertebrate families is one potential option, and would have the advantage of having a larger range of possible values, as there are about 60 possible families which could be recorded. Number of families also shows a good distribution of EQI values. The disadvantage of this potential metric is that it does not have such a strong relationships with environmental degradation as number of Odonata and Megaloptera families.
3. Developing a new index of quality (analogous to the BMWP system) which reflects the likelihood of species or families being associated with undegraded ponds. The NPS database and other literature values would probably be adequate to develop a pilot version of such an index. A benefit of this option is that ASPT scores would also be improved for ponds.

With respect to plant metrics, it was noted above that the number of uncommon plant species (PL_NUS) metric will be able to be improved following the publication of Atlas 2000 data which will allow creation of a greater number of rarity classes and, therefore, greater metric resolution.

Similar improvements in pond Trophic Ranking Score are also possible. In the current system plant TRS values have been derived from Palmer's lake classification (Palmer *et al.*, 1992). This means that (i) some plants do not have TRS scores and (ii) the lake-based scores may not be totally appropriate for ponds. Additional analysis to derive pond TRS scores (using the existing pond data) would be likely to improve this metric. This could either include adding TRS values to Palmer's system for lakes, or developing a new set of TRS values for pond plants.

5. CONCLUSIONS AND DISCUSSION

The aim of Phase 3 work has been to extend PSYM development from a regional trial to a method which can be used across England and Wales to assess pond, small lake and canal quality.

The current report describes:

1. The initial development of PSYM for pond, small lake and canal quality assessment at national level including:
   (i) development of MDA techniques to predict the plant and/or macroinvertebrate species which should occur at a site using simple physico-chemical data alone,
   (ii) identification of biological metrics which can be used to track degradation,
   (iii) initial trials using the project data sets to identify how well the method is working.
2. A preliminary assessment of pond metric variability.

5.1 Prediction of plant and invertebrate communities

Ponds and small lakes

Models to predict the plant and invertebrate communities that should occur in ponds were developed using a data set of 152 minimally degraded sites. This was about double the number of ponds used in Phase 2 analysis. However, since the land area also increased by 70%, overall pond density was lower than in the Phase 2 trial.

TWINSPAN analysis of biotic data from the ponds produced plant and invertebrate classifications with a strong pH gradient. Not surprisingly, therefore, pH and its co-correlates (easting, altitude, base geology) were generally the most effective variables explaining TWINSPAN end group membership. Pond area was also an important predictive variable.

The amount of variation that physico-chemical variables could predict in multiple discriminant analysis was slightly lower than in Phase 2. However, 66% - 69% of ponds could still be placed in their correct end-group, with plant and invertebrate data respectively, using a relatively small number of environmental variables (n=8 for plants, n=13 for invertebrates).

To analyse the potential to extend the Pond PSYM method to encompass small lakes, a second data set was investigated. This comprised the reference ponds plus 15 small lakes (2 ha -10 ha in area). Analysis of these data gave similar results to the pond-only TWINSPAN. The predictive variables were also similar.

Canals

Canal analysis used a data set of 46 minimally degraded sites and involved assessment of invertebrate communities alone.

Following TWINSPAN classification and MDA analysis, six variables were used for end-group prediction. These were related to canal location, boat traffic, sediment and water chemistry characteristics. The amount of variation that physico-chemical variables could predict in multiple discriminant analysis was similar to Phase 2, with 70% of canals placed in their correct end-group using six environmental variables.

5.2. Identification of biological metrics which can be used to track degradation

Ponds

Using the pond data set, 48 plant and 140 invertebrate attributes were calculated in order to identify metrics which could be used to track degradation. The list included abundance attributes (abundance of mayflies, total number of insects etc.) for the first time.

Correlation analysis was used to identify metrics which were strongly related to degradation measures (such as intensive land use, water pollutants etc.), but were relatively weakly associated with 'natural' variation that could potentially 'dilute' the degradation signal. This analysis was undertaken using a data set which included the reference sites plus the 146 variably degraded ponds.

The results of analysis indicated that a wide range of biological variables showed some relationship with degradation. As in Phase 2, correlations between invertebrate taxa and pollutant variables were similar at species-level and family-level. This implies that, for the invertebrate component of Pond PSYM, family level identification is likely to be adequate. Correlation analysis of the relationships between abundance metrics and environmental variables showed that abundance was often strongly associated with degradation, particularly amongst insect groups. Indeed, abundance metrics were often correlated with degradation at similar or greater significance levels than were family or species-level metrics. However, at present abundance metrics could not be predicted with sufficient accuracy for reliable use.

The final choice of six metrics for monitoring pond and lake degradation in PSYM balanced a mixture of taxa-richness metrics and 'pollutant indices' (such as trophic ranking score). They were:

- SM_NTX Number of submerged and marginal plant species
- TRS_ALL Trophic ranking score for aquatic and marginal plants
- PL_NUS Number of uncommon plant species
- ASPT Average Score per Taxon
- F_OM Number of dragonfly and alderfly families
- F_COL Number of beetle families

One metric, number of beetle families, was specifically included to help provide an indication of bank quality.

Multiple regression analysis using these metrics showed that by summing them to create an IBI score it was possible to explain considerably more variation in pond pollution than was possible using single metrics alone.

Canals

Correlation of invertebrate attributes and physico-chemical variables showed that a range of biological attributes had strong monotonic relationships with degradation measures.

Again, the range of significant relationships were similar to those shown by the Phase 2 analyses. ASPT and EPT were both effective metrics for assessing water and sediment pollutants. In contrast, metrics based on Coleoptera richness and total family richness were useful indicators of bank habitat quality. As with the pond analyses correlations between invertebrate taxa and pollutant variables were similar at species-level and family-level.

The final choice of four metrics for monitoring canals using PSYM was therefore:

- ASPT Average Score per Taxon.
- F_EPT Number of Ephemeroptera + Plecoptera + Trichoptera families.
- F_COL Number of Coleoptera families.
- INV_NFA Total number of invertebrate families.

5.3 Initial trials

In order to investigate the current viability of the PSYM method, four trials were undertaken using the project's pond, small lake and canal data sets.

Trial 1. Use of IBIs to describe the ecological integrity of ponds

Comparisons of PSYM scores from some of the least and most polluted sites in the pond database showed clear differentiation of IBI scores between these sites. The lowest IBI scores obtained were about 25% of the possible maximum value whereas minimally impaired sites generally had values of about 80%+ of the maximum.

Trial 2. Use of lake IBIs based on plant and macroinvertebrate assemblages

The application of PSYM techniques to the 15 minimally impaired lakes indicated that most were of high biological quality, as would be expected from their location in landscapes where they were little exposed to environmental degradation. IBI scores were generally higher than for the minimally impaired ponds. This was probably, in part, a reflection of the under-prediction of richness-based metrics caused by the larger size of these waterbodies. Lakes were not identified as a specific species rich group in the TWINSPAN classification, and consequently end-group numbers of taxa predicted were markedly below the average for lakes.

Trial 3. Use of canal IBIs based on plant and macroinvertebrate assemblages

Comparisons of PSYM scores in canals from high and low water chemistry bands showed clear differentiation of IBI scores between these sites. In chemically poor canals the lowest IBI scores obtained were between 13% and 25% of the score which would be expected from a minimally impaired site. High quality sites generally had values of about 88% -100% of the expected value.

Trial 4. Use of canal metrics to distinguish the effects of water quality and bank structure

A comparison of samples taken from hard reinforced banks and well vegetated banks at the same location provided an opportunity to investigate how effective metrics were at assessing water quality (using ASPT and EPT) and bank quality (using number of taxa and number of beetle taxa). The results suggested that the metrics generally performed well. However, ASPT was less effective (i.e. gave more variable results) in samples with very few taxa. Collection of data in additional seasons (cf. RIVPACS) is likely to improve the metric.

5.4 Variability

Trial variability studies were undertaken using Pond PSYM data in order to:

1. Investigate the magnitude of field survey data variability.
2. Evaluate the variability of EQIs and reappraise the banding of EQI categories in the light of metric variability.

Field survey data variability was investigated through collection of replicate physico-chemical and biological data at five sites. The results showed that the variability of most field measures was low (< c.5%). However a number of measures had higher variability (13%-28%).

The most variable physico-chemical measures were: substrate, tree cover and vegetation cover. Differences in substrate measurements were due to within-person variability. Variation in vegetation and tree cover measurement were due to a mixture of within-person and within-season variability. Extending PSYM to further seasons would not greatly alter the ability to estimate substrate and tree cover. Substrate is measured as the composition of the pond base (not superficial sediments) and does not alter seasonally. Tree cover is measured as a percentage of the pond overhung, which can also be estimated irrespective of the season. Vegetation cover would have to be estimated in the summer season.

The most variable biotic metrics were: number of beetle families and number of Odonata and Megaloptera families. The variability of both metrics was due to the relatively small number of taxa included in these groups. This meant that if one more or less family was recorded these metrics inevitably varied by 15%-20%.

Metric EQI variability and the implications for banding categories were investigated by looking at the frequency distribution (around 1.00) of EQI values for each predicted metric using reference site data. The results suggest that indices (e.g. ASPT, TRS) were generally predicted more accurately than metrics based on number of taxa. The metrics which were poorest were number of Odonata and Megaloptera families and number of uncommon plant species. The results of this analysis were used to redefine banding categories for each metric so that divisions between bands currently reflect the natural variability of each metric at high quality sites.

5.5 Recommendations

Following Phase 3 development, PSYM can be used to provide a single season assessment of pond and canal quality in Environment Agency regions across England and Wales.

There are, however, a number of areas in which further refinement could be used to optimise the method's effectiveness in these waterbodies. These include: (i) collection of data from additional sites and seasons (ii) further development of metrics and (iii) further studies of sources of variability in the database and metrics. PSYM is designed for the incorporation of new metrics as the need arises, and the ability to add new metrics is a feature of the system.

Collection of 3 seasons of data for both ponds and canals

Currently, invertebrate predictions for ponds and canals are based on data from a single season. Collection of similar data from a further 2, 3 or 4 seasons would be likely to considerably improve the predictive ability and variability of metrics (cf. RIVPACS).

With respect to ponds, Pond Action have already collected three season invertebrate data from about 100 pond sites in England and Wales. 95% of the invertebrate samples from these sites have now been identified. This means that a start could potentially be made on such an analysis. For canals, however, additional data would have to be collected from all sites.

Collection of data from additional sites

The pond reference database currently comprises only 150 pond sites. Clearly collection of data from additional reference sites would be likely to improve predictions for a wide range of ponds and pond metrics. Gaps which are particularly evident include a need for acid ponds in lowland SE England, small ponds and ponds which naturally have poorly vegetated margins such as shaded sites.

Identification of additional diagnostic metrics

Some of the metrics currently used in the PSYM analysis could undoubtedly be improved.

As noted in Phase 2, the existing data sets contain a considerable amount of information which could be very usefully used to develop metrics. For example, analysis of the existing pond data could be used to refine metrics such as Trophic Ranking Score and BMWP/ASPT so that they reflect the pond environment more specifically.

The metrics which are most variable are those which currently have a small range of possible values (e.g. number of OM families and number of uncommon plant species). For these metrics, small small differences in the number of taxa recorded produce large differences in EQIs.

It will be possible to improve one of these metrics, numbers of uncommon plant species, in the near future, following the publication of DETR/BSBI Atlas 2000 results. This will provide up-to-date information about the distribution status of all wetland plant species across England and Wales, enabling the creation of a greater number of rarity classes and giving greater metric resolution.

The current variability of the number of OM families metric is more difficult to resolve, and ultimately, it may be necessary to remove or replace this metric.

The most likely replacement candidate is total invertebrate family richness (analgous to TAXA in the BMWP system). The disadvantage of this measure as a metric is that its relationships with environmental degradation are weaker than for Odonata and Megaloptera families. This is largely because family richness also responds to a range of natural variables such as pond shade and vegetation abundance. It is, however, possible that as further sites are added to the database it may be possible to recognise groups of sites which are similar both in terms of broad community composition (the basic objective of TWINSPAN) and also in terms of species richness. This would improve the ability to predict metrics based on numbers of taxa.

5.6 Future implementation of PSYM

5.6.1 Developing Pond PSYM

The first draft of a plan for the future implementation of Pond PSYM as a monitoring and assessment method was submitted to the Project Board in September 1999. Further development and implementation of PSYM is needed to assist the Agency in (i) fulfilling its statutory responsibilities for the monitoring of controlled waters, (ii) providing information for State of the Environment reporting purposes, (iii) assisting with the responsibility to monitor catchments as part of the Water Framework Directive and (iv) contributing effectively to biodiversity strategies at local and national level.

A copy of this plan is available from the Project Leader, Shelley Howard. However, in brief, it suggests that the way forward should be to consider the future use and development of Pond PSYM as two tracks:

Track 1. Practical application of PSYM to assess and monitor ponds

The responsibility for using PSYM to monitor and assess ponds should be shared amongst statutory agencies and NGOs with the Environment Agency, DETR, English Nature, CCW, local authorities, Pond Action and the Ponds Conservation Trust as the major partners. It is suggested that, at least initially, the Environment Agency takes a leading role in developing and brokering a pond monitoring framework. Since the negotiations involved are likely to be wide ranging, they are likely to be most effective where undertaken by dedicated member of staff, preferably one seconded to a relevant partner organisation such as the Ponds Conservation Trust.

Track 2. Further development of the method.

The overall responsibility for developing PSYM further should be taken by the Environment Agency and Pond Action in partnership. Possible funding sources include the Agency R&D budget as well as other sources such as the research councils and EU 5th Framework programme.

5.6.2 Developing Canal PSYM

The further development of Canal PSYM depends largely on the approach taken to PSYM by the Agency and other statutory bodies, particularly British Waterways, in developing the method further.

5.6.2 Using PSYM to assess other still waters

To date PSYM has been most fully developed for ponds and canals. The methodology is, however, equally applicable to other still water systems such as ditches and lakes.

Development in these areas has begun for some waterbody types. The creation of Temporary Pond PSYM has been initiated by Pascale Nicolet as part of her PhD work funded by the FBA and Pond Action. With lakes and ditches an initial stumbling block to PSYM development has been the lack of a standard methodology for sampling these waterbodies. As a step towards this, preliminary discussions have been held with biologists in the Southern Region of the Agency, with respect to the Agency agreeing a standard method for ditch sampling. Development of Lake PSYM may be the focus of a Pond Action / Environment Agency bid to the EU submitted under the 5th Framework programme in 2000.

6. REFERENCES

Allaby, M. (1985). *Dictionary of the environment*. Macmillan Press, London.

Armitage, P.D., M.T. Furse and J.F Wright. (1979). A bibliography of works for the identification of freshwater invertebrates in the British Isles. *Freshwater Biological Association Occasional Publication* No. 5.

Armitage, P.D., D. Moss, J.F. Wright, and M.T. Furse (1983). The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. *Water Research*, **17**, 333-347.

Barr, C.J., R.G.H. Bunce, R.T. Clarke, R.M. Fuller, M.T. Furse, M.K. Gillespie, G.B. Groom, C.J. Hallam, M. Nornung, D.C. Howard and M.J. Ness (1993). *Countryside Survey 1990 Main Report*. Countryside 1990 series, **2**. HMSO, London..

Biggs, J., A. Corfield, D. Walker, M. Whitfield, and P. Williams (1997). *Investigation into macroinvertebrate sampling variability*. Environment Agency Thames Region Operational Investigation. No. 0I/T/001. Environment Agency, Reading.

Clarke, R.T., M.T. Furse, J.F. Wright and D. Moss (1996). Derivation of a biological quality index for river sites: comparison of the observed with the expected fauna. *Journal of Applied Statistics*, **23**, 311-332.

Collinson, N.F., J. Biggs, A. Corfield, M.J. Hodson, D. Walker, M. Whitfield and P.J. Williams (1994). Temporary and permanent ponds: an assessment of the effects of drying out on the conservation value of aquatic macroinvertebrate communities. *Biological Conservation*, **74**, 125-133.

Hill, M.O., 1994. *DECORANA and TWINSPAN, for ordination and classification of multivariate species data: a new edition, together with supporting programmes, in FORTRAN 77*. Institute of Terrestrial Ecology, Huntingdon.

Johnes, P., B. Moss and G. Phillips (1994). Lakes - classification & monitoring. *National Rivers Authority R&D Note 253*. National Rivers Authority, Bristol.

Karr, J. R. (1995). Protecting aquatic ecosystems: clean water is not enough. In: *Biological assessment and criteria* (Eds: Davis, T, P. and Simon S., W.). Lewis Publishers, Boca Raton.

Palmer, M.A., S.L. Bell and I. Butterfield (1992). A botanical classification of standing waters in Britain - applications for conservation and monitoring. *Aquatic Conservation - Marine and Freshwater Ecosystems*. **2**, No. 2, 125-143.

Pond Action (1994). *National Pond Survey Methods Booklet*. Pond Action, Oxford.

Pond Action. (1997). *Wetland creation and management*. R&D Technical Report W24. Environment Agency, Bristol.

Ward, J,V. (1992). *Aquatic insect ecology. 1. Biology and habitat*. John Wiley and Sons, New York.

Williams, P., J. Biggs, L. Dodds, M. Whitfield, A. Corfield and G. Fox (1996). *Biological techniques of still water quality assessment. Phase 1 Scoping Study*. Environment Agency R&D Technical Report E7. Environment Agency, Bristol.

Williams, P., J. Biggs, M. Whitfield, A. Corfield and G. Fox, K. Adare (1998). *Biological techniques of still water quality assessment* : *2. Method development.* Environment Agency R&D Technical Report E56. Environment Agency, Bristol.

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

Wright, J.F. (1995). Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. *Australian Journal of Ecology*, **20**, 181-197.

Wright, J.F., D. Moss, P.D. Armitage and M.T. Furse (1984). A preliminary classification of running-water sites in Great Britain based on macro-invertebrate species and the prediction of community type using environmental data. *Freshwater Biology*, **14**, 221-256.

Moss, D., Furse, M.T., Wright, J.F. and Armitage, P.D. (1987). The prediction of the macro-invertebrate fauna of unpolluted running-water sites in Great Britain using environmental data. *Freshwater Biology*, **17**, 41-52.

Wright, J.F., Clarke, R.T., Gunn, R.J.M., Blackburn and Davy-Bowker, J. (1999). Testing and further development of RIVPACS Phase 3. Environment Agency R&D Technical Report E71. Environment Agency, Bristol.

APPENDICES

Appendix 1

A guide to monitoring the ecological quality of ponds and canals using PSYM

MAY 2000

Environment Agency Project Leader
Shelley Howard
Environment Agency Midlands Region
Sapphire East
550 Streetsbrook Road
Solihull
West Midlands B91 1QT

Pond Action
c/o Oxford Brookes University
Headington
Oxford, OX3 0BP
Telephone: 01865 483278
E.mail: jbiggs@brookes.ac.uk

MONITORING THE QUALITY OF STILL WATERS USING PSYM

1. Introduction

PSYM, the Predictive SYstem for Multimetrics, (pronounced sim) has been developed to provide a method for assessing the biological quality of still waters in England and Wales.

The method uses a number of aquatic plant and invertebrate measures (known as metrics)[18], which are combined together to give a single value which represents the waterbody's overall quality status.

Using the method involves the following steps:

1. Simple environmental data are gathered for each waterbody from map or field evidence (area, grid reference, geology etc.).

2. Biological surveys of the plant and animal communities are undertaken and net samples are processed.

3. The biological and environmental data are entered into the PSYM computer programme which:

   (i) uses the environmental data to predict which plants and animals should be present in the waterbody if it is undegraded,

   (ii) takes the real plant and animal lists and calculates a number of metrics[1].

Finally the programme compares the predicted plant and animal metrics with the real survey metrics to see how similar they are (i.e. how near the waterbody currently is to its ideal/undegraded state). The metric scores are then combined to provide a single value which summarises the overall ecological quality of the waterbody. Where appropriate, individual metric scores can also be examined to help diagnose the causes of any observed degradation (e.g. eutrophication, metal contamination).

2. Background

2.1 Why develop the method?

Historically, the Environment Agency and other statutory bodies have undertaken relatively little monitoring of still waters (lakes, ponds, canals, ditches etc.). A major barrier to the future assessment of these waterbodies is the absence of a standardised assessment methodology.

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[18]Metrics are variables such as species richness or rarity which can be used to help identify how damaged a waterbody's community is. They have been shown to have a strong monotonic relationship with degradation.

Development of such a methodology will enable the Agency to assess still water quality for GQA and other reporting purposes, or could be used by the Agency in partnership with others such as DETR or English Nature. Development of the method will also enable public or private sector NGOs (e.g. consultants, community groups) to improve general standards of assessment in waterbody management plans or environmental impact assessments.

2.2 About PSYM

PSYM is a waterbody quality assessment methodology which essentially combines the predictive approach of RIVPACS[19] with multimetric-based methods used for ecological quality assessment in the United States.

In multimetric assessments, a range of variables (metrics) each related to degradation is used to assess water quality giving a broad-based assessment of quality. The values from individual metrics are combined to give a single measure which aims to represent the overall ecological quality of the waterbody. Combining this with predictive techniques gives a powerful method for comparing waterbodies of any type with their undegraded counterpart.

The PSYM methodology directly parallels the approach defined in the EU Water Framework Directive. This includes requirements for (i) comparisons with minimally impacted baseline conditions, and for (ii) assessments to be based on multiple parameters related to degradation.

2.3 Which waterbodies can be monitored using the method?

The PSYM approach is potentially applicable to all still waterbody types (e.g. lakes, ponds, temporary ponds, canals). However, to apply the method, specific data need to be collected from each waterbody type. These data are used both to (i) develop equations which can be used to predict the species which should occur at an undegraded site and (ii) to identify which biotic measures (e.g. species richness, ASPT) are the most effective at tracking degradation in that waterbody type.

So far, the method has been developed for use on two still waterbody types (i) canals (ii) ponds[20] and small lakes (up to about 5 ha in area). An extension of the method for temporary ponds is currently being developed independently by Pond Action with support from the Freshwater Biological Association. Methods have not, so far, been developed for assessing the quality of large lakes, ditches or brackish waters.

2.4 Why assess water quality using both plants and invertebrates?

Ideally, PSYM should use information from both the plant and animal communities present in a waterbody. This is because, together, plants and animal groups span a complementary range of sensitivities to potential degradation factors. Plants are, for example, particularly sensitive to waterbody nutrient status, whereas animals typically exhibit greater oxygen sensitivity.

Matrix analysis suggests that in most waterbodies, the most effective *plant* group to use for assessment is likely to be either diatoms or macrophytes. The most effective *animal* groups are

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

[20]Waterbodies between $1m^2$ and 2 ha in area which usually retain water throughout the year (Collinson *et al*,. 1994). Includes both man-made and natural waterbodies.

likely to be macroinvertebrates and/or potentially fish in large permanent waters. Combining a plant and animal group from these assemblages gives a range of taxa which span a number of trophic levels, occupy a variety of waterbody habitats (e.g. can be found in the littoral zone and open water) and are long-lived, so that they can provide a temporally and spatially integrated measure of the current ecosystem state. Invertebrate, diatom and macrophyte assemblages are also relatively species-rich groups, ensuring that a good cross section of waterbody biodiversity is included in the quality assessment.

In ponds, macroinvertebrates and macrophytes have been chosen as the most practical and effective taxa for quality assessment. In canals, the choice was macroinvertebrates and diatoms. Macrophytes were assessed as being less suitable for canal assessment because the high turbidity and artificial banks which characterise most navigated canals often means that very few higher plant species are present, regardless of overall water quality.

2.5 Do you have to use both plant and invertebrates for PSYM pond assessments?

Although PSYM pond quality assessments should be made using both plant and invertebrate assemblages, a partial assessment can be made using just one assemblage if necessary. If this is the case, macroinvertebrates are likely to be the best single choice of organisms for assessing overall waterbody quality. Macrophytes, however, have the advantage of being very quick to survey and can be used, if necessary, as a rapid bio-assessment method.

2.6 How are the plant and invertebrate metrics chosen?

Metrics are biological tracers: i.e. measures (such as taxa richness) which vary with anthropogenic degradation and can, therefore, be used to measure the extent of ecosystem degradation. The concept underlying multimetric assessment is that by using a number of different measures and summing these together, an overall assessment of environmental degradation can be made. For canals, at present, only an invertebrate option is available.

Metrics are chosen by correlating known degradation gradients (nutrient levels, heavy metal levels, presence of road runoff etc.) with a wide list of *possible* test metrics e.g. EPT, family richness, number of exotic species. The 'test' list is narrowed-down to a list of viable metrics by looking at the significance of relationships between each potential metric and anthropogenic degradation gradients. For invertebrates, metrics are chosen at the highest taxonomic level i.e. family or order level rather than species-level to reduce effort (although species level information can be derived from the samples if needed for conservation work). In practice, there were generally at least equally strong correlations between family-level macroinvertebrate metrics and degradation as there were between species-level metrics and degradation. This enables family-level macroinvertebrate data to be used for quality assessments in both ponds and canals. Plant metrics are generally based on species level information.

Analyses have shown that the most effective metrics for assessing environmental degradation in ponds and canals are:

Ponds

Invertebrates

- Average score per taxon (ASPT)
- Number of dragonfly (Odonata) and alderfly (Megaloptera) families (F_OM)
- Number of beetle (Coleoptera) families (F_COL)

Plants:

- Number of submerged and marginal plant species (SM_NTX)
- Trophic ranking score for aquatic and marginal plants (TRS_ALL)
- Number of uncommon plant species ((PL_NUS)

Canals

Invertebrates

- Average score per taxon (ASPT)
- Number of Ephemeroptera, Plecoptera and Trichoptera families (F_EPT)
- Number of beetle families (F_COL)
- Number of invertebrate families (INV_NFA)

Note that in canals methods for assessing the chosen plant group (diatoms) have not yet been developed.

2.7 Which physical and chemical variables are used in the predictions?

As in RIVPACS, the PSYM method assesses quality by comparing actual and predicted quality scores for each waterbody. The predictions of unimpaired waterbody quality are made using physico-chemical data gathered from the waterbody.

In *ponds* the main predictors of unimpaired community type fall into nine major variable categories. Of these, three are relatively invariant (e.g. grid reference, altitude, base geology) which need only be assessed once. The remaining six categories of variables require on-site field measurement when each assessment is made. These are area, pH, shade, grazing, presence of an inflow and emergent plant cover. In *canals*, the main predictive variables are grid reference, altitude, alkalinity, substrate and boat traffic.

2.8 How are metrics scored?

When a waterbody is assessed, each individual metric is calculated and compared to the computer predicted score for that metric. The relationship between observed and expected is presented as a percentage of similarity, and then transformed to a 4 point scale e.g. 0, 1, 2 and 3 where 0 represents poor quality, and 4 represents good quality (i.e. no deviation from expected). All metric scores are then summed to give an overall quality index, which is presented as a percentage of the maximum score and, potentially, forms the basis of General Quality Assessment (GQA) categorisation of a site.

2.9 Diagnosis

The main objective of the PSYM method is to assess the overall condition of freshwater ecosystems. The system does not, in itself, attempt to diagnose the cause, or causes, of degradation. Indeed it is considered inappropriate for a general quality assessment method to be biased towards the 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 of the raw data to give pollution indices, such as trophic scores or acidification indices.

3. Assessing pond quality using Pond PSYM

3.1 Introduction

Pond PSYM has currently been developed for use in the Summer season (June, July, August), and is based on assessments of both macroinvertebrate and macrophyte assemblages.

3.2 Sites which can be included

Pond PSYM can be used on ponds and small lakes up to about 5 ha in area in England and Wales. The method can, in theory be used to assess the quality of seasonal ponds, but in practice it 'over-predicts' for ponds which are highly seasonal (i.e. which dry hard every year), and is best restricted to ponds which are either permanent, or semi-seasonal (i.e. which dry occasionally in very hot years). An extension of the method is currently being developed for use with fully temporary ponds.

3.3 Field data collection

The environmental data which need to be collected from each pond to use Pond PSYM include:

(i) *locational and other data* used for data processing. This includes: site name and code, county and nearest town, six or eight figure grid reference as necessary to identify the site, survey date, surveyor, site description.

(ii) *predictive variables* used in the pond PSYM programme to predict the undegraded biota for the pond. This includes: map-based locational information (six figure grid reference, altitude), together with site data describing shade, the presence of an inflow, cover of emergent plants, pond base geology and pH.

<u>Collecting predictive variable data</u>

The methods used to collect the main predictive variable data are briefly outlined below.

Grid reference: six figure reference, taken from 1:50,000 or 1:25,000 OS maps.

Altitude: in metres above sea level, taken from 1:50,000 or 1:25,000 OS maps.

pH: measured either (i) in the field in a bucket of water taken from a representative area of the pond, or (ii) using a water sample collected in the field and analysed later in the laboratory. For laboratory analysed samples, use acid washed bottles stored in a cool place after collection (e.g. cold box) and analyse within one day of collection.

Pond area: this is the area lying within the outer edge of the pond (see 3.4 below). The pond dimensions can be measured using a tape, or by careful pacing. A small sketch can help to make this estimate. For large ponds it can be easier to use an OS map outline, with the dimensions checked in the field. Note that for the predictions, area data are entered as log values so, particularly for large ponds, estimates do not need to be highly accurate.

Pond overhung: the percentage of the pond area which is *directly overhung* (e.g. by trees, scrub etc.).

% of pond edge grazed by livestock: the percentage of the perimeter of the pond to which livestock have active access. Note that if cattle, sheep, horses etc. are not grazing at the time of the survey, their presence can be detected by other features such as poaching of the ground.

Pond base: the rock type underlying the pond (beneath the sediment). This can often be assessed directly in the field, or be determined using a geology map. In the field, push the handle of the pond net through the sediment into the base. Exact measurement is not necessary, only broad categorization into one of three percentage categories: 1= 0%-32%, 2=33%-66%, 3=67%-100%.

Inflow: whether or not the pond has a surface inflow. This can be a direct or indirect inflow from a river, stream, ditch, spring or seepage. The inflow can be *dry* at the time of the survey.

Emergent plant cover: the percentage of the pond covered by emergent plant species. The term 'Emergent plant species' includes all species listed as emergents on the wetland plant species list. It includes these species regardless of their habit at the time of the survey (e.g. some emergent species may be growing predominantly under water at the time of the survey). It does not include any other species e.g. terrestrial species or plants specifically defined as 'submerged' or 'floating-leaved' plant species on the wetland plant list.

Estimates of the percentage cover of emergent plants should be made for the whole area within the outer edge of the pond, not the current water area. The cover of sparsely growing stands of plants (e.g. occasional bulrush plants with much open water between), should be estimated as if they were growing closely together. The easiest way of doing this is to imagine all emergent plants pushed together on one side of the pond, with an estimate then made of what proportion of the pond this covers.

At present it is recommended that for those variables for which field estimates are made (pH, area, overhanging trees, grazing, base type and emergent pant cover) the objective of measurement should be to obtain estimates that are within 5-10% of the long term mean. It is expected that further work will be undertaken to refine understanding of the effects of variation in measurements in the future.

3.4 Defining the outer edge of the pond

Identifying the 'outer edge' of the pond is important for many of the physico-chemical survey assessments and for undertaking the plant survey. In all cases, the definition of pond 'outer edge' is 'the upper level at which water stands in winter'.

In practice, the outer edge is usually readily discernible from one or more site characteristics. The best of these is usually the distribution and/or morphology of wetland plants. For example, it may be marked by a fringe of soft rush (*Juncus effusus)* or by thick bundles of fine roots growing out of the trunks of willows etc. Alternatively, the line can often be seen as a ‘water mark’ on surrounding trees or walls and is sometimes evident as a break of slope. The outer boundary of the pond will usually, of course, be dry at the time of the survey.

3.5 Plant survey methodology

The aim of plant recording is to make a complete list of wetland plants present within the outer edge of the pond. The Field Recording Sheet gives a definitive list of the plant species regarded as 'wetland'. Terrestrial plants and wetland plants growing outside the outer edge of the pond are not recorded. The wetland plant list includes *submerged* macrophytes, *floating-leaved* species and *emergent* macrophytes, and these groups are used separately in analysis.

Pond macrophytes are surveyed by walking or wading the entire perimeter of the dry and shallow water areas of the waterbody. Deeper water areas are sampled either using a pond net or by grapnel thrown from shallow water or from a boat.

Most wetland plants are readily identifiable using a hand lens. However, with a few species (especially fine-leaved *Potamogeton* and *Callitriche* spp.) it may be necessary to remove a small amount of plant material for later microscopic examination and confirmation.

3.6 Invertebrate survey methodology

The pond invertebrate survey methods used for PSYM are based on standard three minute hand-net sampling methods developed for the National Pond Survey (Pond Action, 1998).

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

- RIVPACS allocates sampling time on an area basis (i.e. more time is spent sampling extensive habitats). In pond PSYM, time is allocated 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.
- In Pond PSYM the 3 minute survey subsamples are taken around the entire pond site whereas in RIVPACS samples are collected from an area that can be covered comfortably in three minutes: typically a river length of 5-20 m.

3.7 Selecting mesohabitats for invertebrate surveys

All the main mesohabitats in the pond are sampled so that as many invertebrate species are collected from the site as possible. Examples of typical mesohabitats are: stands of *Carex* (sedge); gravel- or muddy-bottomed shallows; areas overhung by willows, including water-bound tree-roots; stands of *Elodea*, or other submerged aquatics; flooded marginal grasses; and inflow areas. As a rough guide, the average pond might contain 3-8 mesohabitats, depending on its size and complexity. It is important that vegetation *structure*, as well as plant species composition, is considered when selecting mesohabitats: it is better to identify habitats consisting of e.g. soft floating leaves, stiff emergent stems, etc. than to make each different plant species a separate habitat. Mesohabitats are identified during the initial walk around the pond examining vegetation stands and other relevant features (this can be combined with the initial plant survey stage).

Invertebrate sampling method

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

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

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

(iii) Amphibians or fish caught whilst sampling are noted on the recording sheet and returned to the pond.

Additional invertebrate sampling

A further 1 minute (total time, *not* net-in-the-water time) is spent searching for animals which may otherwise be missed in the 3-minute sample. Areas which might be searched include the water surface (for whirligig beetles, pond skaters etc.) and under stones and logs (for limpets, snails, leeches, flatworms etc.). Additional species found are added to the main 3-minute sample.

3.8 Processing invertebrate samples

Invertebrate sorting and identification methods follow the standard laboratory techniques used for processing and identifying invertebrate samples at family level.

3.9 Data processing an analysis

Biotic data are used by pond PSYM to calculate three plant metrics and three invertebrate metrics:

Plants:

- Number of submerged and marginal plant species (PL_NTX)
- Trophic ranking score for aquatic and marginal plants (TRS_ALL)
- Number of uncommon plant species (PL_NUS)

Invertebrates

- Average score per taxon (ASPT)
- Number of dragonfly (Odonata) and alderfly (Megaloptera[21]) families (F_OM)
- Number of beetle (Coleoptera) families (F_COL).

Calculating the pond metrics from taxon lists

1. Number of submerged and marginal plant species

This is simply the sum of the number of submerged plant taxa plus number of marginal plant taxa observed at the site. The terms 'submerged' and 'marginal' taxa refer only to the species listed in these groups on the field sheet - not to plants of any species which happen to be submerged below water or growing round the edge of the pond at the time of the survey.

The calculation does *not* include the number of floating-leaved species present. This is because the pond data suggest that the number of floating-leaved plants occurring at a site does not decline significantly with increasing degradation. The metric is therefore improved by omitting this plant group.

2. Trophic Ranking Score (TRS)

TRS is a measure of the average trophic rank for the pond. This is calculated by assigning each plant species with a trophic score based on its affinity to waters of a particular nutrient status. The trophic scores used in the present study were based on work undertaken on lakes by Palmer (1989). Plant scores in this system vary between 2.5 (dystrophic i.e. very nutrient poor conditions) and 10 (eutrophic, i.e. nutrient rich conditions).

Unfortunately, not all plants have trophic scores. This situation has arisen because the current TRS values for standing waters (Palmer *et al.*, 1992) are based only on analysis of lake data, and many plant species which are common in ponds occurred at too low a frequency in lakes to give them a score. Nigel Holmes's Mean Trophic Ranking method, which was developed for assessing the nutrient status of running water communities, cannot be used in the current analysis because trophic values for some plant species can vary between still and running waters (N. Holmes *pers. comm.*).

The TRS value for a site is calculated as follows:

(i) The trophic scores from each plant species present at the site are summed together.

(ii) The summed score is divided by the total number of plant species which have a trophic ranking score (NOTE not the total number of plants at the site) to give the TRS.

3. Uncommon species index

Uncommon species are those which have a rarity score of 2 or more. The number of these species is simply summed to give the number of uncommon species.

[21] Note that there is only one family of Megaloptera in the UK (the Sialidae) and that the metric F_OM is concerned with the combined total of Odonata and Megaloptera, not the occurrence of the family Megaloptera alone.

Uncommon species refers to species which can be described as 'local', 'nationally scarce' or 'Red Data Book'. Descriptions of these categories are given below.

Status[22]	Value	Definition
Common	1	Recorded from >700 10x10 km grid squares in Britain
Local	2	Recorded from between 101 and 700 grid squares in Britain
Nationally Scarce	4	Nationally Scarce. Recorded from 15-100 grid squares in Britain
At risk	8	Red Data Book: Category "At risk"
Vulnerable	16	Red Data Book: Category "Vulnerable:
Endangered	32	Red Data Book: Categories " Endangered" or "Highly Endangered"

4. Average score per taxon

ASPT is calculated, as in RIVPACS, by summing the BMWP scores for all taxa present at the site and dividing by the total number of BMWP taxa present.

5. Number of dragonfly and alderfly families

This metric is the sum of the number of Odonata and Megaloptera families which occur at the site.

6. Number of beetle families

This metric is the sum of the number of Coleoptera families present at the site. The metric has a relationship with bank quality as well as water quality.

4. Assessing canal quality using Canal PSYM

4.1 Introduction

Canal PSYM has currently been developed for use in the Spring season (March, April, May), and is based on a macroinvertebrate assessment only[23]. The method can be used to make assessments of both canal water quality and bank quality.

4.2 Sites which can be included

Canal PSYM can be used to assess the quality of any section of canal, including both reinforced and natural bank sections. The term canal, does not however include major navigations (i.e. canalised rivers), such as the Lee Navigation and Stort Navigation, since these were excluded from the canal survey as many sections are essentially riverine in character.

[22]The rarity status values for Scarce and RDB species are based on existing definitions derived from the Red Data Books and other authorities. The definition of 'local' has been used to define species which are not uniformly common and widespread in Britain: with plants this refers specifically to species recorded from between 101 and 700 10 x 10 km squares (approximately 25% of all 10 km in England, Wales and Scotland).

[23]Ideally PSYM should also include a plant-based assessment, however this has not yet been developed. In canals, diatoms have been identified as the most suitable plant assemblage for assessing quality, since macrophytes often occur in very low abundance where water is at all turbid and banks are reinforced.

4.3 Field sheet data collection

Field data collected from each canal site include:

(i) *locational and other data* used simply to identify the site and enable the site to be re-found for monitoring purposes. These data include information on: site name and collection code, canal name, nearest town, six figure grid reference, survey date, surveyor, description of site.

(ii) *predictive variables* used in the PSYM programme to predict the minimally impaired biota for the canal. This includes map- or desk-based information (six figure grid reference, altitude, number of boats) and field-based measurements (alkalinity, canal substrate).

Field variables

The environmental data which need to be collected from each pond to use Canal PSYM are:

Grid reference: six figure reference, taken from 1:50,000 or 1:25,000 OS maps in the form NS 123456 or 26 123456

Altitude: in metres above sea level, taken from 1:50,000 or 1:25,000 OS maps.

Number of boats: measured in thousands of boat movements per annum. These data can be provided by British Waterways (or other canal authority as appropriate).

Total Alkalinity: measured as meq l^{-1}. Analysed in the laboratory from a water sample collected in the field.

Canal substrate: a field estimate of the canal sediment composition in four percentage categories (i) silt and clay (ii) sand (iii) gravel or larger (iv) organic matter. Sediment composition often varies across the canal, with the edge area usually coarser than the bottom substrate in deeper water. Where this is the case, two substrate measurements should be made, one in shallow water and one in deep water and the average calculated.

4.4 Invertebrate sampling

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.

The sampling technique used to collect invertebrate samples was developed as 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 recommended for sampling deep rivers. The method will also be used by IFE in future canal surveys.

The method comprises:

1. A one-minute search.
2. A two-minute semi-continuous hand-net sampling of the canal margin, shallows and any emergent plant habitats present. This sample typically covers a bank length of 5m to 15m.
3. Four net hauls from deeper bottom sediments along a canal length of approximately 10 m, elutriated on site to wash out the bulk of muds and fine sands. These should be taken at c. 3m intervals along the canal sampling length.

Two directly compatible field techniques can be employed to gather the four bottom sediment sample hauls from deeper areas, the choice depending on canal depth and accessibility:
(i) where canals are shallow enough to wade, bottom samples can be collected using a hand-net haul (c.3m length) taken perpendicular to the bank, (ii) where canals are too deep to use a hand net, bottom samples are collected using a Naturalist's dredge with a hand net sub-sample filling ca. one quarter of the pond net then taken from this dredged material. It is recommended that the bank and bottom samples are kept separate, since this makes the samples easier to sort in the laboratory.

4.5 Processing samples

Invertebrate sorting and identification methods follows the standard laboratory techniques used for processing invertebrate samples. Invertebrate samples are identified to *family* level for most groups and class level for oligochaetes.

4.6 Data processing an analysis

Invertebrate family data are used by PSYM to calculate four metrics:

- Average score per taxon (ASPT)
- Number of Ephemeroptera, Plecoptera and Trichoptera families (F_EPT)
- Number of beetle (Coleoptera) families (F_COL)
- Number of invertebrate families (INV_NFA)

4.7 Data interpretation and diagnosis

In analyses it was shown that ASPT and EPT scores both correlated strongly with a wide variety of water quality parameters, including heavy metals, suspended solids and chemical water quality (i.e. the overall chemical quality class based on suspended solids, BOD and ammonia concentrations). These metrics, however, showed few relationships with bank degradation variables.

In contrast, invertebrate family richness, and particularly beetle, bug and snail richness, showed strong relationships with bank structure and boat traffic, but very few relationships with water quality attributes.

These differences in degradation sensitivity make it possible to assess both water quality and bank effects separately. Thus where the main aim of canal assessments is to investigate water quality, then metrics based on ASPT and EPT taxa will 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 or family richness can be combined into the final integrity index, i.e.:

A. Canal water quality assessment = ASPT + EPT.

B. Canal bank quality assessment = No. Coleoptera families + No. invertebrate families.

Total canal environmental quality = A + B.

Calculating the canal metrics from taxon lists

1. Average score per taxon (ASPT)

ASPT is calculated by summing the BMWP scores for all taxa present at the site and dividing by the total number of BMWP taxa present.

2. Number of Ephemeroptera, Plecoptera and Trichoptera families (F_EPT)

The sum of the number of Ephemeroptera, Plecoptera and Trichoptera families recorded in the sample.

3. Number of Coleoptera families (F_COL)

This metric is simply the sum of the number of Coleoptera families present at the site.

4. Number of invertebrate families (INV_NFA)

The number of all invertebrate taxa recorded on the survey form.

5. References and additional reading

Palmer, M.A. (1989). A botanical classification of standing waters in Great Britain. *Research & survey in nature conservation*, **19**. Nature Conservancy Council, Peterborough.

Palmer, M.A., S.L. Bell and I. Butterfield (1992). A botanical classification of standing waters in Britain - applications for conservation and monitoring. *Aquatic Conservation - Marine and Freshwater Ecosystems*. **2**, No. 2, 125-143.

Pond Action (1998). *A guide to the methods of the National Pond Survey*. Pond Action, Oxford.

Wright, J.F. (1995). Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. *Australian Journal of Ecology*, **20**, 181-197.

Wright, J.F., D. Moss, P.D. Armitage and M.T. Furse (1984). A preliminary classification of running-water sites in Great Britain based on macro-invertebrate species and the prediction of community type using environmental data. *Freshwater Biology*, **14**, 221-256.

More detailed information describing the PSYM methodology is given in the following reports:

Williams, P., J. Biggs, L. Dodds, M. Whitfield, A. Corfield and G. Fox (1996). *Biological techniques of still water quality assessment. Phase 1 Scoping Study*. Environment Agency R&D Technical Report E7. Environment Agency, Bristol.

Williams, P., J. Biggs, M. Whitfield, A. Corfield and G. Fox, K. Adare (1998). *Biological techniques of still water quality assessment* : *2. Method development.* Environment Agency R&D Technical Report E56. Environment Agency, Bristol.

Biggs, J., Williams, P., Whitfield, M., Fox, G. and Nicolet, P. (2000). Biological Techniques of Still Water Quality Assessment: 3. Method Development. Environment Agency R&D Technical Report E110. Environment Agency, Bristol.

Appendix 2. List of survey ponds included in the analysis

Code	Site Name	Grid reference
ABER	Aberhafesp	SO065923
ACLA	Aclam Campas	NZ488168
AFPA	Ashdown Forest Pond A	TQ446328
AFPB	Ashdown Forest Pond B	TQ447329
AL41	Aldershot Pond 41	SU889514
AL48	Aldershot: Small Hottonia	SU885515
APPL	Appleton-le-moors	SE727873
ASFA	Ash Farm	TG017240
ASHA	Ashton Court	ST547715
ASHO	Ashworth Hospital Pond	SD393027
ASME	Asham Meads	SP595135
AZTE	Aztec West	ST602825
BAFO	Bardney Forest Pond	TF153736
BAHO	Bankhouse House Hotel	SO805532
BARF	Barrowden Fox	SK965023
BARL	Barley Green	SD794303
BASI	Barrow Silt Trap	SJ354167
BECK	Beckley Moat	SP577120
BEDW	Plas-y-Bedw, Llandissilio	SN134241
BEGE	Begelly	SN104077
BEGG	Beggar's mouth	SE130887
BEGO	Beeston Golf Course	SK518375
BEGW	Begwyns	SO141448
BENT	Bentley Farm Pond	TQ482163
BEPA	Beacon Park Golf Course	SJ502069
BERB	Beckly Raised Bog	TQ861254
BHNF	Buck Hill Pond	SU380056
BISH	Bishops Cleve Retirement Pond	SO953276
BLHP	Blashford Pond 102	SU146026
BMNF	Burley Moor East	SU211047
BOCO	Bookham Common	TQ124558
BOFA	Boundary Farm	SK296034
BOND	Bondhay Golf Course	SK516788
BOPO	Broad Pool Gower	SS510910
BOUN	Boundary Way Balancing Pond	TL085080
BRAD	Bradford Oxbow	SS814159
BRAY	Brays Cott	SW726182
BRCO	Breney Common	SX050610
BRGO	Brackenwood Golf Course	SJ318837
BRMO	Brown Moss	SJ562397
BRPO	Brechfa Pool	SO116376
BRSC	Brecon School Pond	SO522293
BRWP	Brasenose Wood Newt Pond	SP559055
BUBE	Burnham Beeches Upper Pond	SU949845
BUCO	Burwash Field Pond	TQ679247
BURA	Burcot Rail	SU983709
BUXT	Buxton Town	SK055734
CABR	Cadover Bridge NE Pond	SX552652
CAEN	Cadmore End Common	SU794927
CAHA	Castor Hanglands Main Pond	TF119016
CASS	Cassington Pit	SP455102

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

CEB2	Cefn Bryn Pond 2	SS508909
CEB3	Cefn Bryn Pond 3	SS509912
CEB4	Cefn Bryn Pond 4	SS513914
CEPO	Central Pond Otmoor	SP569145
CFNF	Chubbs Farm Pond	SU199021
CHCR	Chipperfield	TL047013
CHEC	Checkendon Stables	SU663835
CHFA	Charnage Farm	ST832318
CHOE	Chiddingstone	TQ500450
CHUR	Church Cottages	TG335237
CISS	Ciss Hill	SD901166
CLCA	Clatford Carp	SU357434
CLGR	Claypit Green	TL593221
COFE	Cothill Fen	SU460996
COFO	Cors Fochno	SN633920
COLA	Cornwall laughing	SP275270
CREA	Creaton Gallops	SP707723
CRHI	Crickley Hill	SO950170
CROO	Crooks Beck	NY746026
CYHO	Cyder House Pond	TM171653
DALT	Dalton Back Lane	NZ479281
DELL	The Dell Cardiff	ST143778
DOWL	Dowlais Bridge	ST304929
DRME	Dryslwyn Meadows	SN573203
DS2.	Dry Sandford 2	SU468996
DSMP	Dry Sandford Pit Main Pond	SU468996
DUVP	Dummer Village Pond	SU587450
DYOX	Pen y Banc Dynefwr Oxbow	SN605223
EAMA	Eathorpe Marsh	SP389689
EDGO	Edwalton Golf Course	SK595351
EMHI	Emmett Hill	SU009901
EPFO	Epping Forest	TQ415967
ESKE	Eskett Quarry	NY056167
EUDO	Eudon Burnell	SO698895
EV2a	Eversley Black	SU813620
FAWA	Farleigh Wallop	SU620475
FCLA	Friars Court Large	SP291004
FCLR	Friars Court Little Rudge	SP292004
FCMO	Friars Court Moat	SP285009
FCSM	Friars Court Small	SP292004
FERN	Fernyhurst Duck Pond	ST384196
FEWM	Feckenham Wylde Moor	SP012603
FFES	Ffestiniog Hill Pond	SH728429
FFFA	Fford Fawr	SO187400
FIFA	Fields Farm Garden Pond	SJ835773
FIML	Micheldean Iron Mine Main	SO658164
FIRL	Firlands	SU464166
FMIS	Micheldean Iron Mine Small	SO658165
FOBR	Ford Bridge	SN085077
FOPI	Fowl’s Pill Otmoor	SP572141
FQMP	Foggintor Quarry Main Pond	SX566735
FQSP	Foggintor Quarry Small Pool	SX566734

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

FWBR	Micheldean Westbury Brook Reservoir	SO658168
FYDO	Fyfield Down NNR	SU138718
GARL	Gautby Red Lane Pond	TF165733
GAVP	Gautby Viners Pond	TF175723
GAWF	Gautby Wood Farm Pond	TF165733
GAYT	Gayton Thorpe	TF727174
GIZZ	Gizzel	SP582020
GLOO	Glooston	SP473296
GOYT	Goytre Hall Garden	SO319065
GRAN	Grange Farm Pond, Peak	SJ985955
GRBA	Great Bayhall	TQ623394
GRBO	Great Bowden	SP742897
GREE	Greensgate	TG105158
GRFA	Grange Farm Pond	SP885147
GRUR	Greetland Urban	SE080211
GTMO	Great Moreton Pond	SS289070
HADR	Hadrien's Turret	NY669663
HAFA	Harriots Farm Pond	SJ834048
HAWO	Hayley Wood	TL288 532
HAYT	Haythog Farm Pond	SP457273
HEHE	Headley Heath	TQ204541
HEKE	Hell Kettles	NZ281109
HEMS	Hemsford	SX815639
HENW	Henwick Manor Farm Pond	SU497687
HHTP	How Hill Turf Pond	TG368192
HIDU	Hillborough Duck Pond	SP124519
HOLI	Holinhurst	SE288166
HOLM	Holme Farm	NZ493135
HOME	Home Farm	TL954762
HOPA	Honister Pass Pool	NY231147
HOPO	Hornwort Pond	TL994895
IBCO	Ibstone Common	SU749938
JEWE	Jewel House Pond	TQ747436
KENN	Kennicot	SS351098
KEPO	Kennington Pit	SP518033
KEWG	Kew Gardens Pond	TQ181765
KICP	Kingsclere Church Pond	SU524585
KIDI	Kingston ditch	SP409011
KIMA	Kingston Marsh	SP405012
KING	Kingcombe Meadow	SY555988
KINN	Kinnersley Manor	TQ263462
KYME	North Kyme	TF149533
LARK	Larkings Barn	SU893178
LIHA	Little Haweswater	SD480770
LIMB	Limbo Farm Pond	SU968244
LLCO	Llandeilo Common	SO132485
LLFR	Llyn Rhuddwyn (Trefonen)	SJ233287
LOFA	Lodge Farm	SK295391
LPST	Stiperstones Long Pool	SN355977
LUS1	Lushill 1	SU154936
LWLP	Little Wittenham Lower Pond	SP571927
LWUP	Little Wittenham Upper Pond	SP571927

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

MAEL	Maelienydd	SO138174
MAME	Marden Meadow	TQ762445
MANO	Manor Farm	TA162079
MAQU	Malvern Quarry	SO771445
MARO	Malvern Roadside	SO792454
MBTP	Matley Bog Tree Pool	SU336075
MEGR	Meddon Green	SS274 177
MF26	Malham Tarn Mid Fen Pond 26	SD886672
MF29	Malham Tarn Mid Fen Pond 29	SD886672
MILL	Little Mill	NU225173
MOCO	Moor Copse SSSI	SU636740
MOGP	Mortimers Garden Pond	TL571236
MPI3	Malham Tarn Pinewood Pond 3	SD883671
MPLA	Milton Pools A	SU655030
MPLB	Milton Pools B	SU654030
MUME	Maulden Meadow	TL059383
MWF1	Malham Tarn West Fen Pond 1	SD883671
NAZE	Nazeing Whitehouse Pond	TL414065
NCCO	North Chailey Common	TQ390190
NEWE	Newell's Pond	SU608980
NEWS	Newsham Field Pond	NZ384117
NH60	Newtown Harbour Pond 60	SZ438912
NH64	Newtown Harbour Pond 64	SZ348916
NH69	Newtown Harbour Pond 69	SZ432918
NH70	Newtown Harbour Pond 70	SZ432918
NH82	Newtown Harbour Pond 82	SZ442908
NILL	Nill Farm	SP371355
NORT	Northolt	TQ133835
NRRA	New River Ray	SP555141
NTHD	Newtimber Hill Dew Pond	TQ272124
OAKL	Oakland Farm	NZ356129
OLDR	Old Railway Pond	SN485597
OSMA	Osmandthorpe	SK681571
OVER	Overland Farm	TR277597
OVNP	Over North Pond	SO820193
OVSP	Over South Pond	SO820193
PAPA	Patshull Park Hotel Golf Club	SO801997
PIGR	Pinkhill Groundwater Pond	SU439068
PIMA	Pinkhill Main Pond	SU439068
PIPO	Pinkerley Pond	SS722423
PISC	Pinkhill Scrape	SU439068
PISW	Pinkhill Surfacewater	SU439068
PLGR	Platford Green	TQ544891
POCP	Popham Court Pond	TQ559438
POTC	Potcote Pond	SP466251
PPM1	Priddy Pool Mineries	ST545518
PRP2	Priddy Pool 2	ST5285517
QUAR	Quarry House Moor	NT109248
RACA	Ravens Causeway	SO436477
RADN	Radnor Brook	TR222366
REDD	Reddings Large	SO695138
REDM	Redmoor	SX072622

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

REH4	Rease Heath Pond 4	SD635565
RHBU	Robin Hood's Butts	SO425965
RISL	Risley Urban	SJ662927
ROSE	Rosewarne	SW610348
ROSS	Ross Links	NU373138
RSPO	Ruscombe Pond	SU479765
RUPO	Ruan Pool	SW696158
RYMO	Ryer's Moor Pond	SS450923
SADU	Saltfleetby Dunes NNR	TF482895
SAFN	Savernake Forest North	SU217666
SAFP	Snetterton Arable Field Pond	TM011912
SAFS	Savernake Forest South	SU221652
SANG	Sandscale Grazing	SD207743
SANM	Sandscale Wet Meadow	SD194750
SCFA	Scarlett's Farm Pond	SU812779
SHCR	Shepherds Crag Cut-Off Pond	NY258181
SHEN	Sherfield English	SU293221
SHEN	Sherfield English	SU293221
SHIL	Shaw Hill Golf Course	SD574208
SHRE	Shrewsbury Bypass	SJ524114
SHUA	Shuart Pond	TR274679
SKPI	Skipwith Pillwort Pond	SE647374
SKWD	Skipwith Wash Dyke Pond	SE650390
SNCO	Snelsmore Common	SU460710
SNPI	Snakeholme Pit	TF116716
SOCF	Sound Common Main Pond	SJ619480
SOCN	Sound Common North Pond	SJ624482
SOCO	Sole Common SSSI	SU412707
SOSP	Sound Common South Pond	SJ624482
SRCH	Stoke Row Cherry Orchard	SU681841
STAN	Stanhoe	TF807371
STIX	Stixwould Grange	TF171638
STMB	Staines Moor Butts Pond	TQ030736
SW06	Swanholme Lakes Site 6	SK945685
SW09	Swanholme Lakes Site 9	SK946686
SW11	Swanholme Lakes Site 11	SK939685
SWAN	Upper Swanmore Small	SU584177
SWGO	Swindon Golf Course	SO845915
SWSE	Swanholme Lakes Sphagnum East	SK944685
SWSW	Swanholme Lakes Sphagnum West	SK945687
TCP1	Thompson Common Pingo 1	TL937964
TCP2	Thompson Common Pingo 2	TL939966
TFOX	Thorpe Fox Covert Pond	TL035813
THCH	Thomas Chapel	SN105085
THCO	Thursley Common	SU903406
THOR	Thorpe Pasture	SE161515
THOU	Thoulstone Golf Club Pond	ST842484
TICK	Tickford Field Pond	SP888434
TIGR	Tilehurst Green	SP178768
TIMK	Timken, Northampton	SP727615
TMP1	Tiverton Marl Pit 1	SJ538617

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

TMP2	Tiverton Marl Pit 2	SJ538617
TMP3	Tiverton Marl Pit 3	SJ536617
TMP4	Tiverton Marl Pit 4	SJ535617
TODU	Towersey Duck Pond	SU735053
TRBR	Trotton Bridge	SU837224
TSSS	Tower Sub Station	SO936059
TWAP	Twenty Acre Piece	SK639212
TWYN	Twyn dune pool	SN590985
UCLS	UCL Sports Ground Pond	TL188030
UFVP	Uffington Village Pond	SU306894
ULPO	Ullswater Pool	NY397179
UPME	Upwood Meadow	TL250830
UPPI	Uppington House	SU071386
UPTP	Upton Tree Pool	TG389132
VEMO	Ventongimps Moor	SW781513
WALF	Walford	SO383719
WEPO	Welford Pools	SU174996
WETO	West Town	TQ270168
WFBP	Wicken Fen Brick Pit 76A	TL560707
WFBW	Wicken Fen Boardwalk Pond 77B	TL561706
WFDB	Wicken Fen Ditch Pond 78E	TL560707
WICH	Winforton Church	SO298469
WICO	Wimbledon Common	TQ232718
WIDU	Winterton Dunes	TG494203
WIQU	Wingate Quarry	NZ374374
WIWO	Wilmington Wood	TQ567089
WMIL	West Mill	NY626648
WOFE	Woodwalton Fen Experimental Pond	TL225837
WOFP	Wolfhall Farm Pond	SU243622
WOLV	Wolviston Village Pond	NZ450254
WOOD	Woodhouse	SD508833
WOWO	Wolves Wood	TM055441
WRBO	Wroxton Bottom	SP418414
WRTO	Wroxton Top	SP417413
WSNF	Warwickslade	SU272062
WYC1	Wychwood New Hill 1	SP339169
WYC2	Wychwood Forest New Hill 2	SP338169
WYC3	Wychwood Forest New Hill 3	SP338170
WYEV	Wye Valley Pond	SO098436
WYVI	Wyville Pasture	SK489328
YA24	Yateley Site 24	SU878570

Appendix 3. List of survey lakes used in the analysis

Code	Name	Grid Reference	Size
HATC	Hatchet Pond	SU366041	6.8 ha
ACRE	10 Acre Lake, Thorne Moors	SE696072	5.0 ha
BAVI	Bavington Carr	NY992778	2.0 ha
BURT	Burney Tarn	SD254859	2.0 ha
DUNG	Dungeness	TR062184	2.2 ha
HOFE	Holme Fen	TL217886	4.0 ha
LGOR	Llyn Y Gorlan	SN785669	2.7 ha
LHIR	Llyn Hir	SJ024058	10.0 ha
LMOR	Llyn Morwynion	SH736424	10.3 ha
MYTC	Mytchett lake	SU893543	5.7 ha
NARE	Nar End Reservoir	SD896164	3.0 ha
TEWE	Tewet Tarn	NY235305	2.0 ha
UPTO	Upton Broad	TG388134	6.3 ha
WEST	Westhay Moor	ST450440	4.2 ha
WHEL	Whelford Lake	SU174997	2.8 ha

Appendix 4. List of canal sites used in analysis

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	Hartshill	Coventry	SP33139497
23	Hartshill	Coventry	SP33139497
24	Market Bosworth	Ashby	SK38700239
25	Bradley Green	Coventry	SK28350033
26	Kings Bromley	Trent and Mersey	SK11111521
27	Great Bowden	Grand Union	SP73448957
28	Hose	Grantham	SK73202980
29	Redmile	Grantham	SK79603530
30	Stragglethorpe	Grantham	SK63403655
31	Penperlleri	Monmouthshire and Brecon	S031500400
32	Llangynidr	Monmouthshire and Brecon	SO16501960
33	Pelsall Wood	Wyrley Essington	SK01350435
34	Pelsall Wood	Wyrley Essington	SK01350435
35	Brownhills	Wyrley Essington	SK04600445
36	Holland Park, Birmingham	Wyrley Essington	SK04650700
37	Oxley, Wolverhampton	Staffs and Worcs.	SJ90200185
38	Ettingshall, Wolverhampton	Birmingham	SO93759645
39	Sandwell, Birmingham, South	Birmingham	SP02058888
40	Sandwell, Birmingham, North	Birmingham	SP01908900
41	Stone Cross, West Bromwich	Birmingham	SP00509450
42	Ocker Hill, West Bromwich	Birmingham	SO97809410
43	Ocker Hill, West Bromwich	Birmingham	SO97809415
44	Brockmoor, Dudley	Stourbridge	SO90808770
45	Caunsall	Staffs and Worcs.	SO85608115
46	Victoria Park, London	Regents	TQ34008380*
47	Horsenden Hill, Perivale	Grand Union	TQ13808400
48	Fleet	Basingstoke	SU83405358

Appendix 4 (continued). List of canal survey sites

Site no.	Site name	Canal	Grid reference
49	North Warnborough	Basingstoke	SU72935180
50	North Warnborough	Basingstoke	SU72705180
51	Crookham Wharf	Basingstoke	SU78305170
52	Bedworth, Coventry	Coventry	SP37208685
53	Leicester	Grand Union	SK56900105
54	Loughborough	Grand Union	SK52852090
55	Loughborough	Grand Union	SK52852090
56	Burton-under-Needwood	Trent and Mersey	SK20301843
57	Lapworth	Grand Union	SP19327200
58	Willoughby	Oxford	SP52306820
59	Muston	Grantham	SK80508690
60	Welshpool	Montgomery	SJ24150893
61	Wern	Montgomery	SJ25181425
62	Queens Head	Montgomery	SJ34002690
63	Ouston, Ellesmere	Llangollen	SJ38483295
64	Platt Lane, Whixall	Llangollen	SJ51103670
65	Whitchurch	Llangollen	SJ52454145
66	Whitchurch	Llangollen	SJ52454145
67	Market Drayton	Shropshire Union	SJ67833525
68	Audlem	Shropshire Union	SJ64904625
69	Wenbury	Shropshire Union	SJ60704870
70	Hurlston Junction, Nantwich	Shropshire Union	SJ61955505
71	Church Minshall	Shropshire Union (Middlewich)	SJ67056085
72	Congleton	Trent and Mersey	SJ85856135
73	Church Lawton, Alsager	Trent and Mersey	SJ82005565
74	Stone	Trent and Mersey	SJ91583195
75	Acton Trussell	Staffs and Worcs	SJ93501835
76	Wychnor, Alrewas	Trent and Mersey	SK18351608
77	Wychnor, Alrewas	Trent and Mersey	SK18351608
78	Outward, Taunton	Bridgewater and Taunton	ST30302830
79	Bankland, Taunton	Bridgewater and Taunton	ST30802945
80	Huntworth, North Petherton	Bridgewater and Taunton	ST31803440
81	Eelmoor, Farnborough	Basingstoke	SU84005290
82	Ash Vale	Basingstoke	SU89445335
83	Ash Vale	Basingstoke	SU89445335
84	Turnerwood	Chesterfield	SK54008140
85	Rhodesia	Chesterfield	SK56108050
86	Rhodesia	Chesterfield	SK56108040
87	Dobson Bridge	Prees Branch	SJ49703370
88	Newport	Newport	SJ74001940
89	Great Wyrley	Cannock Extension	SJ01900530
90	Great Wyrley	Cannock Extension	SJ01900550
91	Brownhills	Worcester and Birmingham	SO91605890
92	Brownhills	Worcester and Birmingham	SO91705910
93	Mossley	Huddersfield Narrow Canal	SD97600240
94	Mossley	Huddersfield Narrow Canal	SD97500240
95	Stalybridge	Huddersfield Narrow Canal	SD97600260
96	Marple	Peak Forest	SJ96708660
97	Marple	Peak Forest	SJ96608660
98	Bredbury	Peak Forest	SJ93509160
99	Ashton	Ashton	SJ87709840
100	Failsworth	Hollingwood	SJ87809840
101	Millness	Lancaster	SD53808270

Appendix 4 (continued). List of canal survey sites

Site no.	Site name	Canal	Grid reference
102	Millness	Lancaster	SD53808250
103	Wigan	Leeds-Liverpool	SK56200690
104	Snarestone	Ashby	SK34300850
105	Snarestone	Ashby	SK34300850
106	Great Glen	Grand Union	SP64809600
107	Leeds	Leeds-Liverpool	SE23403580
108	Leeds	Leeds-Liverpool	SE23403580
109	Ripon	Ripon	SE32606950
110	East Cottingwith	Pocklinton	SE70404270
111	Melbourne	Pocklinton	SE74804450
112	Melbourne	Pocklinton	SE74804450
113	Little Leven	Leven	TA10204500

Appendix 5. National Pond Survey methodology and survey sheet

The method used to survey ponds for the current study was originally developed to gather data for the National Pond Survey (NPS) initiated by Pond Action in 1989. It has subsequently been used as the basis for many other regional and national surveys including DETR's Lowland Pond Survey 1996 (Williams *et al.*, 1998) and Pond Action's national survey of degraded ponds currently being undertaken under the ROPA scheme. Modified extracts from the NPS methods booklet which describe the field sampling protocol (Pond Action 1994) are given below.

5.1 Summary of pond survey procedure

The following list gives a broad outline of the information gathered at each pond.

- A description of the main physical features of the pond and its surroundings together with notes about the age, history and management of the pond (see field sheet).

- Water chemistry (using field meters and laboratory analysis).

- A list of the wetland plant species found within the outer boundary of the pond, together with estimates of the abundance of species or major vegetation stands which occupy more than 5% of the pond.

- A list of the species of macroinvertebrates recorded from the pond with estimates of their abundance.

- Notes on the presence of amphibians and fish.

5.2 Pond survey procedure

Methods for measuring most field survey parameters are described on the National Pond Survey Field Recording Sheet itself. The following sections provide additional information which details, in particular, methods for collecting biological data.

5.2.1 Defining the pond outline

Identifying the 'outer edge' of the pond is important for many pond survey measures including pond area, percentage drawdown, and the cover of wetland plants. In the National Pond Survey, the outer edge is defined as the 'upper level at which water stands in winter'. In practice this line is usually readily distinguishable from the distribution of wetland plants. It is, for example, often marked by a fringe of soft rush (*Juncus effusus*). Alternatively, the line can often be seen as a 'water mark' on surrounding trees or walls, and is sometimes evident as a break of slope. The outer boundary of the pond will usually, of course, be dry at the time of the survey.

5.2.2 Mapping the pond

Many measurements such as pond size, percentage tree cover etc. are easier to estimate if a scale sketch map of the pond is made. In small or simply shaped ponds compass and tape measurements alone are adequate for mapping the pond outline. At larger ponds, useful outlines can often be obtained from Ordnance Survey maps (1:2500 scale enlarged on a photocopier). However the accuracy of these maps still needs to be checked in the field with a tape measure and compass.

5.2.3 Water chemistry

Water samples from the ponds are taken in spring (April, May). Two water chemistry samples (filtered and unfiltered water) are collected at each site.

Water quality determinands which required immediate analysis (e.g. pH) are measured at all sites immediately after collection. The remaining analyses are undertaken in the laboratory. The following chemical determinands are analysed: 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.

5.2.4 Recording plant species and vegetation abundance

The aims of plant recording are:

- to make a complete list of wetland plants present within the outer boundary of the pond,

- to record the extent of emergent, floating-leaved and submerged plant stands, together with the approximate abundance of dominant species.

Recording wetland plants

Wetland plants growing within the outer boundary of the pond are noted on the Field Recording Sheet. This gives a definitive list of the plant species regarded here as wetland (to reduce the length of the list some rare aquatic species are omitted but these should be noted in the space provided). In deep ponds aquatic plants are surveyed using a grapnel and/or boat. Terrestrial plants and wetland plants growing outside the pond boundary are not used in the analysis. Many wetland plants are readily identifiable using a hand lens. However, with a few species (especially fine-leaved *Potamogeton* and *Callitriche* spp.) it may be necessary to remove a small amount of plant material for microscopic examination and confirmation.

Botanical texts which are particularly useful for wetland plant identification are listed in Pond Action (1994).

5.2.5 Sampling aquatic macroinvertebrates

The aims of invertebrate sampling is:

- to obtain, within the available sampling time (3 minutes in each of 3 seasons), as complete a species list as possible for the pond,

- to obtain information on the relative abundance of each species recorded.

Survey periods

Invertebrate surveys for the Environment Agency analyses were undertaken in the summer season (June, July or August).

Selecting mesohabitats for invertebrate surveys

Using NPS methods, all the main mesohabitats in the pond are sampled so that as many species are collected from the site as possible. Examples of typical mesohabitats are: stands of *Carex* (sedge); gravel- or muddy-bottomed shallows; areas overhung by willows, including water-bound tree-roots; stands of *Elodea*, or other submerged aquatics; flooded marginal grasses and inflow areas. The average pond might contain 5-10 mesohabitats. It is important that vegetation structure, as well as species composition, is considered when selecting mesohabitats.

Mesohabitats are identified by an initial walk around the pond examining vegetation stands and other relevant features.

Invertebrate sampling is based on the following protocol:

(i) A one minute search (total time, not net-in-the-water time) is spent searching for animals which may otherwise be missed in the main 3-minute sample (below). Areas which might be searched include the water surface (for whirligig beetles and pond skaters), hard substrates (for firmly-attached animals), the silty or sandy bottom sediments (for dragonflies and mayflies) and under stones and logs (for limpets, leeches, flatworms and caddis).

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

(iii) Each mesohabitat is netted vigorously to dislodge and collect animals. In ponds with stony or sandy substrates these are kicked-up to disturb and capture inhabitants. Deep accumulations of sediment are avoided, since this makes later sorting extremely difficult.

The three-minute sampling time refers only to 'net-in-the-water' time and does not include time moving between adjacent mesohabitats.

(iv) Amphibians or fish caught whilst sampling are noted on the field recording sheet and returned to the pond.

Storage of invertebrate samples prior to sorting

Samples are sorted as soon as possible after collection since they deteriorate quickly. If the sample cannot be sorted immediately upon return from the field it is kept in cold storage in a refrigerator or a refrigerated cold room. It is important that all samples are sorted within three days of collection.

5.2.6 Sorting and identifying macroinvertebrate samples

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

Preparing the sample for sorting

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

Sorting the sample

A small amount (handful) of material to be sorted is placed in a white tray with approximately 2-5 mm depth of water. This material is sorted gradually and carefully using forceps. Individual animals recorded for the survey are removed and placed in a labelled bottle of 70% Industrial Methylated Spirits ('70% alcohol') for later identification. The exceptions are leeches and flatworms which are not readily identifiable after preservation and are placed in water for immediate identification. A list of invertebrate groups included in the NPS analysis is given in Table 4.1.

In general the aim of sorting the sample is to remove and identify all individual invertebrates. In samples where one or two species are present in large numbers (e.g. thousands of specimens), specimens of these species are counted in a subsample and numbers then extrapolated to the whole sample. All specimens of species which cannot be reliably identified in the sorting tray are removed from the sample with the following exceptions: Baetidae, Caenidae, Leptophlebiidae, Nemouridae, Gammaridae and Asellidae. In the case of these families about 100 individuals are removed to provide a reasonable chance that all the species likely to be present are removed. Particular care is taken with pairs of species which are similar and where small numbers of one species often occur amongst very large numbers of the other species (e.g. *Asellus meridianus* with *A. aquaticus*, *Cloeon simile* with *C. dipterum*, *Anisus leucostoma* with *A. vortex*). On average, sorting a pond sample to remove invertebrates takes approximately 6-8 hours. Samples containing a considerable amount of algae or duckweed may take considerably longer.

Identification of invertebrates

Species which are immediately identifiable whilst sorting are noted on a "sorting list" (e.g. *Ilyocoris cimicoides*, *Nepa cinerea* and many snails). Most others require use of biological keys and a microscope with a magnification of at least x30. Armitage *et al*. (1979) produced a comprehensive list of keys used in the identification of aquatic macroinvertebrates. An updated list including more recently published guides is given in Pond Action (1994). Many species (especially the larval stages of insects) cannot be identified below certain sizes. Appropriate sizes are given in identification keys.

After identification, invertebrates are returned to a labelled bottle for future reference or checking.

Appendix Table 5.1 Macroinvertebrate taxa included in pond and canal surveys

Taxon	*Identification level*	*Notes*
Tricladida	Species	Identified live
Gastropoda	Species	
Bivalvia	Species	Including *Sphaerium* spp., but excluding *Pisidium* spp. (which may be retained for identification, if necessary, at a later stage).
Crustacea (Malacostraca)	Species	
Hirudinea	Species	Identified live
Ephemeroptera	Species	As larvae
Odonata	Species	As larvae
Megaloptera (inc. spongeflies)	Species	As larvae
Hemiptera	Species	As adults
Coleoptera	Species	As adults
Plecoptera	Species	As larvae
Lepidoptera	Species	As larvae
Trichoptera	Species	As larvae
Oligochaeta	Class	May be retained for identification at a higher taxonomic level, if necessary, at later stage.
Diptera	Family	may be retained for identification at a higher taxonomic level if necessary, at later stage.

Note: water mites, zooplankton and other micro-arthropods are not included in the survey.

INSERT COPY OF NATIONAL POND SURVEY FIELDSHEET 1

INSERT COPY OF NATIONAL POND SURVEY FIELDSHEET 2

INSERT COPY OF NATIONAL POND SURVEY FIELDSHEET 3

INSERT COPY OF NATIONAL POND SURVEY FIELDSHEET 4

INSERT COPY OF NATIONAL POND SURVEY FIELDSHEET 5

INSERT COPY OF NATIONAL POND SURVEY FIELDSHEET 6

Appendix 6. Canal survey methodology and survey sheet

Collection of physico-chemical field survey data from canals was based on the parameters given in the field survey pro-forma (over page). It should be noted that a wider range of environmental data are currently required for PSYM for canals than is actually used in predictions at present. This is to ensure that further development of the method is not compromised by lack of environmental data which *may* be important in the development of the method at a future date.

The sampling technique used to collect invertebrate samples was developed as 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 method comprised:

1. A one-minute search.
2. 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.
3. Four net hauls from deeper bottom sediments, elutriated on site to wash out the bulk of muds and fine sands.

The bottom sediment samples from deeper areas, were collected using one or other of two methods the choice depending on canal depth and accessibility. Where canals were shallow enough to wade, bottom samples were collected using a hand-net haul (c.3 m length) taken perpendicular to the bank. 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. In all cases the net bag (standard net bag from GB nets) was filled to approximately 25%.

Invertebrate sorting and identification methods followed the techniques used for pond samples described in Appendix 5.2.6.

Appendix 6.1 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_NSP	Number of invertebrate species
INV_NFA	Number of invertebrate families
INV_NOR	Number of invertebrate orders
INV_SRS	Invertebrate Species Rarity Score
INV_SRI	Invertebrate Species Rarity Index
INV_NUS	Number of uncommon species
INV_RSS	Rare Species Score
S_TRIC	Number of Tricladida species
S_MOLL	Number of Mollusca species
S_HIRU	Number of Hirudinea species
S_ISOP	Number of Crustacea species
S_EPHE	Number of Ephemeroptera 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_TRICH	Number of Trichoptera species
S_PLAN	Number of Planariidae species
S_DUGE	Number of Dugesiidae species
S_DEND	Number of Dendrocoelidae species
S_VIVI	Number of Viviparidae species
S_VALV	Number of Valvatidae species
S_HYDR	Number of Hydrobiidae species
S_BITH	Number of Bithyniidae species
S_PHYS	Number of Physidae species
S_LYMN	Number of Lymnaeidae species
S_PLAN	Number of Planorbidae species
S_ANCY	Number of Ancylidae species
S_FERR	Number of Ferrissidae species
S_ACRO	Number of Acroloxidae species
S_UNIO	Number of Unionidae species
S_SPHA	Number of Sphaeriidae species
S_PISC	Number of Piscicolidae species
S_GLOS	Number of Glossiphoniidae species
S_HIRU	Number of Hirudidae species
S_ERPO	Number of Erpobdellidae species
S_ARAN	Number of Araneae species

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

Code	Attribute description
S_ASTA	Number of Astacidae species
S_ASEL	Number of Asellidae species
S_CRAN	Number of Crangonyctidae species
S_GAMM	Number of Gammaridae species
S_NIPH	Number of Niphargidae species
S_SIPH	Number of Siphlonuridae species
S_BAET	Number of Baetidae species
S_POTA	Number of Potamanthidae species
S_LEPT	Number of Leptophlebiidae species
S_EPHE	Number of Ephemeridae species
S_CAEN	Number of Caenidae species
S_NEMO	Number of Nemouridae species
S_COEN	Number of Coenagrionidae species
S_LEST	Number of Lestidae species
S_AESH	Number of Aeshnidae species
S_LIBE	Number of Libellulidae species
S_MESO	Number of Mesoveliidae species
S_HEBR	Number of Hebridae species
S_HYDR	Number of Hydrometridae species
S_VELI	Number of Veliidae species
S_GERR	Number of Gerridae species
S_NEPI	Number of Nepidae species
S_NAUC	Number of Naucoridae species
S_NOTO	Number of Notonectidae species
S_PLEI	Number of Pleidae species
S_CORI	Number of Corixidae species
S_HALI	Number of Haliplidae species
S_HYGR	Number of Hygrobiidae species
S_NOTE	Number of Noteridae species
S_DYTI	Number of Dytiscidae species
S_GYRI	Number of Gyrinidae species
S_HYDP	Number of Hydrophilidae species
S_HYDA	Number of Hydraenidae species
S_LIMB	Number of Limnebiidae species
S_HETE	Number of Heteroceridae species
S_DROP	Number of Dryopidae species
S_ELMI	Number of Elmidae species
S_LIMN	Number of Limnichidae species
S_SIAL	Number of Sialidae species
S_HYDT	Number of Hydroptilidae species
S_PSYC	Number of Psychomyiidae species

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

Code	Attribute description
S_ECNO	Number of Ecnomidae species
S_POLY	Number of Polycentropodidae species
S_PHRY	Number of Phryganeidae species
S_LEPI	Number of Lepidostomatidae species
S_LIMP	Number of Limnephilidae species
S_BERA	Number of Beraeidae species
S_ODON	Number of Odontoceridae species
S_LEPT	Number of Leptoceridae species
S_GLC	Number of Gastropoda + Leeches + Crustacea species
S_GH	Number of Gastropoda + Hirudinea species
S_PHEMI	Number of predatory Hemiptera species
S_DHEMI	Number of detritivore Hemiptera species
S_EPT	Number of Ephemeroptera + Plecoptera + Trichoptera species
S_ETO	Number of Ephemeroptera + Trichoptera + Odonata species
F_TRICL	Number of Tricladida families
F_GAST	Number of Gastropoda families
F_BIVA	Number of Bivalvia families
F_HIRU	Number of Hirudinea families
F_GAMA	Number of Gastropoda + Malacostraca families
F_TRHI	Number of Tricladida + Hirudinea families
F_MALA	Number of Malacostraca families
F_EPHE	Number of Ephemeroptera families
F_PLEC	Number of Plecoptera families
F_ODON	Number of Odonata families
F_HEMI	Number of Hemiptera families
F_COLE	Number of Coleoptera families
F_MEGA	Number of Megaloptera families
F_TRICH	Number of Trichoptera families
F_PHEM	Number of predatory Hemiptera families
F_GHM	Number of Gastropoda + Hirudinea + Malacostraca families
F_GH	Number of Gastropoda + Hirudinea families
F_EPT	Number of Ephemeroptera + Trichoptera families
F_ETO	Number of Ephemeroptera + Trichoptera + Odonata families
F_OM	Number of Odonata + Megaloptera families
F_EM0	Number of Ephemeroptera + Megaloptera + Odonata families
P_BMWP	Pond BMWP score
P_ASPT	Pond ASPT
AB_TRIC	Abundance of Tricladida species
AB_GAST	Abundance of Gastropoda species
AB_BIVA	Abundance of Bivalvia species
AB_HIRU	Abundance of Hirudinea species

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

Code	Attribute description
AB_TRHI	Abundance of Tricladida + Hirudinea
AB_ISOP	Abundance of Isopoda species
AB_AMPH	Abundance of Amphipoda species
AB_GAMA	Abundance of Gastropod + Malacostraca
AB_MALA	Abundance of Malacostraca
AB_EPHE	Abundance of Ephemeroptera species
AB_PLEC	Abundance of Plecoptera species
AB_ODON	Abundance of Odonata species
AB_HEMI	Abundance of Hemiptera species
AB_COLE	Abundance of Coleoptera species
AB_MEGA	Abundance of Megaloptera species
AB_TRIC	Abundance of Trichoptera species
AB_OM	Abundance of Megaloptera + Odonata
AB_EPMO	Abundance of Ephemeroptera + Plecoptera + Megaloptera + Odonata
AB_EPMOT	Abundance of Ephemeroptera + Plecoptera + Megaloptera + Odonata + Trichoptera
AB_TAX	Average number of individuals per taxon
AB_NINS	Abundance of non-insects
AB_INS	Abundance of insects
AB_NI_I	Abundance of Non-Insects/Insects
AB_TOT	Total number of individuals

Appendix 7b. Macrophyte attributes tested as possible metrics (ponds only)

Code	Attribute description
NTX_ALL	Number of all wetland plant species
NTX_EMER	Number of emergent plant species
NTX_FFL	Number of free-floating plant species
NTX_FLT	Number of floating plant species
NTX_SUB	Number of submerged plant species
NTX_AQU	Number of aquatic plant species
NTX_SPOT	Number of Potamogeton species
%ALLPLT	Cover of all wetland plant species (%)
%EMERG	Cover of emergent plant species (%)
%FFLOAT	Cover of free-floating plant species (%)
%FLOAT	Cover of floating plant species (%)
%SUBMER	Cover of submerged plant species (%)
%AQUATIC	Cover of aquatic plant species (%)
EX_%ALL	Total number of exotic species (%)
EX_%EMER	Cover of emergent exotic species (%)
EX_%FLT	Cover of floating exotic species (%)
EX_%SUB	Cover of submerged exotic species (%)
EX_%AQU	Cover of aquatic exotic species (%)
EX_ALL	Number of all exotic species
EX_EMER	Number of emergent exotic species
EX_FLT	Number of floating exotic species
EX_SUB	Number of submerged exotic species
EX_AQU	Number of aquatic exotic species
IN_FF`SU	Free-floating plants/submerged plants
IN_SB`FL	Submerged plants/floating plants
NUS_ALL	Number of all uncommon wetland plant species
NUS_EMER	Number of uncommon emergent plant species
NUS_FLT	Number of uncommon floating plant species
NUS_SUB	Number of uncommon submerged plant species
NUS_AQU	Number of uncommon aquatic plant species
SRI_ALL	Species Rarity Index: all wetland plant species
SRI_EMER	Species Rarity Index: emergent plant species
SRI_FLT	Species Rarity Index: floating plant species
SRI_SUB	Species Rarity Index: submerged plant species
SRI_AQU	Species Rarity Index: aquatic plant species
RSS_ALL	Rare Species Score: all wetland plant species
RSS_EMER	Rare Species Score: emergent plant species
RSS_FLT	Rare Species Score: floating plant species
RSS_SUB	Rare Species Score: submerged plant species
RSS_AQU	Rare Species Score: aquatic plant species
SRS_ALL	Species Rarity Score: all wetland plant species
SRS_EMER	Species Rarity Score: emergent plant species
SRS_FLT	Species Rarity Score: floating plant species
SRS_SUB	Species Rarity Score: submerged plant species
SRS_AQU	Species Rarity Score: aquatic plant species
TRS_ALL	Trophic Ranking Score: all plants
TRS_AQU	Trophic Ranking Score: aquatic plants
TRS_EMER	Trophic Ranking Score: emergent plants

Appendix 8. Environmental attributes

Appendix 8a. Pond environmental attributes

ALTITUDE	Altitude
EASTING	Easting
NORTHING	Northing
PAREA	Pond area
WAREA	Water area
DRAW_%	Drawdown area (% water remaining)
DRAW_CM	Drawdown height
PMC	Pond Margin Complexity Rating
PERM	Permanence (ranked)
PSHADE_%	Shade: % of pond area overhung
WSHADE_%	Shade: % of water area overhung
SHADE_PM	Shade % of pond margin overhung
SHADE_WM	Shade % of water margin overhung
DECID_5	Land cover % within 5m: deciduous woodland
CONIF_5	Land cover % within 5m: coniferous woodland
SCRUB_5	Land cover % within 5m: scrub and hedge
HEATH_5	Land cover % within 5m: heath and moor
BOG_5	Land cover % within 5m: bog
MARSH_5	Land cover % within 5m: marsh and fen
RANK_5	Land cover % within 5m: rank vegetation
UNIMPG_5	Land cover % within 5m: unimproved grassland
SEMIG_5	Land cover % within 5m: semi-improved grassland
IMPG_5	Land cover % within 5m: improved grassland
ARABLE_5	Land cover % within 5m: arable
PARK_5	Land cover % within 5m: parks and gardens
BUILD_5	Land cover % within 5m: buildings
ROAD_5	Land cover % within 5m: roads
PATH_5	Land cover % within 5m: paths and tracks
POND_5	Land cover % within 5m: ponds and Lakes
STREAM_5	Land cover % within 5m: streams and ditches
ALLWS_5	Land cover % within 5m: total wood and scrub
ALLSNG_5	Land cover % within 5m: semi-natural grassland
ALLGR_5	Land cover % within 5m: total grassland
ALLWET_5	Land cover % within 5m: total wetlands
ALLSNAT5	Land cover % within 5m: all semi-natural landuse
ALLAG1_5	Land cover % within 5m: all intensive agriculture
ALLAG2_5	Land cover % within 5m: intensive ag.+ semi-improved grass
ALLURB_5	Land cover % within 5m: all urban areas
ALLINT_5	Land cover % within 5m: all intensive landuse
DECID_1	Land cover % within 100m: deciduous woodland
CONIF_1	Land cover % within 100m: coniferous woodland
SCRUB_1	Land cover % within 100m: scrub and hedge
HEATH_1	Land cover % within 100m: heath
BOG_1	Land cover % within 100m: bog
MARSH_1	Land cover % within 100m: marsh

Appendix 8a (continued). Pond environmental attributes

RANK_1	Land cover % within 100m: rank vegetation
UNIMPG_1	Land cover % within 100m: unimproved grassland
SEMIG_1	Land cover % within 100m: semi-improved grassland
IMPG_1	Land cover % within 100m: improved grassland
ARABLE_1	Land cover % within 100m: arable
PARK_1	Land cover % within 100m: parks and gardens
BUILD_1	Land cover % within 100m: buildings
ROAD_1	Land cover % within 100m: roads
PATH_1	Land cover % within 100m: paths and tracks
DUMP_1	Land cover % within 100m: dumps and waste areas
POND_1	Land cover % within 100m: ponds and Lakes
STREAM_1	Land cover % within 100m: streams and ditches
ALLWS_1	Land cover % within 100m: total wood and scrub
ALLSNG_1	Land cover % within 100m: semi-natural grassland
ALLGR_1	Land cover % within 100m: 0-100m all grassland
ALLWET_1	Land cover % within 100m: 0-100m all wetlands
ALLSNAT1	Land cover % within 100m: all semi-natural lands
ALLAG1_1	Land cover % within 100m: intensive agriculture
ALLAG2_1	Land cover % within 100m: intensive ag.+ semi-improved grass
ALLURB_1	Land cover % within 100m: all urban areas
ALLINT_1	Land cover % within 100m: all intensive land
FLOOD	Location on a floodplain (ranked)
TRADWET	Located in an area of traditional wetlands (ranked)
ISOLAT	Isolation from other waters and wetlands (ranked)
WSGROUND	Water Source: % groundwater
WSSURFAC	Water Source: % surfacewater
WSPPT	Water Source: % precipitation
WSFLSPR	Water Source: % flush+spring
WSSTREAM	Water Source: % stream or ditch
WSFLOOD	Water Source: % flood
WSDRAIN	Water Source: % land drains
WSGSF	Water Source: % groundwater+spring+flush
AVDEPTH	Water depth
AVSILT	Sediment depth
SSTGEOL	Sandstone catchment geology
CLAYGEOL	Clay catchment geology
LSTGEOL	Limestone catchment geology
IGMGEOL	Igneous and metamorphic catchment geology
BASECLAY	Pond base: clay, silt
BASEBUTY	Pond base: artificial
BASESAND	Pond base: sand
BASEGRAV	Pond base: gravel
BASEPEBB	Pond base: pebbles
BASEROCK	Pond base: rock
BASEPEAT	Pond base: peat
BASESTON	Pond base: stone blocks

Appendix 8a (continued). Pond environmental attributes

SEDLEAV	Sediment: % leaves
SEDDEBR	Sediment: % coarse debris
SEDOOZE	Sediment: % clay and silt
SEDSAND	Sediment: % sand
SEDGRAV	Sediment: % gravel
SEDPEAT	Sediment: % peat
SEDPEBB	Sediment: % pebbles
SEDBOUL	Sediment: % boulders
INFLOW	Inflow present
INFLVOL	Inflow volume
OUTFLOW	Outflow present
OUTVOL	Outflow volume
BNKEARTH	Bank type natural: earth
BNKROCK	Bank type natural: rock.
BABKARTF	Bank type artificial
EDGE_MIN	Water depth at edge: minimum
EDGE_MAX	Water depth at edge: maximum
DREDGED	Pond recently dredged (ranked)
GRAZED	Grazed by livestock
%MGRAZ	% of margin grazed
%PGRAZ	% of pond grazed
GRAZINT	Grazing intensity (ranked)
FISH	Fish presence
FISHINT	Fish Intensity (ranked)
AGE	Pond age (ranked)
TUBIDITY	Water turbidity (ranked)
RUBBISH	Rubbish present
%RUBBISH	Rubbish: % of pond
OIL	Oil present
POL_AG	Pollution Index: agricultural land
POL_URB	Pollution Index: urban
POL_ROAD	Pollution Index: road runoff
POL_STRE	Pollution Index: stream and other inflows
POL_DUCK	Pollution Index: fish
POL_FISH	Pollution Index: ducks
POL_STOC	Pollution Index: stock
POL_LITT	Pollution Index: litter
POL_CESS	Pollution Index: cess runoff
POL_CONI	Pollution Index: conifer plantation
POL_ACID	Pollution Index: acidification
POL_PEOP	Pollution Index: urban/people disturbance
POL_GOLF	Pollution Index: golf course runoff
POL_AMEN	Pollution Index: amenity areas
POL_MINE	Pollution Index: mining/quarry
POL_OVER	Overall Pollution Index
POL_DILU	Overall Pollution diluted by groundwater inputs

Appendix 8a (continued). Pond environmental attributes

POL_WL	Physical damage: water levels (e.g. pumped)
POL_SIDE	Physical damage: reinforced banks
PH_SITE	Water quality: pH (measured on site)
CON_SITE	Water quality: conductivity (measured on site)
ALK_SITE	Water quality: alkalinity (measured on site)
CAL_SITE	Water quality: calcium (measured on site)
LAB_PH	Water quality: pH (lab. measured)
LAB_COND	Water quality: conductivity (lab. measured)
LAB_SS	Water quality: suspended solids (lab. measured)
LAB_TON	Water quality: total organic nitrogen (lab. measured)
LAB_SRP	Water quality: soluble reactive phosphate (lab. measured)
LAB_AL	Water quality: aluminium (lab. measured)
LAB_CU	Water quality: copper (lab. measured)
LAB_FE	Water quality: iron (lab. measured)
LAB_MG	Water quality: magnesium (lab. measured)
LAB_NI	Water quality: nickel (lab. measured)
LAB_PB	Water quality: lead (lab. measured)
LAB_ZN	Water quality: zinc (lab. measured)
LAB_CA	Water quality: calcium (lab. measured)
LAB_K	Water quality: potassium (lab. measured)
LAB_NA	Water quality: sodium (lab. measured)

Appendix 8b Canal environmental attributes

ALTITUDE	Altitude
EASTING	Easting
NORTHING	Northing
DAY	Day from start of survey
WIDTH	Width of canal (m)
EDGE%CONC	Bank type: Concrete (%)
EDGE%EARTH	Bank type: Earth (%)
EDGE%HAR_EXS	Bank type: Total hard bank excluding stone (%)
EDGE%HAR_INS	Bank type: Total hard including stone (%)
EDGE%METAL	Bank type: Metal piling (%)
EDGE%OTHER_STONE	Bank type: Other: stone or concrete blocks (%)
EDGE%WOOD	Bank type: Wood (%)
EDGE_%OTHER_BRICK	Bank type: Other: brick (%)
EDGE_ANGLE	Angle of bank
DEPTH_ED	Water depth at the canal edge
DEPTH:TOTAL_D1	Sediment + water depth 1m from the canal edge
DEPTH:TOTAL_D2	Sediment + water depth 2m from the canal edge
DEPTH:TOTAL_D3	Sediment + water depth 3m from the canal edge
DEPTH_TOTAL_AV	Sediment + water depth average
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_AV	Water depth average
DEPTH_SED_1	Sediment depth 1m from the canal edge
DEPTH_SED_2	Sediment depth 2m from the canal edge
DEPTH_SED_3	Sediment depth 3m from the canal edge
DEPTH_SED_AV	Sediment depth average
SED%BOULDER	Substrate at edge: % boulders and cobbles
SED%COARSE	Substrate at edge:% coarse detritus
SED%FINE	Substrate at edge: % fine detritus
SED%GRAVEL	Substrate at edge: % gravel
SED%PEBBLES	Substrate at edge: % pebbles
SED%SAND	Substrate at edge: % sand
SED%SILT	Substrate at edge: % Silt/clay
SED_AV_BOUL	Substrate average: % boulders and cobbles
SED_AV_COAR	Substrate average:% coarse detritus
SED_AV_FINE	Substrate average: % fine detritus
SED_AV_GRAV	Substrate average: % gravel
SED_AV_PEBB	Substrate average: % pebbles
SED_AV_SILT	Substrate average: % Silt/clay
SHADE%_B	% of bank edge overhung
SHADE%_W	% of water area overhung

Appendix 8b (continued). Canal environmental attributes

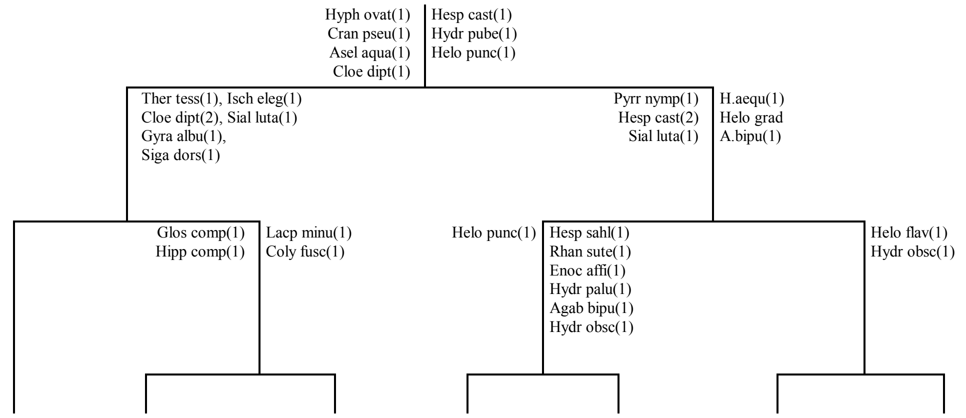
%AQUA_SA	Aquatic plant cover (%) in the sampling area
%FLOA_SA	Floating plant cover (%) in the sampling area
%MARG_SA	Marginal emergent plant cover (%) in the sampling area
%ALG_SA	Filamentous algae cover (%) in the sampling area
%TOTAL_SA	Total vegetation cover (%) in the sampling area
%TOTAL_SA+ALGAE	Total vegetation cover (%) inc. algae in the sampling area
BANK_50	Length of bank vegetated (%) in the sampling area
%AQUA_50	Aquatic plant cover (%) along 50m bank length
%FLOA_50	Floating plant cover (%) along 50m bank length
%MARG_50	Marginal emergent plant cover (%) along 50m bank length
%ALG_50	Filamentous algae cover (%) along 50m bank length
%TOTAL	Total vegetation cover (%) along 50m bank length
V%TOTAL_50+ALGAE	Total vegetation cover (%) inc. algae along 50m bank length
VEGBANK_50_BANK	Length of bank vegetated (%) along 50m bank length
BOATS	Boat traffic (thousands of movements/yr)
SECCHI	Turbidity (secchi depth)
FLOW	Average flow (Ml/day)
AL(PA)	Aluminium (mg/l) (analysed by Pond Action)
ALKALINITY (PA)	Alkalinity (Meq/l (analysed by Pond Action)
AMMONIA (EA)	Ammonia (analysed by Pond Action)
AMMONIA (PA)	Ammonia (mg/l) (analysed by the Environment Agency)
BOD(EA)	Biological Oxygen Demand (analysed by the Agency)
CALCIUM (PA)	Calcium (mg/l) (analysed by Pond Action)
CHLORIDE (PA)	Chloride (mg/l) (analysed by Pond Action)
COPPER (PA)	Copper (mg/l) (analysed by Pond Action)
DO (EA)	Dissolved oxygen (analysed by the Environment Agency)
IRON (PA)	Iron (analysed by Pond Action)
METALS (PA RANKED)	Iron (mg/l)
METALS (BW SEDIMENT)	Metals sum of ranked values (BW sediment sample)
SODIUM (PA)	Sodium (analysed by Pond Action)
PAH (BW SEDIMENT)	PAH (BW sediment sample)
CONDUCTIVITY (PA)	Conductivity (analysed by Pond Action)
PH (PA)	pH (analysed by Pond Action)
LEAD (PA)	Lead (mg/l) (analysed by Pond Action)
PHENOLS (BW SEDIMENT)	Phenols (BW sediment sample)
POTASSIUM (PA)	Potassium (mg/l) (analysed by Pond Action)
SRP (PA)	Soluble reactive phosphorus (mg/l) (analysed by Pond Action)
SS (PA)	Suspended solids (mg/l) (analysed by Pond Action)
TON (PA WATER)	Total oxidised nitrogen (mg/l) (analysed by Pond Action)
TP (BW SEDIMENT)	Sediment total phosphorus concentration (mg/kg) (BW sediment sample)
ZINC (PA)	Zinc (mg/l) (analysed by Pond Action)
CHEMICAL QUALITY	Environment Agency Water quality category
SED_QUAL	BW sediment quality category

Appendix 8b (continued). Canal environmental attributes

LU_GRASS	Land use 0-5m sample side: % all grassland
LU_WATER	Land use 0-5m sample side: % waterbodies
LU_SEMI_N	Land use 0-5m sample side: % seminatural
LU_URBAN	Land use 0-5m sample side: % urban
LU_INT_AG	Land use 0-5m sample side: % intensive agriculture
LU_INT_ALL	Land use 5-100m sample side: % total intensive
LU_GRASS_1	Land use 5-100m sample side: % all grassland
LU_WATER_1	Land use 5-100m sample side: % waterbodies
LU_SEMI_N_1	Land use 5-100m sample side: % seminatural
LU_URBAN_1	Land use 5-100m sample side: % urban
LU_INT_AG_1	Land use 5-100m sample side: % intensive agriculture
LU_INT_ALL_1	Land use 5-100m sample side: % total intensive

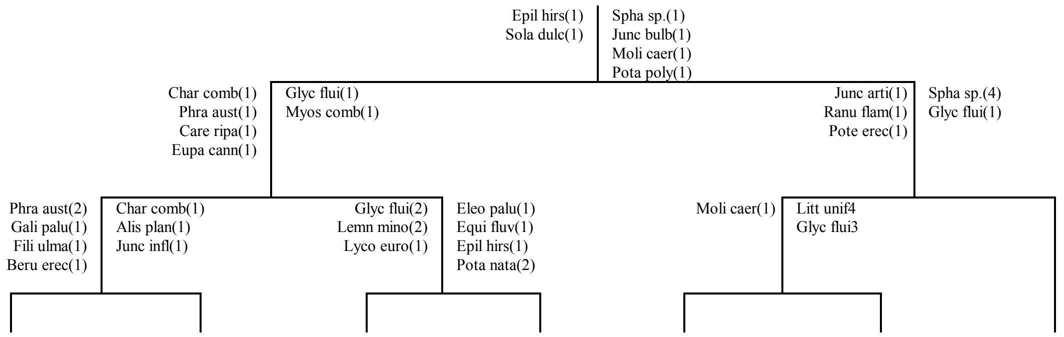
Appendix 9. TWINSPAN diagrams for each assemblage

A.9a. TWINSPAN classification of pond macroinvertebrate assemblages



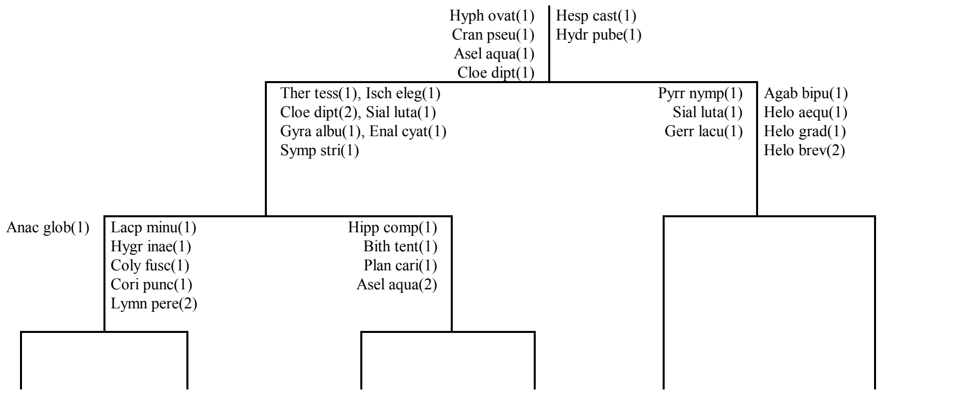
1	2	3	4	5	6	7
AFPA	AFPB	BRAY	BMNF	BAR1	BEGW	BEGE
AL48	AL41	BRPO	BOPO	CRO1	BHNF	CAEN
ASME	APPL	BUBE	BRCO	FFES	CEB2	CISS
BERB	BAFO	CASS	CABR	FQSP	CEB3	KING
BOCO	BLHP	CEPO	COFO	HOPA	CEB4	REDM
BRMO	BUCO	CFNF	FIML	MF26	LLCO	
BRWPCH	CAHA	EMHI	FIMS	MF29	MAEL	
OE	COFE	FYDO	FQMP	MPI3	RUPO	
CRHI	DSMP	HEHE	SOCO	MWF1	RYMO	
DELL	EV2A	LLFR	SWSE	QUA1	ULPO	
DS02	FOPI	LPST	SWSW	ROS1	WSNF	
DYOX	FWBR	MILL	THCO	SKWD		
EAMA	HADR	NH82	VEMO			
FEWMFO	HEKE	PIGR	WICO			
BR	KEPO	PIMA				
GAYT	LIHA	PISC				
HAWO	LWIL	PISW				
HHTP	LWIU	SADU				
IBCO	MAQU	SAFS				
MAME	MEGR	SNCO				
MBTPMO	OVNP	SOCF				
CO	OVSP	UPME				
MUME	PPMI	WIDU				
NH60	RIS1	WYEV				
NH64	SHCR					
NH69	SHEN					
NH70	SKPI					
NRRANT	SNPI					
HD	STMB					
SAFN	SW06					
SANM	SW09					
SOCN	SW11					
SOSP	WEPO					
SRCH	WFBP					
TCP1TCP2	WFBW					
THOR	WFDB					
TRBR	WW1					
TWAP	WW2					
TWYN	WW3					
UPTP	YA24					
WIWOWO						
FE						
WOWO						

A.9b. TWINSPAN classification of pond plant assemblages



1	2	3	4	5	6	7
BERB	CAHA	SAFS	AFPA	BMNF	BARL	CROO
COFE	CASS	SNPI	AFPB	BOPO	BEGW	FFES
EAMA	DS2.	STMB	APPL	BRAY	BRPO	FQSP
FEWM	DSMP	TRBR	ASME	BRCO	ULPO	LLCO
HEKE	LWUP	TWAP	BAFO	CABR		SKWD
HHTP	MAQU	UPME	BEGE	CEB2		SWSE
KEPO	MOCO	WICO	BUBE	CEB4		BHNF
LIHA	NH82	YA24	EMHI	CFNF		CEB3
UPTP	PIGR	BRMO	FWBR	COFO		HOPA
WFBP	PIMA	CAEN	HADR	FIML		SWSW
WFBW	PISC	CHOE	HEHE	FMIS		
WFDB	PISW	CISS	LLFR	FQMP		
	RISL	FYDO	LPST	MAEL		
	WOFE	HAWO	MBTP	MF26		
	WYC1	KING	MEGR	MF29		
	WYC2	LWLP	MILL	MPI3		
	WYC3	REDM	NH64	MWF1		
		SHEN	NH69	PIPO		
		SRCH	NH70	RHBU		
		TCP2	PPM1	RUPO		
		WIWO	QUAR	RYMO		
		WOWO	ROSS	SANM		
			SADU	SOCO		
			SHCR	THCO		
			SKPI	VEMO		
			SNCO	WIDU		
			SOCF	WSNF		
			SOCN			
			SOSP			
			SW06			
			SW09			
			SW11			
			TCP1			
			TWYN			
			WEPO			
			WYEV			

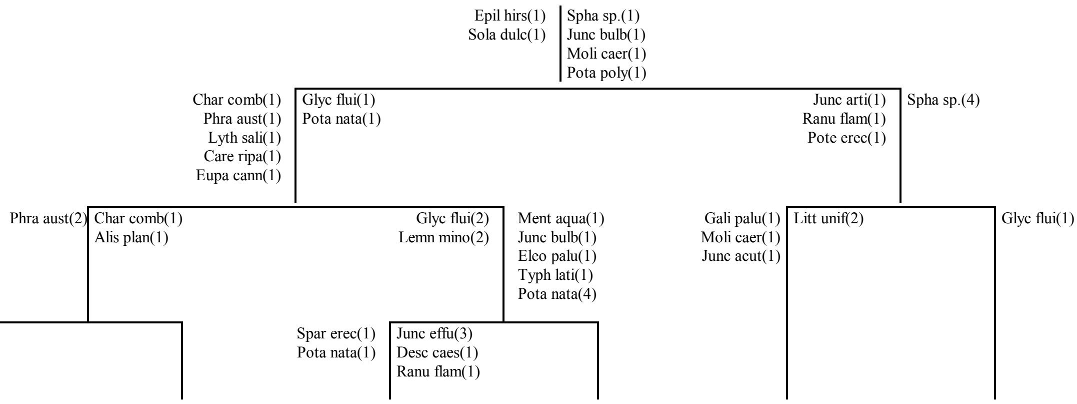
A.9c. TWINSPAN classification of pond and lake invertebrate assemblages



1	2	3	4	5	6
AFPA	ASME	AL41	AFPB	BAR1	BEGE
AL48	BOCO	BAFO	APPL	BMNF	BEGW
BERB	BRMO	CAHA	BLHP	BOPO	BHNF
BRWP	BUCO	FOPI	BRAY	CABR	BRCO
CHOE	CEPO	KEPO	BRPO	COFO	CAEN
CRHI	DELL	LIHA	BUBE	CRO1	CEB2
EAMAHAWO	DS02DYOX	OVNPSNPI	CASSCFNF	FFESFI	CEB3CEB4
IBCO	FEWM	STMB	COFE	ML	CISS
MUME	FYDO	WEPO	DSMP	FIMS	FOBR
SOCN	GAYT	WFBP	EMHI	FQMP	KING
SOSP	HHTP	WFBW	EV2A	FQSP	LLCO
TRBR	MAME	WFDB	FWBR	HOPA	MAEL
UPTPWOFE	MOCONH60	YA24DUNG	HADRHEHE	LPST	MBTPREDM
	NH64	**HOFE**	HEKE	MF26MF	RUPO
	NH69	**UPTO**	LLFR	29	RYMO
	NH70	**WEST**	LWIL	MPI3	ULPO
	NRRA	**WHEL**	LWIU	MWF1	WSNF
	NTHD		MAQU	QUA1	
	OVSPSAFN		MEGRMILL	ROS1	
	SANM		NH82	SHCR	
	SKPI		PIGR	SKWDS	
	SRCH		PIMA	OCO	
	TCP1		PISC	SWSE	
	TCP2		PISW	SWSW	
	THORTWAP		PPMIRIS1	THCO	
	WIWO		SADU	TWYN	
	WOWO		SAFS	VEMO	
			SHEN	WICOB	
			SNCO	URT	
			SOCF	**LGOR**	
			SW06SW09	**LMOR**	
			SW11	**NARE**	
			UPME	**TEWE**	
			WIDU		
			WW1		
			WW2		
			WW3WYEV		
			ACRE		
			BAVI		
			HATC		
			LHIR		
			MYTC		

NOTE: Lake sites in bold text

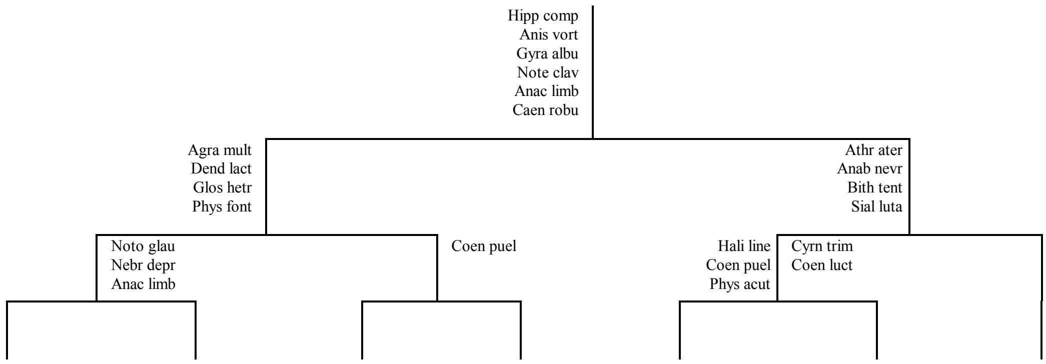
A.9d. TWINSPAN classification of pond and lake plant assemblages



1	2	3	4	5	6
BERB	CAHA	AL48	AFPA	BMNF	CROO
COFE	CASS	BLHP	AFPB	BOPO	FFES
EAMA	DS2.	BOCO	AL41	BRAY	FQSP
EV2a	DSMP	BUCO	APPL	BRCO	LLCO
FEWM	LWUP	CEPO	ASME	CABR	SKWD
HEKE	MAQU	CRHI	BAFO	CEB2	SWSE
HHTP	MOCO	DELL	BEGE	CEB4	BHNF
KEPO	PIGR	DYOX	BUBE	COFO	CEB3
LIHA	PIMA	FOBR	EMHI	FIML	HOPA
LWLP	PISC	FOPI	FWBR	FMIS	SWSW
TCP1	PISW	GAYT	HADR	LPST	
UPTP	RISL	MAME	HEHE	MAEL	
WFBP	STMB	MUME	LLFR	MBTP	
WFBW	WOFE	NH60	MILL	MEGR	
WFDB	WYC1	NRRA	NH64	MF26	
HOFE	WYC2	NTHD	NH69	MF29	
UPTO	WYC3	OVNP	NH70	MPI3	
	ACRE	OVSP	NH82	MWF1	
	DUNG	SAFN	PPM1	PIPO	
	WEST	SAFS	QUAR	REDM	
	WHEL	SNPI	SADU	RHBU	
		TRBR	SHCR	RUPO	
		TWAP	SHEN	RYMO	
		UPME	SKPI	SANM	
		BRMO	SNCO	SOCO	
		BRWP	SOCF	THCO	
		CAEN	SOCN	VEMO	
		CHOE	SOSP	WIDU	
		CISS	SW06	WSNF	
		FYDO	SW09	BARL	
		HAWO	SW11	BEGW	
		IBCO	TWYN	BRPO	
		KING	WEPO	CFNF	
		ROSS	WYEV	FQMP	
		SRCH	YA24	ULPO	
		TCP2	**BAVI**	**NARE**	
		WICO	**MYTC**	**BURT**	
		WIWO		**HATC**	
		WOWO		**LGOR**	
				LHIR	
				LMOR	
				TEWE	

NOTE: Lake sites in bold text

A.9e. TWINSPAN classification of canal invertebrate assemblages



1	2	3	4	5	6	7
44 Stourbridge	27 Grand Union	01 Oxford	48 Basingstoke	18 Grand Union	02 Oxford	12 Oxford
89 Cannock	29 Grantham	03 Oxfortd	51 Basingstoke	31 M & Brecon	04 Kennet & Avon	21 Grand Union
107 Leeds/L'pool	59 Grantham	13 Oxford	81 Basingstoke	32 M & Brecon	05 Kennet & Avon	58 Oxford
108 Leeds/L'pool	88 Newport	24 Ashby	82 Basingstoke	49 Basingstok	06 Kennet & Avon	21 Grand Union
	90 Cannock	57 Grand Union	83 Basingstoke	50 Basingstoke	07 Kennet & Avon	70 Shropshire
	101 Lancaster	60 Montgomery		64 Llangollen	93 Huddersfield	
	102 Lancaster	78 B & Taunton			94 Huddersfield	
	109 Ripon	79 B & Taunton				
	111 Pocklington	106 Grand Union				
	113 Pocklington					
	114 Leven					

Appendix 10. The proportion of minimally impaired reference sites predicted to the correct TWINSPAN endgroup using MDA

Table A10.1. Pond macroinvertebrates: comparison of the prediction of a seven-group site classification of reference sites using different combinations of variables (1999)

Physical variables used:	**14**	**13**	**9**	**7**	**5**
Easting	+	+	+	+	+
Northing	+	+	+	+	
Altitude	+	+	+	+	
pH	+	+	+	+	+
Shade: % pond area overhung	+	+	+	+	+
Margin grazed by livestock (%)	+	+	+	+	+
Pond area	+	+	+	+	+
Cover of emergent plants (%)	+	+	+		
Inflow (presence/absence)	+	+	+		
Base geology: clay (%)	+	+			
Base gelogy: sand, gravel, pebbles (%)	+	+			
Base geology: rock (%)	+	+			
Base geology: peat (%)	+	+			
Drawdown area (%)	+				
Percent of sites assigned to the correct classification group	**74**	**69***	**67**	**63**	**61**

* Chosen option

Table A10.2. Pond macrophytes: comparison of the prediction of a seven-group site classification of reference sites using different combinations of variables

Physical variables used:	**9**	**8**	**6**	**5**	**4**
Easting	+	+	+	+	+
Northing	+	+	+	+	
pH	+	+	+	+	+
Base geology: clay (%)	+	+			
Base geology: sand, gravel, pebbles (%)	+	+			
Base geology: rock (%)	+	+			
Base geology: peat (%)	+	+	+	+	+
Shade: % pond area overhung	+	+	+	+	+
Inflow	+				
Percent of sites assigned to the correct classification group	**67**	**66***	**64**	**58**	**50**

* Chosen option

Table A10.3. Pond and small lake macroinvertebrates: comparison of the prediction of a six-group site classification of reference sites using different combinations of variables

Physical variables used:	**11**	**10**	**7**	**6**	**4**
Altitude	+	+	+	+	+
Easting	+	+	+	+	+
Pond water depth	+	+	+	+	+
pH	+	+	+	+	+
Shade: % pond area overhung	+	+	+	+	
Isolation	+	+	+	+	
Catchment geology: igneous & metamorphic (%)	+	+			
Catchment geology: limestone (%)	+	+	+		
Surrounding land cover 100m: woodland (%)	+	+			
Surrounding land cover 100m: grassland (%)	+	+			
Cover of submerged plants (%)	+				
Percent of sites assigned to the correct classification grou	**67**	**65**	**64***	**62**	**56**

*Chosen option

Table A10.4. Pond and small lake macrophytes: comparison of the prediction of a six-group site classification of reference sites using different combinations of variables

Physical variables used:	**7**	**6**	**5**	**4**
Easting	+	+	+	+
pH	+	+	+	+
Shade: % pond area overhung	+	+	+	+
Surrounding land cover 100m: grassland (%)	+	+	+	
Base geology: peat (%)	+	+	+	+
Base geology: clay (%)	+	+		
Base geology: rock (%)	+			
Percent of sites assigned to the correct classification group	**75***	**71**	**70**	**66**

*Chosen option

Table A10.5. Canal macroinvertebrates: comparison of the prediction of a seven-group site classification of reference sites using different combinations of variables

Physical variables used:	7	6	5	4
Easting	+	+	+	+
Northing	+	+	+	+
Altitude	+	+	+	+
Alkalinity	+	+	+	+
Sand (percentage of bottom substrate)	+	+	+	
Turbidity (Secchi depth)				
Boats (number per annum)	+	+		
Percentage of canal which has submerged vegetation	+			
Percentage of bank artificially reinforced				
Percent of sites assigned to the correct classification group	**75**	**70***	**57**	**45**

***Chosen option**

Appendix 11. Environmental variables used to predict TWINSPAN endgroups for each biotic assemblage in each waterbody data set each

Table A11.1. Pond invertebrate assemblage: environmental variables used to predict TWINSPAN endgroups

EASTING	Easting
NORTHING	Northing
ALTITUDE	Altitude
AREA	Pond area (Log)
PH_SITE	pH
INFLOW	Presence of an inflow
PSHADE%	Shade: % pond area overhung
%MGRAZ	Margin grazed by livestock (%)
BASECLAY	Base geology: clay(%)
BASESGP	Base geology: sand, gravel and pebbles (%)
BASEROCK	Base geology: rock (%)
BASEPEAT	Base geology: peat (%)
EMPLTS%	Cover of emergent plants (%)

Number of variables: 13

Percent of sites assigned to the correct classification group: 69%

Table A11.2. Pond macrophyte assemblage: environmental variables used to predict TWINSPAN endgroups

EASTING	Easting
NORTHING	Northing
PH_SITE	pH
BASECLAY	Base geology: clay (%)
BASEROCK	Base geology: rock (%)
BASEPEAT	Base geology: peat (%)
BASESAND&GRAVEL	Base geology: sand, gravel and pebbles (%)
PSHADE%	Shade: % pond area overhung

Number of variables: 8

Percent of sites assigned to the correct classification group: 66%

Table A11.3. Pond and small lake invertebrate assemblage: environmental variables used to predict TWINSPAN endgroups

ALTITUDE	Altitude
EASTING	Easting
AVDEPTH	Pond water depth
PH_SITE	pH
PSHADE%	Shade: % pond area overhung
ISOLAT	Isolation
IGMGEOL	Catchment geology: limestone (%)

Number of variables: 7

Percent of sites assigned to the correct classification group: 68%

Table A11.4. Pond and small lake macrophyte assemblage: environmental variables used to predict TWINSPAN endgroups

EASTING	Easting
PH_SITE	pH
PSHADE%	Shade: % pond area overhung
ALLGRASS_1	Surrounding land cover 100m: grassland (%)
BASEPEAT	Base geology: peat (%)
BASECLAY	Base geology: clay (%)
BASEROCK	Base geology: rock (%)

Number of variables: 7

Percent of sites assigned to the correct classification group: 75%

Table A11.5. Canal macroinvertebrate assemblage: environmental variables used to predict TWINSPAN endgroups

EASTING	Easting
NORTHING	Northing
ALTITUDE	Altitude
ALK_PA	Alkalinity
AV_SAND	Sand (percentage of bottom substrate)
BOATS	Boats (number per annum)

Number of variables: 6

Percent of sites assigned to the correct classification group: 70%

Appendix 12. Relationships between pond plant and invertebrate metrics and environmental degradation

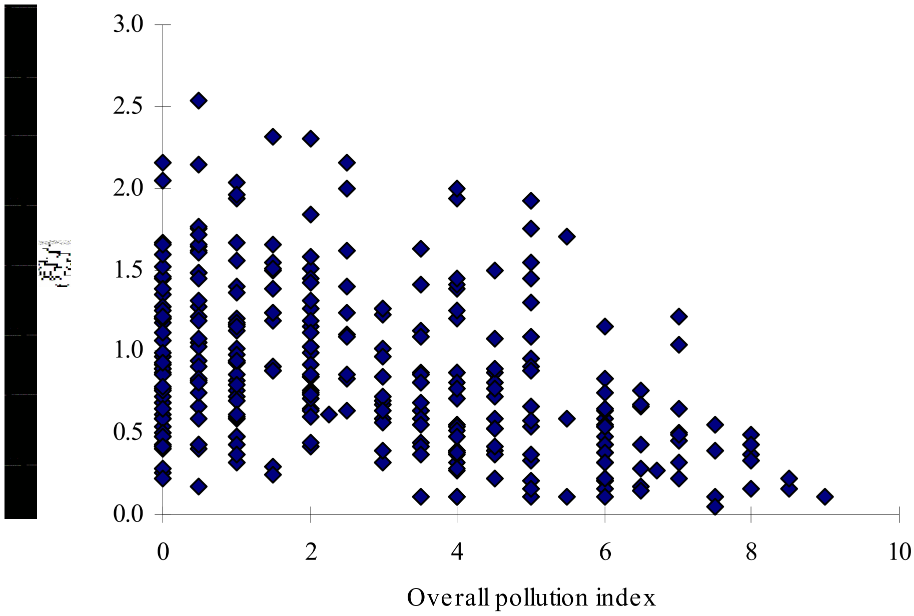


Figure A12.1 The relationship between marginal and submerged plant species richness EQI and overall pollution index (a measure of point and diffuse source pollution); $r_s = -0.42$, $p < 0.00001$.

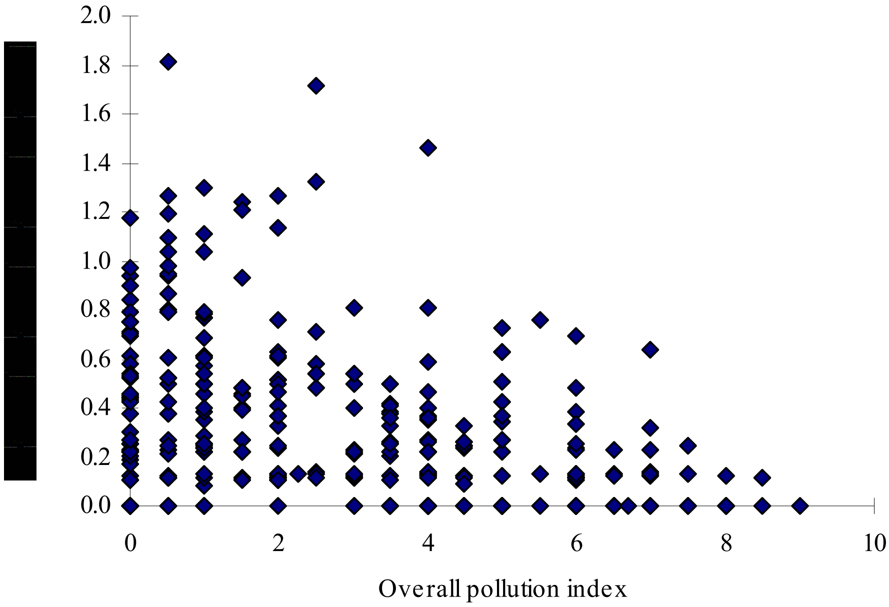


Figure A12.2 The relationship between number of uncommon plant species EQI and overall pollution index (a measure of point and diffuse source pollution); $r_s = -0.37$, $p < 0.00001$.

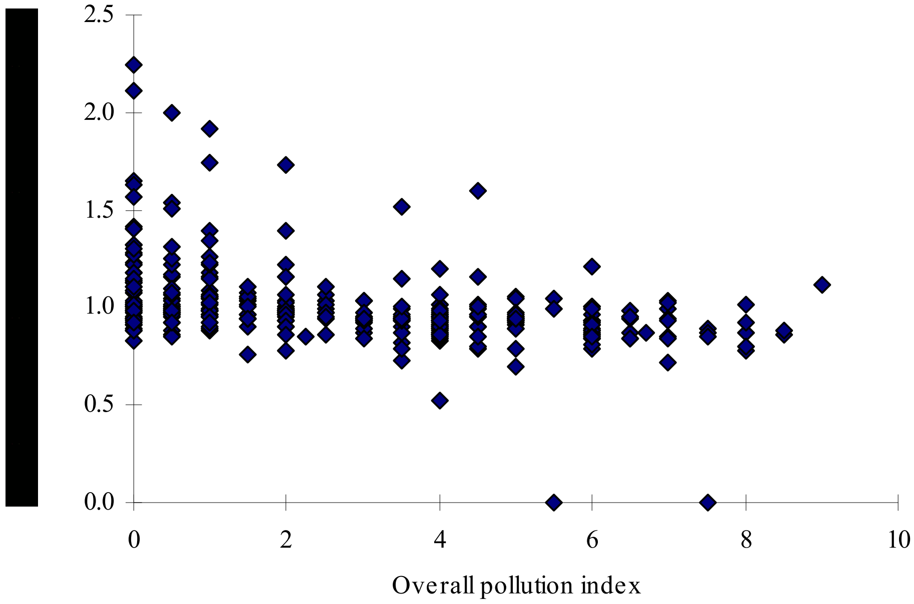


Figure A12.3 The relationship between Trophic Ranking Score EQI and overall pollution index (a measure of point and diffuse source pollution); $r_s = 0.48$, $p < 0.00001$.

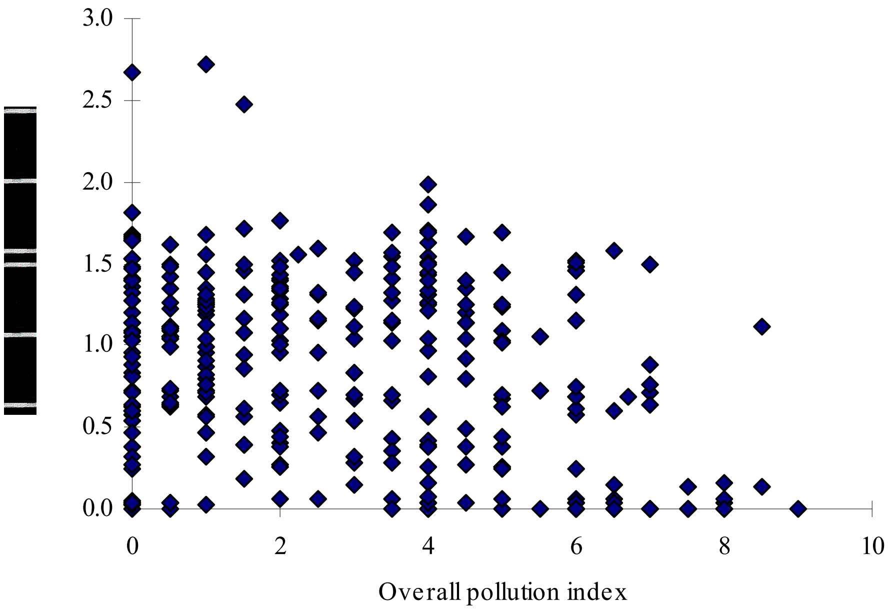


Figure A12.4 The relationship between aquatic plant cover EQI and overall pollution index (a measure of point and diffuse source pollution); $r_s = -0.24$, $p < 0.00001$.

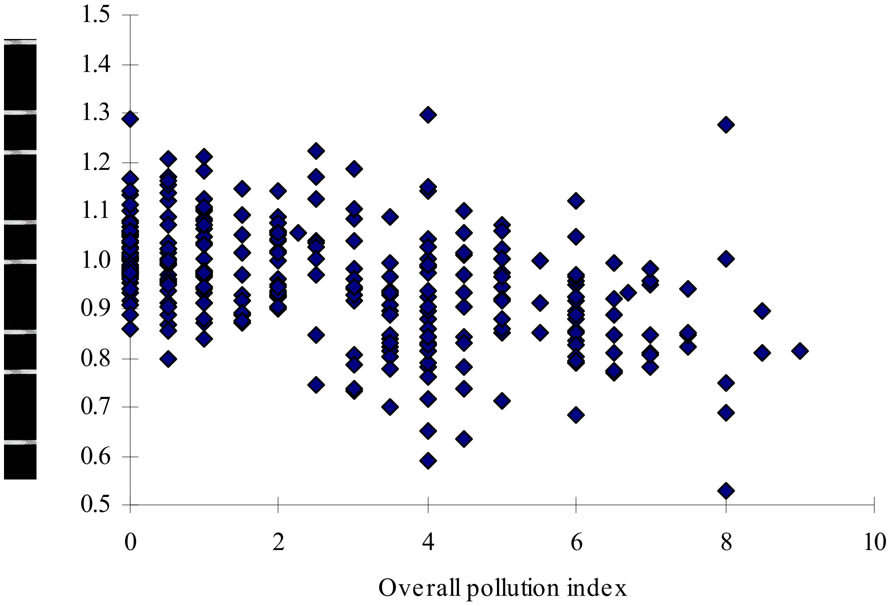


Figure A12.5 The relationship between pond average score per taxon (P_ASPT) EQI and overall pollution index (a measure of point and diffuse source pollution); $r_s = -0.46$, $p < 0.00001$.

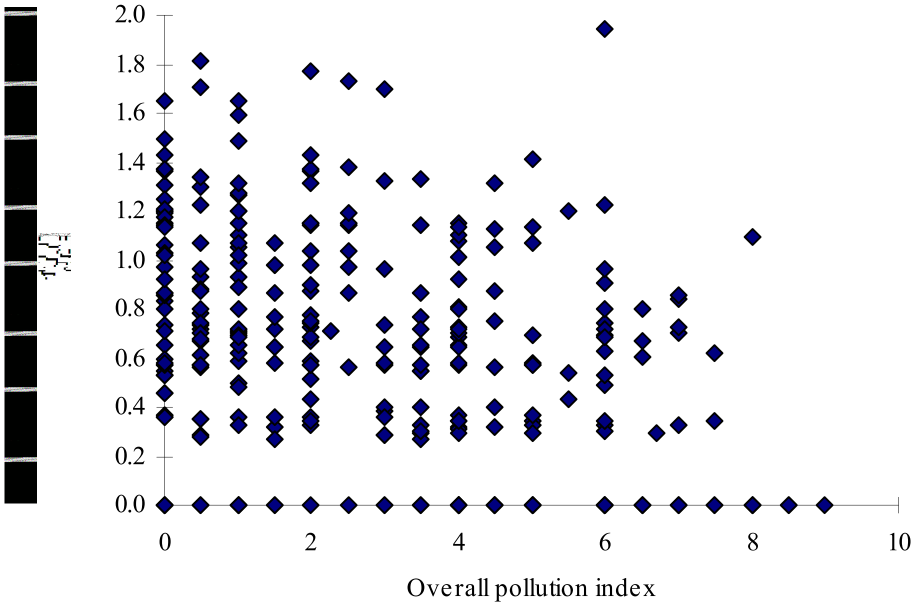


Figure A12.6 The relationship between number of Odonata and megaloptera families EQI and overall pollution index (a measure of point and diffuse source pollution); $r_s = -0.36$, $p < 0.00001$.

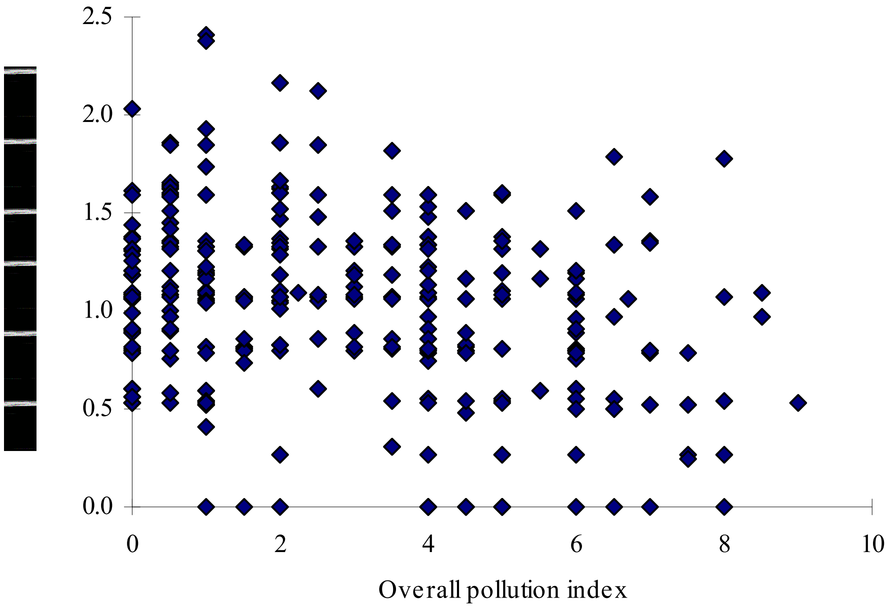


Figure A12.7 The relationship between number of Coleoptera families EQI and overall pollution index (a measure of point and diffuse source pollution); $r_s = -0.22$, $p < 0.0001$.

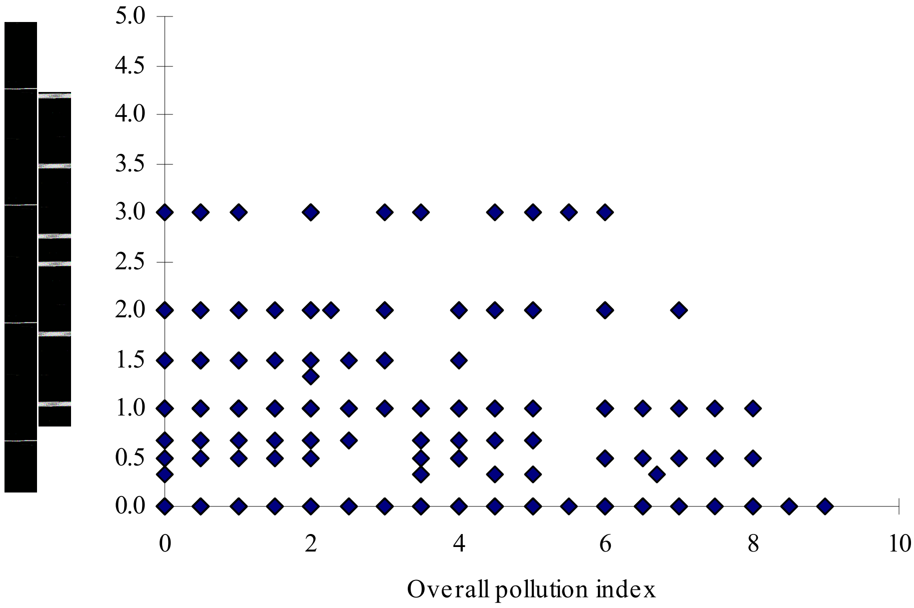


Figure A12.8 The relationship between abundance of Ephemeroptera, Plecoptera, Odonata and Megaloptera abundance EQI and overall pollution index (a measure of point and diffuse source pollution); $r_s = -0.25$, $p < 0.00001$.

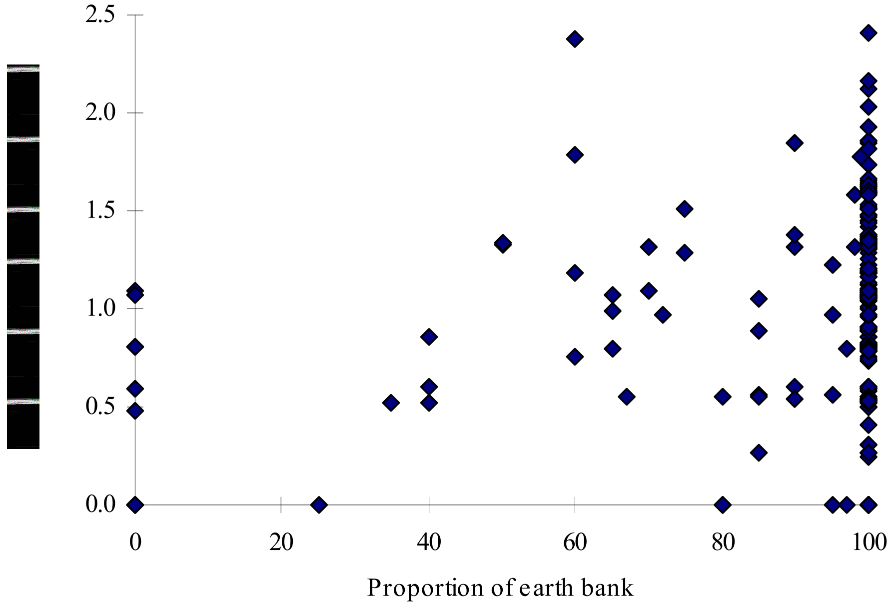


Figure A12.9 The relationship between number of Coleoptera families EQI and proportion of natural bank; $r_s = 0.15$, $p < 0.01$.

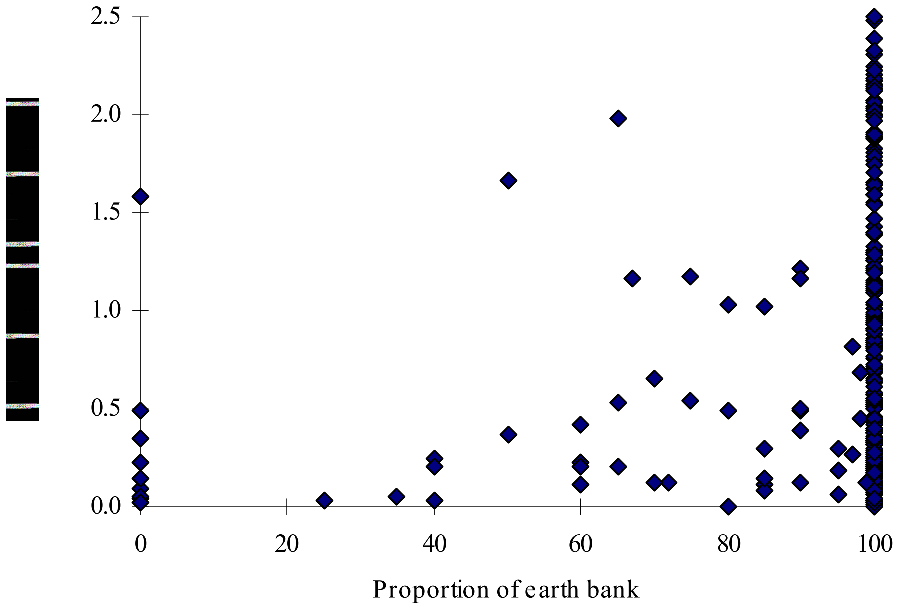


Figure A12.10 The relationship between marginal plant cover (%) EQI and proportion of natural bank; $r_s = 0.25$, $p < 0.00001$.

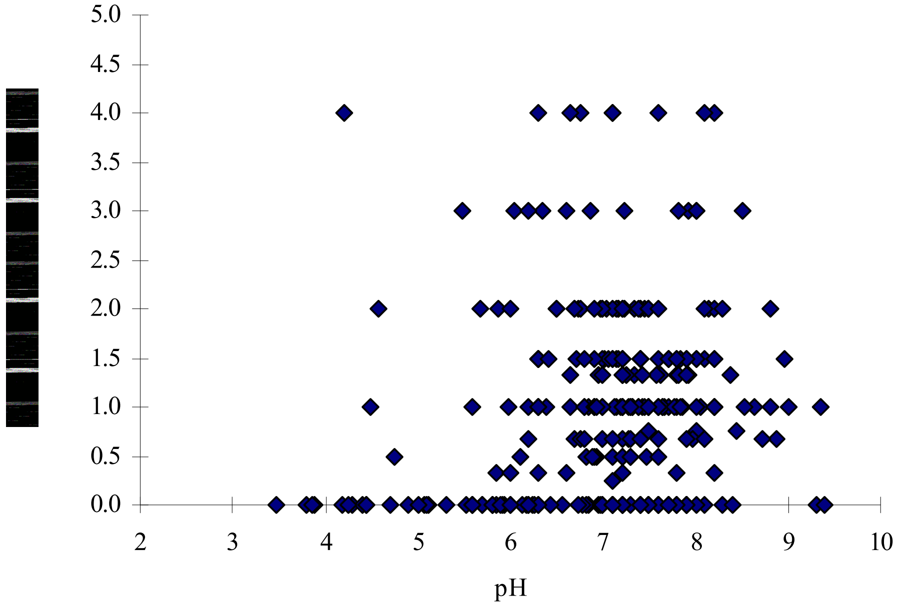


Figure A12.11 The relationship between abundance of Gastropoda EQI and pH; $r_s = 0.067$, ns.

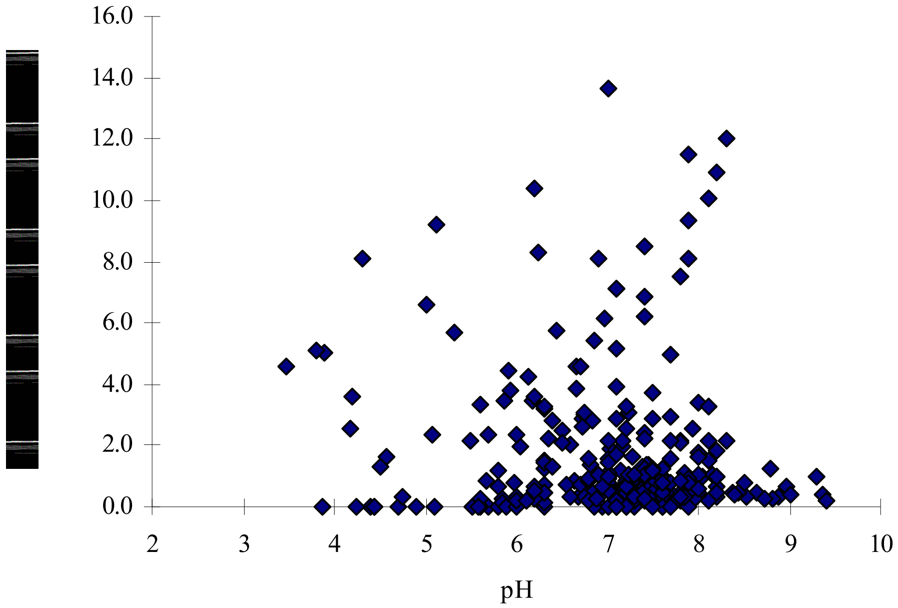


Figure A12.12 The relationship between abundance of Non-Insects/Insects EQI and pH; $r_s = -0.02$, ns.

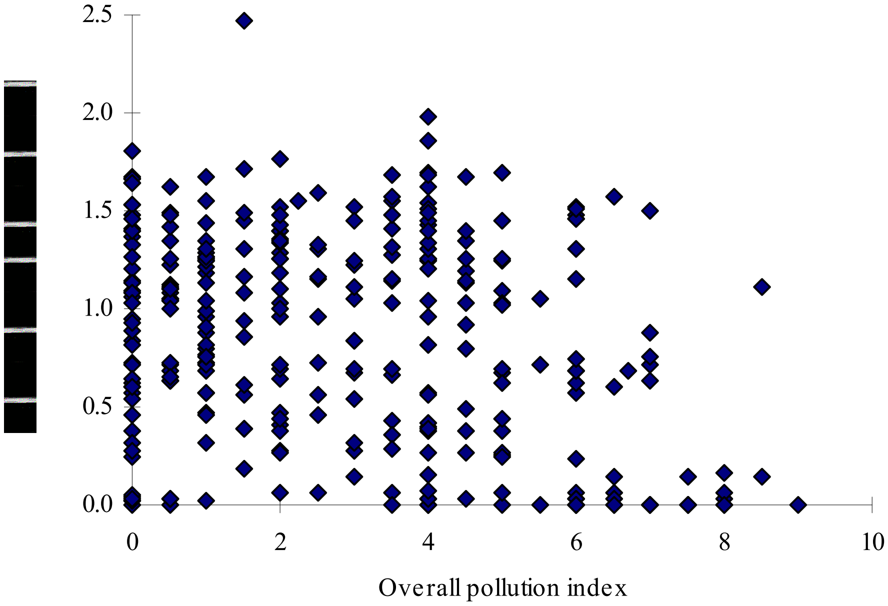


Figure A12.13 The relationship between log aquatic plant cover EQI and overall pollution index (a measure of point and diffuse source pollution); $r_s = -0.24$, $p < 0.00001$.

Appendix 13. Relationships between canal invertebrate metrics and chemical degradation

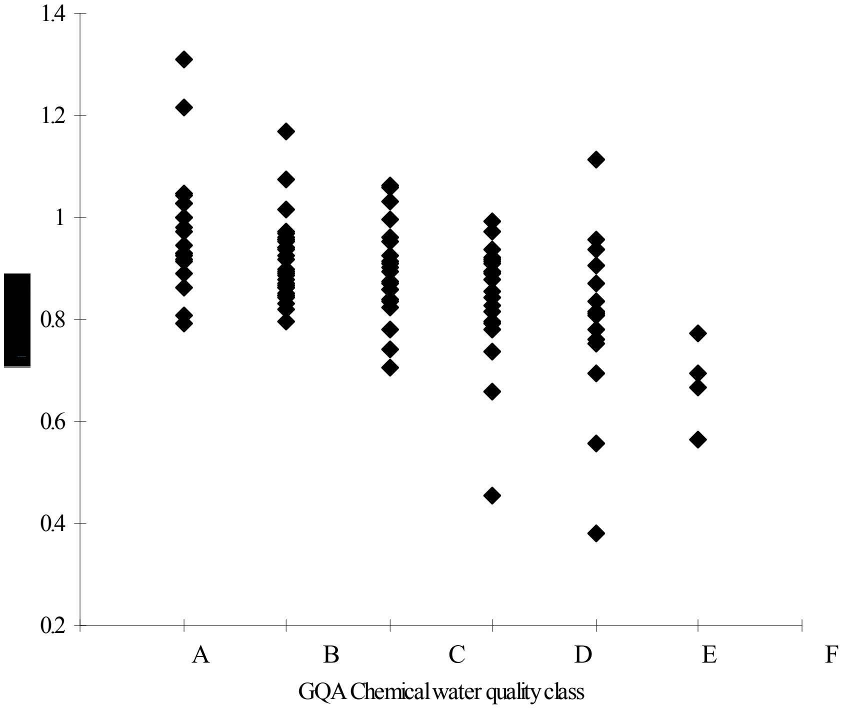


Figure A13.1 The relationship between canal ASPT EQI and water quality impairment (measured as GQA chemical class); rs = -0.26, p <0.0001.

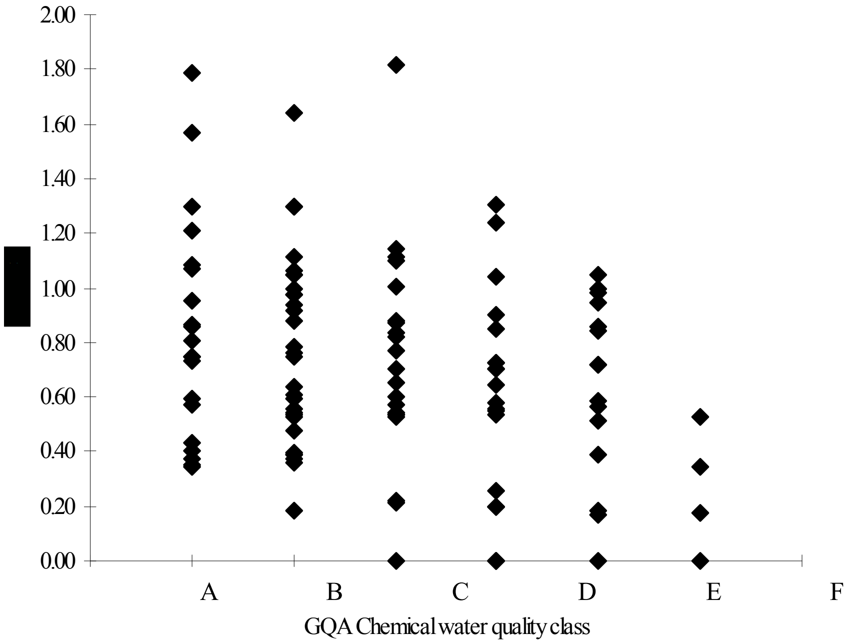


Figure A13.2 The relationship between canal EPT (Ephemeroptera + Plecoptera + Trichoptera) EQI and water quality impairment (measured as GQA chemical class); rs = -0.228, p <0.0001.

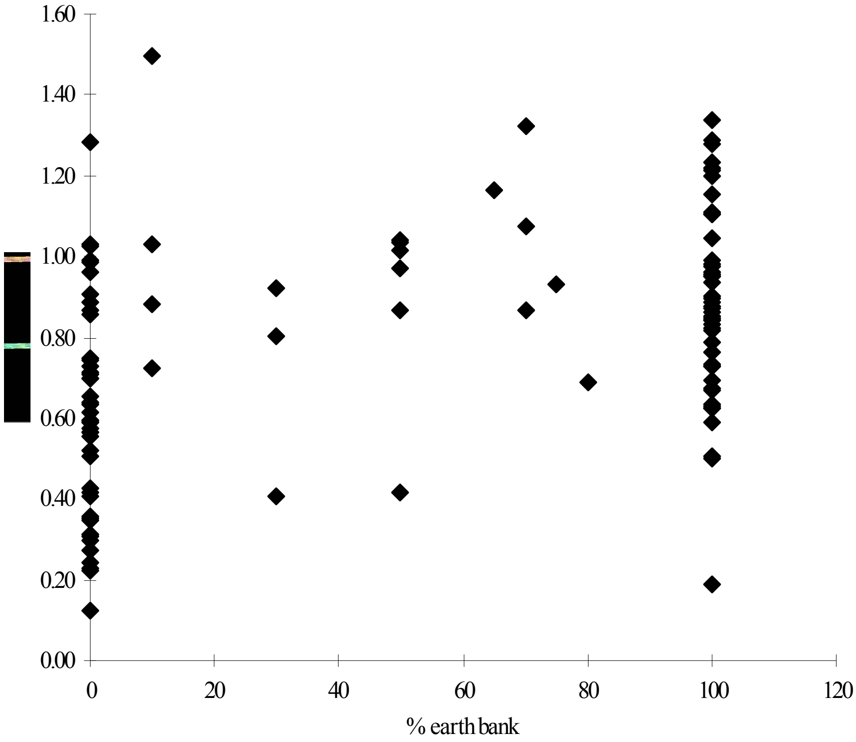


Figure A13.3 The relationship between canal invertebrate family richness EQI and bank structure impairment (measured as as % earth bank); rs = 0.17, p <0.0001.

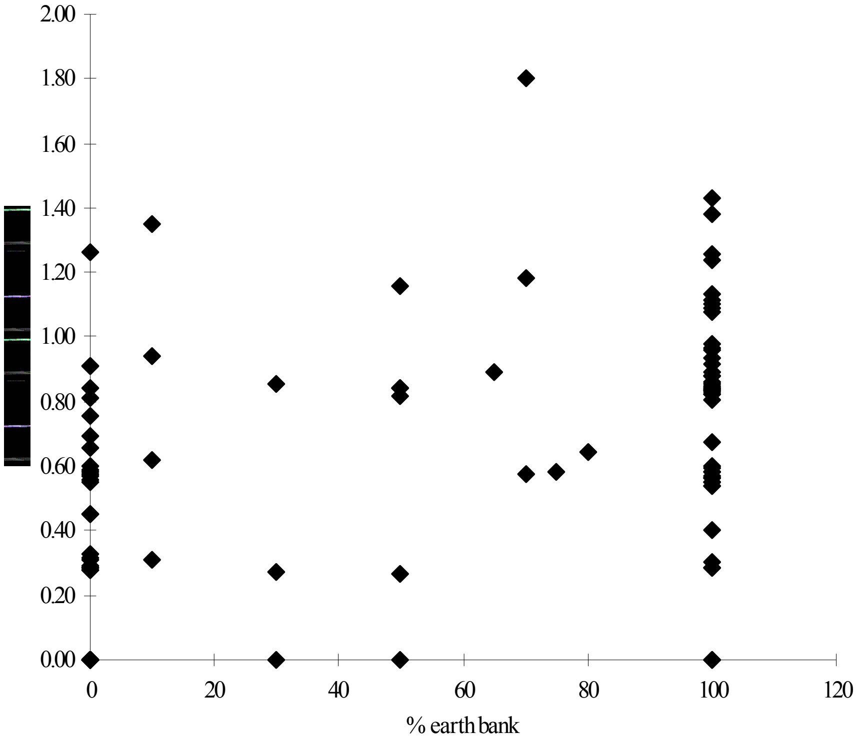


Figure A13.4 The relationship between canal Coleoptera family richness EQI and bank structure impairment (measured as as % earth bank); rs = 0.25, p <0.0001.

Appendix 14. Results of agency workshops for pond and canal PSYM

To train Environment Agency staff in Pond and Canal PSYM methods, four one day workshops were held for Agency biology and conservation staff. These workops were spread around Agency regions being held in Worcester, Nottingham, Leeds, and Berkshire.

The timetable for each day was:

- a 1 hour introductory talk
- visit to a pond to review the plant and invertebrate survey methods (morning)
- visit to the canal to review invertebrate survey methods (afternoon)
- a round up session to review results and discuss PSYM with staff.

For each workshop an existing canal site was selected nearest to the relevant regional office, and a pond selected nearby. Each pond and canal site had already been surveyed to provide a full standard dataset for the workshop[24].

Feedback

Pond PSYM generally worked well at the 4 sites. However, at the Berkshire site, which was a minimally impaired heathland pond, the TRS metric was overpredicted (i.e. PSYM predicted a more eutrophic TRS than was observed). This was probably a result of the database having very few acid sites from that part of the country.

Specific comments from participants about the working method included:

- Provision of lists of plant identification guides would be helpful;
- Plant species identification might be a problem and may need additional training to be made available;
- Further categorisation of environmental variables (as opposed to scoring variables as percentages) would be useful.
- More information would be useful on the robustness of environmental variables (i.e. how precise and accurate do measurements need to be).

With the exception of training in plant ID, these suggestions have been incorporated into the Pond PSYM fieldsheet and methods booklet.

Comments from the participants indicated that most would find the Pond PSYM method useful either for internal use or as a method which could be used outside the Agency (e.g. for EIA assessments).

[24]Interestingly, the ponds used for the training courses all turned out to have high biodiversity interest, altough only one was inside a nature reserve and previously known to be of biological interest; data from the survey work for the training courses showed that all of the ponds were either exceptionally rich or supported nationally scarce plants and invertebrates. Lower Smite Farm Pond, nr Worcester supported the nationally scarce plant Soft Hornwort (Rigid Hornwort is the much commoner species normally encountered). Ireland Wood Pond, Leeds (in a small area of woodland in the Leeds suburbs) had native crayfish and Britain's rarest water-milfoil, *Myriophyllum verticilatum*. Spike Island Pond, nr Nottingham, an unexceptional looking field pond, had remarkable growths of freshwater sponge and the second longest list of aquatic macroinvertebrates (88 species) ever recorded by Pond Action in a single 3-minute pond sample.

Since the training courses, South West region have begun to use the method to assess ponds in the R. Piddle floodplain: work which was undertaken in the course of a survey of native crayfish in that area.

Canals

The canal methods were generally favourably received. There was some discussion in the field about lone working and wading in the canal. It was acknowledged that wading the canal where possible was preferable to throwing a dredge from the bank. However, the choice would depend on local Health and Safety policy on lone working and the use of chest waders and dredges.

Appendix 15. Invertebrate taxa recorded in the 1999 canal survey

	Canal site number														
	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
Planariidae															
Polycelis nigra	3														
Polycelis tenuis	4	2		15	5		3					1			2
Dugesidae															
Dugesia lugubris				2											
Dugesia polychroa				2			1								
Dugesia tigrina									1						
Dendrocoelidae															
Dendrocoelum lacteum		1		2	6		1					1			
Neritidae															
Theodoxus fluviatilis															
Viviparidae															
Viviparus viviparus							1		1	8	8			1	21
Viviparus fasciatus															
Valvatidae															
Valvata cristata	1	2		2											
Valvata piscinalis		4	38			51	6								
Hydrobiidae															
Potamopyrgus antipodarum		2	4			7									
Bithyniidae															
Bithynia leachi				24		7	7		19						
Bithynia tentaculata		11	2	4	2	16	24		28	8	2	3		86	25
Physidae															
Physa acuta	2	5		6			1					15			
Physa fontinalis	2		1	6					7						
Lymnaeidae															
Lymnaea auricularia													1		
Lymnaea palustris	2			15										44	
Lymnaea peregra	4			1	4	7			6			7		4	
Lymnaea stagnalis				2	171	1				2		1			
Lymnaea truncatula	5														
Planorbidae															
Planorbis carinatus	3	5		56	15		1					24			1
Planorbis planorbis	5			1						5		1			1
Anisus vortex	1	94	9	229	371		19		3					1	
Bathyomphalus contortus				5											
Gyraulus albus					93	19	2		7			28		1	
Armiger crista		1	1		132	18	5								
Hippeutis complanatus				8	245	23	12		116						
Planorbarius corneus				3	5										
Ancylidae															
Ancylus fluviatilis						1									
Acroloxidae															
Acroloxus lacustris				13		1	11		6					57	
Unionidae															
Anodonta cygnea					2				1						
Unio pictorum						1									
Sphaeriidae															
Sphaerium corneum				54	7	1	1		7	13	1	3		22	
Sphaerium lacustre					1				4						
Sphaerium rivicola															
Dreissenidae															
Dreissena polymorpha						1									
Piscicolidae															
Piscicola geometra							1			1		1			2
Glossiphoniidae															
Theromyzon tessulatum															
Glossiphonia complanata					3		1		2			1			
Glossiphonia heteroclita															
Helobdella stagnalis		2		3	12		2		13						1

Appendix 15. Invertebrate taxa recorded in the 1999 canal survey

	Canal site number														
	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
Hirudidae															
Haemopis sanguisuga															
Erpobdellidae															
Erpobdella octoculata	6	8		13	11		4		1			1			
Erpobdella testacea															5
Araneae															
Argyroneta aquatica				3			2								
Asellidae															
Asellus aquaticus	16	37	16	61	622	64	435	5	342	17		494		133	16
Corophiidae															
Corophium curvispinum															
Crangonyctidae															
Crangonyx pseudogracilis	559	1278		494	43	4	51		278	82	5	33	2	187	118
Gammaridae															
Gammarus pulex	39														64
Baetidae															
Cloeon dipterum	3	3	1		49	31	5			9		2			
Ephemeridae															
Ephemera vulgata															
Caenidae															
Caenis horaria		6			52	279	7			12	29	43			
Caenis luctuosa		22	74							1	2	21			
Caenis macrura															
Caenis robusta					29	4	1					1			
Platycnemidae															
Platycnemis pennipes															
Coenagriidae															
Ischnura elegans		195	1	6	171	32	33		8	4					
Enallagma cyathigerum									1						
Coenagrion puella/pulchellum				7			41								
Erythromma najas						5	1								
Aeshna cyanea															
Aeshna grandis						1	2								
Aeshna mixta															
Hydrometridae															
Hydrometra stagnorum				2	2										
Veliidae															
Velia caprai															2
Microvelia reticulata				2	13										
Gerridae															
Gerris argentatus															
Gerris lacustris					4					6					2
Nepidae															
Nepa cinerea	2			4								1			1
Naucoridae															
Ilyocoris cimicoides															
Notonectidae															
Notonecta glauca	1				3		1			1					
Pleidae															
Plea leachi					1										
Corixidae															
Micronecta poweri															
Callicorixa praeusta	1														
Sigara dorsalis	9	2	1		23	1				5					
Sigara distincta	5														
Sigara falleni										11					
Sigara concinna	1														
Haliplidae															
Haliplus confinis															
Haliplus flavicollis															

Appendix 15. Invertebrate taxa recorded in the 1999 canal survey

	Canal site number														
	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
Haliplus immaculatus					7	1	2								
Haliplus lineatocollis			1												
Haliplus lineolatus					13	4									
Haliplus ruficollis	1			1	2	2	4								
Haliplus wehnckei							1								
Noteridae															
Noterus clavicornis				5	36	1	4		3						
Noterus crassicornis				4											
Dytiscidae															
Laccophilus hyalinus					7										
Laccophilus minutus															
Stictotarsus duodecimpustulatus											4	4		1	
Hyphydrus ovatus					3							1			
Hygrotus inaequalis															
Hygrotus versicolor					1										
Hydroporus angustatus				9											
Hydroporus palustris	1	1													
Hydroporus planus					1										
Hydroporus tesselatus															
Hydroporus tristis				1											
Graptodytes pictus															
Nebrioporus depressus		2	24							2	1				
Agabus nebulosus															
Agabus sturmii	2			3											
Ilybius fenestratus															
Ilybius fuliginosus															
Ilybius quadriguttatus					1										
Dytiscus marginalis															1
Colymbetes fuscus					1										
Copelatus haemorrhidalis				1											
Hydaticus seminiger				1											
Rhantus suturalis															
Suphrodytes dorsalis															
Gyrinidae															
Gyrinus substriatus					1										4
Gyrinus marinus															
Gyrinus urinator															
Hydrophilidae															
Cercyon convexiusculus				1											
Cercyon marinus															
Coelambus impressopunctatus															
Hydrobius fuscipes				2			2								
Anacaena globulus															
Anacaena limbata	7			12	1				2						
Cymbiodyta marginella				1			1								
Laccobius minutus	1			1	1										
Enochrus coarctatus				7	1		1								
Enochrus testaceus	1				2		1								
Helophorus aequalis															
Helophorus brevipalpis						1									
Helophorus minutus					1										
Hydraenidae															
Ochthebius minimus					1										
Hydraena riparia				1											
Hydraena testacea															
Elmidae															
Oulimnius tuberculatus						4				2					
Sialidae															
Sialis lutaria	1					11	1		1	8	13	1			
Hydroptilidae															
Agraylea multipunctata	1		1		1	1									

Appendix 15. Invertebrate taxa recorded in the 1999 canal survey

	Canal site number														
	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
Psychomyiidae															
Lype phaeopa															
Tinodes waeneri			4										4		
Ecnomidae															
Ecnomus tenellus													1		
Polycentropodidae															
Cyrnus flavidus					5										
Cyrnus trimaculatus									1	3	9		7		
Holocentropus picicornis					1		2								
Phryganeidae															
Agrypnia varia															
Limnephilidae															
Halesus radiatus														2	
Potamophylax latipennis															
Anabolia nervosa						1			1	8					1
Glyphotaelius pellucidus														1	
Limnephilus decipiens															
Limnephilus flavicornis				9		3	3					3		2	
Limnephilus lunatus	4	45	3	37	41	2	1		26	58		11		13	21
Limnephilus marmoratus	1				34	2	4								
Molannidae															
Molanna angustata						2	2			1					
Leptoceridae															
Athripsodes aterrimus		1	1		27	2	3			6				1	
Athripsodes cinereus			3								2				
Ceraclea dissimilis												1			
Ceraclea fulvus															
Mystacides azurea			2							4	5	3			
Mystacides longicornis					1		1								
Mystacides nigra						7									
Triaenodes bicolor				1	7	1									
Oecetis lacustris									20						
Ceraclea senilis															
Lepidoptera															
Nymphula nymphaeata										1					
Cataclysta lemnata				9			25								
Additional taxa															
Oligochaeta	18	2	2	2	2	2	2	129	150	2	2	2	2	2	2
Chironomidae	21	2	2	2	2	2	2	56	120	2	2	2	2	2	2
Ceratapogonidae	7								2						
Tipulidae	1	1		1	1		1		7					1	
Psychodidae	25														
Stratiomyidae	2														
Sciomyzidae			1												
Pisidium spp.									75						
Corixidae				1			1								
Dropidae					1										
Dytiscidae							1				1		1		
Elmidae															
Gerridae															
Gyrinidae										1					
Haliplidae		2													
Hydroptilidae															
Limnephilidae													1		
Notonectidae				1					2			1			1
Phryganeidae															
Veliidae		1				1				1					

Appendix 15. Invertebrate taxa recorded in the 1999 canal survey

	Canal site number														
	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113
Planariidae															
Polycelis nigra															1
Polycelis tenuis		4	2	279		8				26			2	6	9
Dugesidae															
Dugesia lugubris															
Dugesia polychroa									3						2
Dugesia tigrina													1		
Dendrocoelidae															
Dendrocoelum lacteum			1	3		1				3			6		1
Neritidae															
Theodoxus fluviatilis									1						
Viviparidae															
Viviparus viviparus						2	1	19	38	73					
Viviparus fasciatus		1													
Valvatidae															
Valvata cristata			4	98	3					1	9		5	2	
Valvata piscinalis			6	19	9			1		6	16	15	1	5	
Hydrobiidae															
Potamopyrgus antipodarum							2	8		1	28				
Bithyniidae															
Bithynia leachi						8	1	15			1	1	23	9	
Bithynia tentaculata	2		14	48	21	13	2	14	7	41	7	15	24	37	19
Physidae															
Physa acuta								5							
Physa fontinalis			3	5		9		17		3	1	1	4	15	97
Lymnaeidae															
Lymnaea auricularia							17	2		1					
Lymnaea palustris								1							
Lymnaea peregra	9	37	122	49	5	2		19	98	12	5		28	94	73
Lymnaea stagnalis						6	1	2	1	14				2	32
Lymnaea truncatula															
Planorbidae															
Planorbis carinatus		295	15	5		6		5	1				1	23	28
Planorbis planorbis		6								1					
Anisus vortex	2	14	21	8	2	122		11	1	71	5	17	4	61	18
Bathyomphalus contortus	1		1												
Gyraulus albus			152	86	6		1	12	7	1	1	4	4	4	24
Armiger crista			28	34	1			2	2	1			1		
Hippeutis complanatus			2	3	1	18		17	5	2	1		13	1	18
Planorbarius corneus		12								12	1				
Ancylidae															
Ancylus fluviatilis										12					
Acroloxidae															
Acroloxus lacustris		2	1			6		23	4	49				8	22
Unionidae															
Anodonta cygnea				1											2
Unio pictorum															
Sphaeriidae															
Sphaerium corneum	1	59	14	11	16	12	1	74		3		6	37	23	1
Sphaerium lacustre													19		
Sphaerium rivicola										1					
Dreissenidae															
Dreissena polymorpha									1						
Piscicolidae															
Piscicola geometra	2		3	6	2		4		1	3			2		
Glossiphoniidae															
Theromyzon tessulatum			1						1						
Glossiphonia complanata				2		1		1		2					
Glossiphonia heteroclita		4	3	3		1			2	4					2
Helobdella stagnalis			3	1	1				1	1	7	1	2	3	1

Appendix 15. Invertebrate taxa recorded in the 1999 canal survey

	Canal site number														
	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113
Hirudidae															
Haemopis sanguisuga										3					
Erpobdellidae															
Erpobdella octoculata	1	12	11	15	5	13	1	11	1	14	2	7	9	32	2
Erpobdella testacea											1				
Araneae															
Argyroneta aquatica								1							
Asellidae															
Asellus aquaticus	52	248	47	571	62	45	14	169	1178	611	83	19	26	229	248
Corophiidae															
Corophium curvispinum									3	1					
Crangonyctidae															
Crangonyx pseudogracilis	18	14	39	368	15	186	1	59	12	257	11	163	554	11	98
Gammaridae															
Gammarus pulex															4
Baetidae															
Cloeon dipterum				3				1	1	2			14	3	
Ephemeridae															
Ephemera vulgata			5					1	5	1	1				
Caenidae															
Caenis horaria				1	4	3	2	149	247	2	1		64	1	58
Caenis luctuosa			7			3	2		47	18	1				
Caenis macrura									1						
Caenis robusta			2	1				31		2		15	242	49	11
Platycnemidae															
Platycnemis pennipes								1							
Coenagriidae															
Ischnura elegans		11		11		24	2	44	3	42	3	9	1	71	48
Enallagma cyathigerum													1		
Coenagrion puella/pulchellum							1								1
Erythromma najas								9				2		1	7
Aeshna cyanea										1					1
Aeshna grandis								3	1						
Aeshna mixta															2
Hydrometridae															
Hydrometra stagnorum								2							
Veliidae															
Velia caprai											1				
Microvelia reticulata						1								3	5
Gerridae															
Gerris argentatus															5
Gerris lacustris				2		1		11		6	1			2	
Nepidae															
Nepa cinerea								1		3				1	
Naucoridae															
Ilyocoris cimicoides															3
Notonectidae															
Notonecta glauca			2	2				1						3	4
Pleidae															
Plea leachi			1	1										2	
Corixidae															
Micronecta poweri								1							
Callicorixa praeusta			1	1											
Sigara dorsalis			39	9			2		1	1		2	5	8	1
Sigara distincta			3	1											1
Sigara falleni			1	8		1					2			1	
Sigara concinna															
Haliplidae															
Haliplus confinis											2				
Haliplus flavicollis	1		1	3				7							5

Appendix 15. Invertebrate taxa recorded in the 1999 canal survey

	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113
Haliplus immaculatus								2				1	1	14	2
Haliplus lineatocollis				1							2				
Haliplus lineolatus			1	1				19				3		2	
Haliplus ruficollis		5		4				1		1		1			11
Haliplus wehnckei				15							3			1	
Noteridae															
Noterus clavicornis			3			3		2		8	3			1	21
Noterus crassicornis															
Dytiscidae															
Laccophilus hyalinus			2					7		17					7
Laccophilus minutus			1												
Stictotarsus duodecimpustu	1		1								1		6	1	
Hyphydrus ovatus	1	1	4	7				9		23	2				
Hygrotus inaequalis			1								1				
Hygrotus versicolor												1	3	27	21
Hydroporus angustatus		17												15	
Hydroporus palustris		8		2										1	
Hydroporus planus														8	
Hydroporus tesselatus											1				
Hydroporus tristis															
Graptodytes pictus											2				
Nebrioporus depressus	2		8	1		1	2				3	1	2	1	
Agabus nebulosus															1
Agabus sturmii															
Ilybius fenestratus								4							2
Ilybius fuliginosus														1	1
Ilybius quadriguttatus	1		1							1					
Dytiscus marginalis															
Colymbetes fuscus						2									
Copelatus haemorrhidalis															
Hydaticus seminiger															
Rhantus suturalis		1													
Suphrodytes dorsalis									2						
Gyrinidae															
Gyrinus substriatus											1				
Gyrinus marinus														2	1
Gyrinus urinator											2				
Hydrophilidae															
Cercyon convexiusculus														3	
Cercyon marinus														1	
Coelambus impressopunctatus		1													
Hydrobius fuscipes		1	1							1				3	
Anacaena globulus		2													
Anacaena limbata		4						75			2			45	3
Cymbiodyta marginella															
Laccobius minutus															
Enochrus coarctatus															
Enochrus testaceus		1													
Helophorus aequalis														3	
Helophorus brevipalpis						1						1		5	
Helophorus minutus														1	
Hydraenidae															
Ochthebius minimus														2	
Hydraena riparia											1	2		6	
Hydraena testacea								7						6	
Elmidae															
Oulimnius tuberculatus				1				8						2	
Sialidae															
Sialis lutaria			1	1			2	3	13	48			3		5
Hydroptilidae															
Agraylea multipunctata					1				22	4			17	7	

Appendix 15. Invertebrate taxa recorded in the 1999 canal survey

	Canal site number														
	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113
Psychomyiidae															
Lype phaeopa				2											2
Tinodes waeneri							1						13		
Ecnomidae															
Ecnomus tenellus	1				1				43	2					1
Polycentropodidae															
Cyrnus flavidus	1					3									5
Cyrnus trimaculatus			2												
Holocentropus picicornis						4									11
Phryganeidae															
Agrypnia varia															12
Limnephilidae															
Halesus radiatus											1				
Potamophylax latipennis			2												
Anabolia nervosa						5		1							
Glyphotaelius pellucidus															
Limnephilus decipiens															7
Limnephilus flavicornis				3				3						16	21
Limnephilus lunatus		2		22		29		53			16	2	2	37	9
Limnephilus marmoratus		1		3								2	16	31	27
Molannidae															
Molanna angustata	2						3		3	3	1				2
Leptoceridae															
Athripsodes aterrimus	1	1		3		39	1	8	4	35	1			1	36
Athripsodes cinereus			3				1								
Ceraclea dissimilis				2									1		
Ceraclea fulvus															1
Mystacides azurea				1											
Mystacides longicornis			1	11	1				9	14	1		5		
Mystacides nigra	1								3	3			12		1
Triaenodes bicolor	3	7				2		2		1					7
Oecetis lacustris								1					2	1	
Ceraclea senilis	1														
Lepidoptera															
Nymphula nymphaeata						1			1						
Cataclysta lemnata		1		2											
Additional taxa															
Oligochaeta	2		2	2	2	2	1	2	1	2	2		2	2	2
Chironomidae	2	1	2	2	2	2	2	2	1	2	2		2	2	2
Ceratapogonidae												2			
Tipulidae	1	1	1	1		1		1	1			2		2	
Psychodidae															
Stratiomyidae															
Sciomyzidae															
Pisidium spp.															
Corixidae		2						1	1	1					1
Dropidae															
Dytiscidae		1													
Elmidae													1		
Gerridae		1												1	
Gyrinidae						1	1	1							1
Haliplidae	1		1		1	1		1							1
Hydroptilidae	1									1					1
Limnephilidae															
Notonectidae				1				1		1		1			1
Phryganeidae					1	1	1								
Veliidae	1									1	1				