Interim Report R&D Project 346

PHYSICAL ENVIRONMENT FOR RIVER INVERTEBRATE COMMUNITIES

University of Leicester

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Physical Environment for River Invertebrate Communities

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SUMMARY

This report documents the progress of NRA R&D Project 346 between 1 April and 31 October, 1991. Attention is drawn to three prior reports which have been submitted to the Project Leader – some of the material which dealt with development of the strategy is not duplicated in this report.

Several meetings were held with Regional Biology and Conservation staff to discuss the results of the previous Operational Investigation (A13–38A), and to obtain information for the current project. The discussions proved extremely valuable to development of the best strategy for further work.

Using the river classification developed by the Institute of Freshwater Ecology (Wright *et al.* 1984, 1989), ten reaches were selected which together characterise 91 % of the main river which they studied. The intention is to carry out functional habitat analysis on these reaches, similar to that already carried out on the River Welland and River Wissey.

A preliminary survey was carried out at each of the prospective study reaches, to assess the number of 'potential habitats' for sampling in 1992, and to locate several examples of each habitat. The results have not been reported in detail at this stage, since they are of limited value except for their intended purpose. The surveys will be discussed more fully at the November 1991 Steering Group meeting.

A paper was presented at an International Stream Conservation Workshop in Lund, Sweden and has been submitted for publication in Freshwater Biology. This develops the functional habitat theme (Smith *et al.*, 1990; Harper *et al.*, 1992) with a discussion of options in the method and a first example of its practical application.

Anglian Region intend to carry out channel rehabilitation works on the middle reaches of the River Welland. A report was submitted which recommended priorities for enhancement, based on a survey of the functional habitats on a 2 km length of the river at Harringworth. Further involvement with the project has been agreed with the Steering Group, since this is a good opportunity to prepare the ground for further trials which are scheduled in the Project Investment Appraisal for 1993.

Topics of work for the remainder of the project year are outlined. These will be discussed in detail at the Steering Group Meeting in November.

KEY WORDS

Invertebrates, habitat, classification, survey, conservation, river management

1. INTRODUCTION

This report documents the progress of NRA R&D Project 346 between 1 April and 31 October, 1991. The targets for this period have been –

- Liaison with Regional Biologists and Conservation Officers over project achievements to date and proposed development.
- Collaborative selection of representative rivers of appropriate geomorphology and water chemistry.
- Initial survey of the selected rivers.

Some of the information contained in previous reports to the Project Leader and Steering Group has become redundant, through development of the Project Strategy, and is not reproduced in this document.

2. OBJECTIVES

2.1 Overall objective

To expand and develop a unified method for the ecological assessment of water quality and conservation by 'functional habitat' analysis.

2.2 Specific objectives

i) To relate macroinvertebrate abundance and diversity to the nature and richness of the various channel substrates found in British rivers.

ii) To broaden the scope of the habitat investigation carried out as part of the existing project with respect to macroinvertebrate 'functional habitats'.

iii) To consider together the roles of habitat availability and chemical water quality in structuring the macroinvertebrate community.

iv) To compile a draft methodology which addresses river macroinvertebrate conservation through attention to the availability of habitats.

v) To proceed with preliminary trials as part of the development process for the draft methodology.

3. PROGRESS TO DATE

3.1 Regional liaison

Regional Biology and Conservation staff readily arranged meetings to discuss the functional habitat methodology, selection of study sites and the general prospects for the research. Improvements to the strategy for site selection were recommended after considering points of caution which were raised at the meetings, and subsequently agreed by the Steering Group.

Awareness of R&D Projects within the organisation might be better. The habitat investigation has been running since January 1987 but some key personnel were unaware of the work. Copies of the publications and NRA reports are being sent to each Region, together with a brief document explaining the principles of the functional habitat approach.

One purpose of the Regional liaison was to locate existing macroinvertebrate species/habitat information (collected, for example, during local project work) which is not available through the scientific and technical literature. In fact there is little information to be found – regions have all stressed the potential value of such knowledge, aside from its incorporation in functional habitat analyses.

3.2 Site selection

The most critical decision for the project was to select a number of reaches which represent the physical and chemical variety of main river. There are two important existing classifications from which the selection could be made. These are derived from the distribution of macrophytes (Holmes 1983, 1989) and macroinvertebrates (Wright *et al.* 1984, 1989) on a large nuber of British rivers. Each classification has relative merits as the basis for the present site selection. The macrophyte scheme is derived from more, longer reaches, whilst only the macroinvertebrate scheme is based on data from three seasons. There are two eventual reasons for preferring the macroinvertebrate system.

Firstly, it is possible to represent a large proportion of the 268 sites sampled for Wright *et al.* (1984) using ten of their river types (Table 1, corresponding to Step 1 in Figure 1). The timescale set out in the Project Investment Appraisal allows a 12 month period for functional habitat determinations, which will form the basis of the draft 'Standard Methods' handbook. From experience of the sampling and analysis involved in the studies of the River Welland and River Wissey, the work is feasible for 8-10 reaches within 12 months. The macrophyte classification (Holmes 1983) produced 56 distinct community types with the inclusion of both aquatic and riparian species. The Nature Conservancy Council (1989) amalgamated the 56 types to form a working classification of ten groups but the detailed distinctions made by Holmes (1983) are difficult to ignore.

Secondly, the macroinvertebrate classification is used more frequently by NRA biology and conservation staff, through the RIVPACS programme. Precise details of the integration of RIVPACS into water quality monitoring are varied between Regions but continued reference to the scheme is expected. This has three effects which favour that classification as the basis for our work, as follows –

- The river types will be more familiar to the NRA end-users.
- A substantial body of data on the distribution of river types will become available.
- Invertebrate-based river types are intuitively preferred by the prospective end-users.

Ten reaches have been chosen to represent the most frequent river types, where each covers at least three consecutive sites of the same type (Table 2, corresponding to Step 2 in Figure 1). Thus they cover a distance of at least 20 km, or 15 km if the top site on a river is included (sites approximately 5, 10, 20, 30 m *etc.* from source).

Functional habitat analysis of the ten reaches (Step 3 in Figure 1) is scheduled for the second year of the project. The key to the success of the study lies in comparison of results between river types (Step 4 in Figure 1). This procedure will be developed in collaboration with the Steering Group and other NRA personnel who are involved with the project.

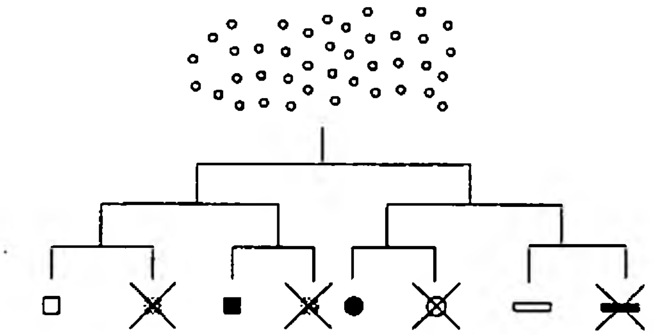
3.3 Preliminary surveys

The preliminary surveys were scheduled for the 1991 summer months. Amendments to the Project strategy brought corresponding changes to the selection of study reaches. The revised list of reaches was surveyed during late September and October. The aims were to list the potential habitats present; locate several examples of each; and ensure that access to the proposed reach is possible. The Wansbeck, Swale and Teifi were in spate, so they will be re-visited although the macrophytes have died back considerably since the summer.

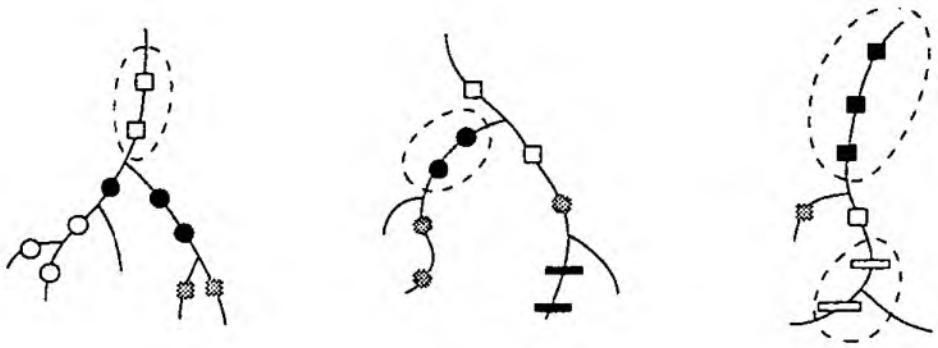
The care required to gain sufficient access varies between the rivers, depending on adjacent land-use and the fishery/conservation status of the river. The Smite and the Swale are at one extreme, with effectively open access by means of public footpaths or courteous trespass. Permissions will need to be obtained in advance for access to most sites on the Itchen and the Avon, while advice will be sought from the National Trust and Countryside Council for Wales in respect of the Dove and Teifi.

Detailed results of the surveys are not presented in this document. The information is of little value aside from its practical application in the current project, but an Annex will be available if required. Generally, the number of potential habitats is considerably lower than on the diverse study reach on the River Welland. This means that the sample load will not be great and that there is no notable risk to successful completion of the 1992/1993 element of the investigation. Furthermore, we may be able to carry out some quantitative estimations of macroinvertebrate biomass in different habitats, as an extension to the riffle/pool/run study carried out in 1987. The Regional staff were agreed that quantitative estimates of the value of habitats, in terms of macroinvertebrate abundance, would be of great value in comparing management options and in preparing a strong case for conservation.

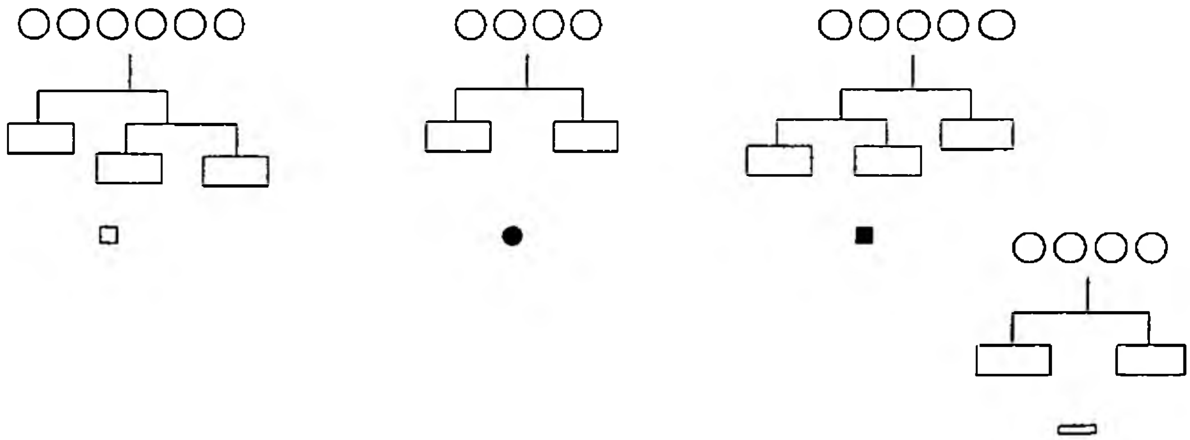
1. Select the most frequent river types from the classification of Wright *et al.* (1984)



2. Select reaches in England & Wales to represent the river types.



3. Carry out a functional habitat classification for each reach (river type).



4. Compare the functional habitats for differing river types and produce a draft methodology for the use of functional habitats in conservation management.

Figure 1 Strategy towards Specific Objectives i & ii (Section 2.2)

Table 1 List of river types defined by Wright *et al.* (1984). The ten chosen types are marked thus *

Type	No. Sites	Description
16	6	Top sites on upland rivers ...
* 17	12	Top and also upstream sites on upland rivers. Similar in character to group 16.
* 18	28	Top and upstream sites on upland rivers. Typically high altitude sites with higher discharge and lower alkalinity than groups 16 and 17. Restricted fauna.
* 19	52	Mainly sites in the middle and lower reaches of upland rivers whose upstream sites occur in groups 16-18.
* 20	40	Middle and lower reach sites on rivers whose upper sites occur in groups 16-19 and also 21-23. Compared to group 19, these sites have a lower slope, less coarse substratum, higher macrophyte cover and a higher alkalinity.
* 21	8	A small group distinguished from group 20 by lower alkalinity but a richer invertebrate community.
* 22	17	Upper and middle reach sites with a higher alkalinity than groups 16-21.
23	4	A small group ...
* 24	9	Lower reaches or 'pool' sites typically deep with a small mean substratum particle size and little macrophyte present.
* 25	33	Sites in the middle and lower reaches of lowland rivers having a high alkalinity.
* 26	26	Sites in the upper and more particularly the middle reaches of lowland rivers with a high alkalinity and high macrophyte cover.
* 27	19	Typically sites in the upper and middle reaches of lowland rivers with a high alkalinity.
28	4	Four sites in ...
29	2	Two sites in ...
30	6	Six further sites in ...
31	2	Two deep water sites ...

Table 2 List of reaches which represent the ten most frequent river types defined by Wright *et al.* (1984).

Type	River	O.S. Grid Reference				
17	Dove	SK 084 665	SK 121 598	SK 146 504		
18	Swale	NY 885 015	SD 933 978	SE 046 985	NZ 146 007	
19	Wansbeck	NY 996 844	NZ 053 842	NZ 119 850		
20	Torridge	SS 324 178	SS 399 126	SS 470 061	SS 542 064	
21	Teifi	SN 684 628	SN 642 547	SN 523 454	SN 373 403	SN 217 437
22	Itchen	SU 523 325	SU 481 282	SU 470 233		
24	Y. Ouse	SE 467 621	SE 556 552	SE 591 455		
25	H. Avon	SU 163 174	SU 149 035	SZ 158 933		
26	Mimram	TL 193 207	TL 208 180	TL 282 134		
27	Smite	SK 690 262	SK 697 333	SK 773 427		

3.4 Promotion of work

A paper was presented at an international Workshop on Lowland Stream Restoration, in collaboration with the Project Leader. The paper was well received – it was felt that the work bridges the gap between detailed ecological studies and the technology of practical stream restoration. The workshop took place in Lund, Sweden from 24-31 August 1991. A list of oral and poster papers presented at the workshop is given as Appendix A. The titles reflect a large proportion of the current research into stream restoration policy and technology in Europe, North America and elsewhere.

The convenors intend to publish the proceedings of the workshop as individual refereed papers in the journal Freshwater Biology. The manuscript which we have submitted, building on previous publications from the project (Smith *et al.* 1990; Harper *et al.* 1992), is reproduced as Appendix B.

A Working Group has been organised on the subject of stream restoration technology, with 25 participants representing 11 countries. The initial meeting of the group at Lund produced a draft 'position statement' from which basis we hope to maintain a continuing exhange of ideas.

3.5 Welland restoration project

NRA Anglian Region are planning a scheme for conservation enhancement of the middle reaches of the River Welland, which was channelised during arterial drainage schemes in the late 1960s. The research which led to the current project was based largely on the Welland and so input to the planning stage of the restoration work has been made, with agreement of the Project Leader. The physical features of the channel and functional habitats were surveyed for 1 km either side of Harringworth road bridge (SP 915 976). Recommendations for channel restoration were made from an assessment of existing functional habitats and the predicted characteristics of the reach. The report is reproduced as Appendix C.

Explicit stream restoration is an increasing priority for river management in Britain and elsewhere, but there is still a shortage of well-documented works. The enhancement measures on the Welland provide us with a timely opportunity to demonstrate the benefits of improvement work; and that they can be designed for compatibility with flood protection. The Steering Group agreed in principle that involvement with the restoration scheme should be recognised as part of the current project. The objectives of our involvement were decided as follows –

1. Preliminary survey and consultation with engineers, reporting to the Anglian Regional Conservation Officer.

2. Thorough physical and habitat survey of the target reach, with a photographic record. Identify key features for detailed monitoring in a 'demonstration' context.

3. Quantitative recommendations submitted with the Interim Report [this report]. First draft of recommendations to be passed to Anglian Region as soon as possible.

4. Monitoring of the 'key features' before, during and after works. Important to have clear objectives against which success can be gauged.

5. Preparation, with Conservation Officer and Engineers, of –

- Operational Report
- Publication in scientific/technical literature
- Material for a possible distribution document

Draft recommendations (point 3 above) were prepared for the end of September. Points 4 and 5 above are for continuing action, on an *ad hoc* basis until the scope of the restoration project is decided.

4. FUTURE WORK

The main areas of work for the remainder of the Project year (to 31st March 1992) are stated below. These may be subject to revision by the Steering Group which will meet next on November 21st 1991 and January 23rd 1992.

1. Functional habitat analysis is essentially a 'top-down' approach to investigation of species-habitat relationships. The corresponding 'bottom-up' approach of considering individual species requirements would not be feasible across the whole range of stream macroinvertebrates. We can, however, take the known requirements of well-studied species and compare these to the functional habitats. This will allow us to test whether the needs of individual species are addressed properly by the community-based functional habitat method. A survey of the scientific literature with respect to species' habitat requirements will be commenced during the winter months. A substantial body of information is already available from work towards this project and towards other NRA R&D projects undertaken at Leicester.

2. There are a range of existing approaches to habitat identification and management. Among the well-developed systems are those used in North America to manage restoration of the 'hydraulic habitats' of fish. The methods used for identification and quantification of habitats will be compared with the present classification approach. Such comparison will benefit the draft methodology and its wider promotion as a technique for conservation management.

3. The details of the way in which the TWINSPAN classification is interpreted need to be more objective. Most of the results from the River Welland and River Wissey were clear (similar to Figure 1a of Appendix B) while only the submerged macrophytes on the River Welland gave results which were difficult to interpret. A consistent procedure will be decided for the treatment of outliers, allowing reproducible decisions where the results are not so clear-cut as for the Welland. The use of $\log_{10}$ abundance classes will be reviewed, with the possibility of adopting categories which are based on percentiles of the distribution of species' abundance values.

4. The necessary field equipment and laboratory consumables for 1992 work will be obtained at such time as continued funding is approved. There are no major new items of equipment or software known to be required at present; and travel and subsistence is likely to fall well within budget.

5. Computer file storage will be structured in advance for the large body of data generated during 1992. Laboratory practice will be examined and revised if necessary to ensure that samples, specimens and records are not lost or ambiguously labelled.

6. Expertise in identification will be upgraded in anticipation of taxa which were not encountered on the east midlands rivers. The identification of some taxa (eg Tipulidae, Tabanidae), which has to now been left at the family level, will be investigated. We should at least be looking to assign specimens to a genus. Hydracarina are present in great numbers in most streams and species-rich assemblages were passed over during the previous work. The IFE ceased identifying Hydracarina further, on the basis that the end-user would not be able to reproduce the results. The essence of functional habitat analysis is that the end-user is not required to carry out biological sampling and identification, so we will investigate the possibility of identification at least to

family or genus.

7. A quantitative investigation of the macroinvertebrates associated with the physical substrate of riffles, pools and runs was carried out in 1987. The results from this provided strong evidence for the reinstatement of a riffle-pool system where it is degraded on the River Welland. The potential value of such quantitative information has been emphasised by Regional Biology and Conservation staff, in setting priorities for conservation and choosing between alternative strategies. The first priority for 1992 sampling and analysis must be to complete the functional habitat determinations to schedule but the possibility of quantitative sampling will be explored, subject to agrement of the Project Steering Group.

8. The Regional contacts will be informed in detail of proposals for rivers in their respective areas. Preferences for additional site-specific information will be solicited in advance of the fieldwork, in so much as this does not compromise successful progress towards the Project objectives.

9. To date, a series of miscellaneous written reports have been used to keep the Project Leader and other key personnel informed of developments with the project, supplementing the prescribed reporting regime. This practice has proved most useful and will be continued. The Annual Report will include details of progress on points 1-8 above, a full timescale of forthcoming work, and such other information as decided by the Steering Group.

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APPENDIX A

STREAM RESTORATION WORKSHOP - LUND, AUGUST 1991

A list of oral and poster papers is given on the following pages. The titles reflect a large proportion of the current research into stream restoration policy and technology, in Europe and elsewhere.

Oral papers (in order of presentation)

Falkenmark M. (Swedish Natural Science Research Council, Sweden) The importance of land/ water interactions in stream restoration.

Holmes N. & Holt V. (Alconbury Environmental Consultants, UK) River restoration as an integral part of river management.

Large A. *et al.* (Loughborough University of Technology, UK) Where have all the ecotones gone? Influences of boundary loss on the future management of the floodplain of the River Trent, England.

Statzner B. & Sperling F. (Université Lyon I, France) Contribution of system related knowledge to stream management decisions.

Petto H. & Humpesch U. (Austrian Academy of Sciences, Austria) Relationship between the benthic community and the channel habitat of the River Danube in Austria.

Petersen R.C. (University of Lund, Sweden) Ecology, sociology and economics of stream restoration.

Brookes A. (National Rivers Authority, UK) Lowland stream restoration: examples from the Thames catchment.

Muller E. & Decamps H. (CNRS, France) Utilization of remote sensing in stream ecology.

McDowell W.H. & Bowden B. (University of New Hampshire, USA) Impact of Hurricane Hugo on stream and groundwater chemistry in a tropical rain forest.

Puchalski W. *et al.* (University of Lodz, Poland) Improving recovery of biota in perturbed streams of contrasting trophy.

Triska F. *et al.* (US Geological Survey, USA) Nutrient cycling in the hyporheic zone of fluvial environments: the terrestrial–aquatic linkage.

Gibert J. (Université Lyon I, France) In what ways has the field of groundwater ecology developed in floodplains?

Vervier P. (CNRS/CERR, Toulouse, France) Spatial and temporal fluctuation of dissolved organic carbon in subsurface flow.

Newbury R. (Wilson Creek Watershed, Canada) Exploration and rehabilitation of hydraulic habitats in streams.

Rabeni C.F. (University of Missouri, USA) The relation of fluvial hydraulics to fish habitat in low gradient alluvial streams.

Osborne L. (Illinois Natural History Survey, USA) The role of riparian buffer strips in stream restoration and management.

Jensen A. *et al.* (Department of Lands, Australia) Rehabilitation techniques for wetland systems: a case study in the South Australian River Murray.

Iversen T.M. *et al.* (National Environmental Research Institute, Denmark) Application of stream restoration technology in Denmark.

Kouwe F.A. & van Rijen J.P.M. (GTD Oostbrabant & Ministry of LNV, The Netherlands) Restoration of the Tonglereep.

Cooper C. & Schiebe F.R. (USDA–ARS, USA) Restoration of a lowland riverine lake.

Nielsen M.B. (Sønderjyllands AMT, Denmark) Remeandering and other examples of stream restoration in Southern Jutland, Denmark.

Taylor E. *et al.* (University of Leicester, UK) Riverbed manipulation in the tidal River Bure using an artificial substrate.

Higler, L. (RIN, The Netherlands) The riparian ecotone: Vascular system of the landscape.

Borchardt D. (University of Kassel, Germany) Response of benthic macroinvertebrates to flow forces at different appearance of refugial space.

Frank C. (Laboratorium für Angewandte Biologie und Ökologie, Germany) Stream restoration for habitat richness in the catchment area and oligotrophication of a downstream pond.

Karr J. (Virginia Polytechnic Institute, USA) Biological foundations for stream restoration: From landscapes to toxicology.

Bayley P.B. & Osborne L. (Illinois Natural History Survey, USA) Natural rehabilitation of Illinois stream fish populations following the 1988 drought.

Smith C.D. *et al.* (Leicester University, UK) Objective identification of macroinvertebrate habitats.

Poster papers

Agostini N. *et al.* (Italy) An interdisciplinary study to project the rehabilitation of drainage channel in the lowland of Bologna (North Italy).

Battegazzore M. *et al.* (Italy & Sweden) Comparison between chemical and biological approaches for the evaluation of the organic enrichment of the River Po (Italy).

Fuglsang A. (Denmark) Marginal Lands Project, County of Funen, Denmark: The denitrification capacity of established uncultivated land along watercourses.

Gopal B. & Sah M. (India) Restoration of the River Ganges: Riparian ecotones ignored.

Gutiérrez B. & del Tanago M.G. (Spain) Restoration project of a channelized reach of Monegro Stream (Palencia, central north of Spain).

Huhta A. *et al.* (Finland) Ecological backgrounds of river restoration with notes on short-term recovery of benthos after severe substrate disturbance.

Hyldegaard P. (Denmark) Restoration of Funen streams.

Maiolini B. & Siligardi M. (Italy) Mapping of the river ecosystems in an alpine region (Trentino, Italy) with the R.C.E. inventory.

Mander U. (Estonia) Retention of biogenes and heavy metals in riparian biotopes.

Mokadem A. *et al.* (Belgium) Satellite data applied to riparian land use.

Moog O. *et al.* (Austria) Alternative reservoir-operation strategies to minimize the detrimental effects of artificial short term flow fluctuations.

Mutz M. (Germany) Geographic information systems and remote sensing, tools to get a hand on data from the watershed.

Niemitalo V. & Jutila E. (Finland) Stocking experiments with brown trout (*Salmo trutta* L.) parr in the restored rapids of the River Iijoki watercourse, northern Finland.

Oberdorff T. (France) Fish communities in rivers of the same drainage basin, and use of an index of biotic integrity to assess anthropic perturbations.

Olivieri E. & Petersen R.C. (Italy & Sweden) Riparian plant community structure and leaf processing in channelized and natural Mediterranean streams.

Richards C. *et al.* (USA) Relative influences of water chemistry and physical habitat in structuring macroinvertebrate communities in a midwestern agricultural catchment, USA.

Roberto L. *et al.* (Italy) Comparison between E.B.I. index and R.C.E. inventory in some North Italian streams and rivers.

Schütz W. (Germany) Changes of riparian and submerged vegetation in the upper Rhine plain according to changed water management.

Sode A. & Wiberg-Larsen P. (Denmark) Are running-water invertebrates always fast colonizers following stream restoration?

Taylor L.R. (South Africa) A history of, and proposed model for river restoration in South Africa.

Urtans A. (Latvia) Prospects for restoration of small streams and rivers.

Wasson J-G. & Malavoi J-R. (France) Assessing reversibility of man's intervention: a key for stream management.

APPENDIX B

MANUSCRIPT SUBMITTED FOR PUBLICATION - OCTOBER 1991

In August 1991 we presented a paper at a 'Lowland Stream Restoration Workshop' in Lund, Sweden. The convenors have decided to publish the proceedings of the conference as individual refereed papers in the journal Freshwater Biology. The manuscript which we have submitted, reporting progress with the project, is reproduced in the following pages.

FUNCTIONAL HABITATS AS A TOOL FOR THE MANAGEMENT OF STREAM RESTORATION: PRINCIPLES AND PRACTICE

Colin D. Smith, David M. Harper and [1] Peter J. Barham

Summary

1. A method for objective determination of the 'functional habitats' of benthic macroinvertebrates has previously been described (Harper *et al.*, 1992). This paper develops the theme with respect to details of the method, its practical application in restoration management, and future improvements.

2. The main options in using the method are discussed in relation to results from the River Welland and River Wissey in the east midlands of England.

3. A first use of functional habitats in stream restoration is described. Recommendations for the preservation of existing value and the restoration of a degraded channel can both be made most clearly in terms of habitats.

4. Priorities for further research into the use of functional habitats are discussed. We are presently trying to reduce costs and to assess the degree of habitat generality between major stream types.

Introduction

The conservation of riverine ecosystems has generally followed two pathways. One is the preservation of species and communities known to be unique or threatened (Ratcliffe, 1977). The other is the re-creation of ecosystems which have been damaged by past events; by chemical (Herricks & Osborne, 1985) or physical (Nielsen, this vol) rehabilitation.

The preservation approach has been the more specific – a river manager can be clearly informed about the conservation importance of a particular river stretch, through single measures such as species richness (Coles *et al.*, 1989) or through a more broadly based assessment (O'Keeffe, Danilewitz & Bradshaw, 1987). The requirements of 'sensitive' management can then be costed; and compared objectively with more damaging options. The restoration approach has consisted mostly of a variety of physical techniques of clear qualitative value (Lewis & Williams, 1984); but for which it is hard to measure quantitative benefits, set quantitative goals, or objectively monitor their success.

We have developed a new method for use in river conservation which enables both preservation and restoration to be quantified in terms of the habitats for macroinvertebrates. The first stage of this method was to use principles of geomorphology to quantify the physical habitats of a river; and then to superimpose ecological measures of the value of each habitat (family richness, biomass). This gave a numerical estimate of the impact of dredging, in terms of loss of families and reduction of biomass. The gain in families and biomass from sensitive management of existing resources and the restoration of degraded reaches can also be predicted (Smith, Harper & Barham, 1990). The second stage developed an objective technique to determine the full range of 'functional habitats', which a semi-natural lowland river requires in order to support its total complement of macroinvertebrate species (Harper, Smith & Barham, 1992). This technique was developed on two rivers with diverse habitats and tested on a third, physically uniform river.

There is no need to separate preservation and restoration – the criterion for either approach is richness with respect to the set of habitats. This may be met by ensuring that any river management proposal retains examples of existing functional habitats and specifies the restoration of under-represented habitats.

This paper develops the concept of functional habitats in river restoration by examining aspects of the method and presenting a practical example of restoration recommendations.

Methods

Functional habitats were identified on two stretches of lowland river; one each on the River Welland and River Wissey, in eastern England. They were derived from an indicator species analysis (Hill, Bunce & Shaw, 1975), using TWINSPAN (Hill, 1979) of macroinvertebrate species data collected in replicate samples from all 'potential habitats' in the river stretch. A potential habitat was defined subjectively by the investigator as any physical habitat, or combination with flow (eg. flow and substrate, or flow and macrophyte species) which was reproducibly distinct. Greater detail may be found in Harper *et al.* (1992).

Options in the method

There is considerable flexibility in the procedures used for sampling and classification of habitats. The important options in the use of the method are discussed below.

The initial list of potential habitats decides the limit of resolution of the method. Particulate substrates recognised in the River Welland study were silt (with and without leaf litter), sand (above and below riffles and on point bars), gravel (above and below riffles) and riffle substrate. Ecological variation within the single 'riffle substrate' category, for example, could not produce separate functional habitats. Particulate substrata could be categorised precisely according to their size composition and organic content. Our objective, however, was to produce a list of habitats for subsequent visual site assessment, where the set of habitats which the surveyor can reliably distinguish is limited.

The TWINSPAN classification was interpreted by following sets of samples from each potential habitat through the divisions. If the replicates from two or more potential habitats remained mixed, this was taken to show a single functional habitat (Harper *et al.*, 1992). The degree of confidence in the results is dependent upon the number of replicates from each potential habitat. Outliers occur due to the contagious distribution of invertebrates between small samples and these are recognised more easily if several other replicates stay together in the classification (Fig. 1). The procedure is analagous to an analysis of variance. It is also important that the replicates are taken from a wide range of the environmental conditions which are associated with each habitat, otherwise the classification might suggest more functional habitats than there actually are. The number of replicates taken in our initial studies was a compromise between that needed for analytical clarity and that possible with the time and manpower available. The approach which we now adopt is to take a minimum of five replicates, from stands as well spaced as possible within a study reach.

Indicator species analysis is a classification on the presence or absence of species. The use of numerical abundance levels as 'pseudospecies' (Hill, 1979) has enabled quantitative aspects of species distribution to be included. Log_{10} abundance categories have been successfully used (*eg* Wade, Ormerod & Gee, 1989; Harper *et al.*, 1992). Alternative categories based on percentiles of the distribution of species abundance values might also be considered. Presence-absence data is affected by sample size as progressively less common species are included in larger samples; and sample-size dependence is maintained for common species in the recognition of several abundance classes. Samples should be of similar 'size', which is a problem where several different methods are used to sample diverse potential habitats. Our approach was to take samples which were intuitively equivalent in terms of volume or area.

The preparation and identification of chironomids and oligochaetes accounted for a large part of the time spent on sample analysis. These taxa occurred frequently as indicators in the classification, however, and so were important in determining the list of functional habitats. They formed a large proportion of the macroinvertebrate community on both the River Welland (28 of 142 taxa) and River Wissey (36 of 122 taxa), so are important in conservation. The resources required for attention to these 'difficult' groups are further justified, in the context of stream restoration, by their major functional role in the food web.

Some functional habitats produced by the classification were notable only by species' absence. Sand was indicated as a functional habitat in the River Welland classification when replicates separated from those of silt and the roots of emergent macrophytes; and on the River Wissey when sand replicates separated from gravel replicates (Fig. 2). On the River Welland, 25 species present in the silt and root samples were absent from sand, whilst only one uncommon chironomid was confined to sand samples. Forty-eight taxa present in Wissey gravels were absent from sand; three taxa were found in sand but not gravel. Of those three, *Simulium angustipes* and *Nais* sp. were surely not characteristic of the substrate and were present in greater numbers elsewhere. In assessing the habitat richness of a site, we have subsequently disregarded habitats which are distinguished by the absence of species; and given lesser priority to their management.

Functional habitats in restoration management

A physically diverse part of the River Welland was chosen for development of the functional habitat methodology. Many other parts of the river suffered severe ecological damage in the late 1960s from arterial drainage schemes, which removed meanders and created a trapezoidal cross-section. The subsequent engineering maintenance of the channel has taken conservation into account by the application of river corridor survey (Nature Conservancy Council, 1985) results; but this has generally been a preservation approach and parts of the middle reaches of the river remain habitat-poor.

The National Rivers Authority, formed after the Water Act 1989 to manage rivers in England & Wales (Anon, 1989), has been given stronger legal powers than its predecessors to actively promote conservation. This gives practical stream restoration a much higher priority in the NRA, and the middle Welland has been selected as one of the first such restoration projects within the Anglian Region. Practical recommendations based upon the functional habitat methodology have been prepared, following from a study of the frequency of existing functional habitats.

The functional habitats for the middle reaches of the River Welland, determined by Harper *et al.* (1992), were surveyed along a 2 km length of the river centred on Harringworth road bridge (Ordnance Survey grid reference SP 915 976). Figures 3 & 4 show the study reach and the approximate position of weirs, riffles and riparian trees. The occurrence of functional habitats in each 100 m section is shown in Table 1. Some of the recommendations for conservation, based on habitat survey results and existing physical information on the river, are summarised below.

Riffles (and therefore '*Fontinalis* in riffle') were absent from the section 0-900 m upstream. Smith *et al.* (1990) showed that the restoration of a riffle system to degraded reaches of the River Welland should bring a five-fold increase in macroinvertebrate biomass and at least a two-fold increase in their production. Reinstatement of riffles to the upstream section should therefore be the first priority for action. For reaches of the Welland which have recovered a riffle-pool system, riffle spacing and length are correlated with stream size as follows:

$$S = 0.0032\,D^{0.576} \qquad L = 0.0036\,D^{0.472}$$

where S = mean riffle spacing (m), L = mean riffle length (m) and D = mean annual discharge (m^3). The predicted mean riffle spacing at Harringworth is 106 m and nine or ten riffles should therefore occur naturally in each 1000 m. The downstream section meets this expectation while due to serial impoundment by weirs the upstream section shows only two riffles. There are however, a series of localised shallow areas with coarser substrate on the upstream section, which may be the appropriate sites for riffle restoration. These provide the predicted number of riffle sites for the upstream 1000 m together with the two existing riffles, which are above the influence of the weirs.

The functional habitats which are provided by herbaceous marginal plants were present throughout the study reach, but those rooted below the water level (*Rorippa* etc.) were less abundant on the upstream section. The depth of water which they require is found only in small areas, often within stands of tall emergent species. If removal of the weirs for riffle restoration is possible, then the position and aspect of the margins on the upstream section will be improved without further intervention. Development of the riffle-pool system will generate areas of shallow water for colonisation by herbaceous macrophytes. If the weirs remain, central and lateral shoals which have formed in the channel need to be retained, since they provide the only existing location for marginal plants (other than within the tall emergents). The margins could be made more extensive with the present water level by adjusting the channel section to include a shallow shelf or shallower bank slope. This would require extra land unless restricted to sites where the bank has already slumped.

Distinct assemblages of macroinvertebrate species are associated with silt, with and without leaf litter, on the River Welland (Harper *et al.*, 1992). Previous management of the Welland has included the systematic removal of trees from a major proportion of the river corridor. 'Silt with leaf litter' as a functional habitat was restricted to the sections which had significant coverage of riparian trees. Tree planting should be undertaken and need not prevent access for channel maintenance, if planned in consultation with the engineers responsible for flood protection.

Future research developments

Functional habitats offer an objective basis for instream conservation assessment and restoration. The procedure used to determine functional habitats for the River Welland was expensive, so we are investigating more economic methods. The first step in this process is to assess the similarity of functional habitats between sections of the same river, and between rivers.

The list of functional habitats which was determined over an 8 km reach of the River Welland has been used at neighbouring sites. This approach is possible because there is a constant set of potential habitats and macroinvertebrates found through much of the river. Functional habitats may not be so 'portable' through a catchment of more varied character, which will increase the cost of the method. Therefore an objective of current research is to find out how far the habitat information can typically be transported within a catchment.

The River Welland list of functional habitats is probably applicable to many similar rivers in the east midlands of England (Harper *et al.*, 1992). The set of environmental conditions and range of species found on these rivers are, however, different from those of many rivers elsewhere in Great Britain. We are carrying out the functional habitat classification for ten further sites, which represent the main river types in Great Britain according to the macroinvertebrate-based classification of Wright *et al.* (1984). Functional habitat classifications from these rivers will allow us to test the hypothesis that there is a common set of functional habitats even though the systems have different potential habitats and macroinvertebrate communities.

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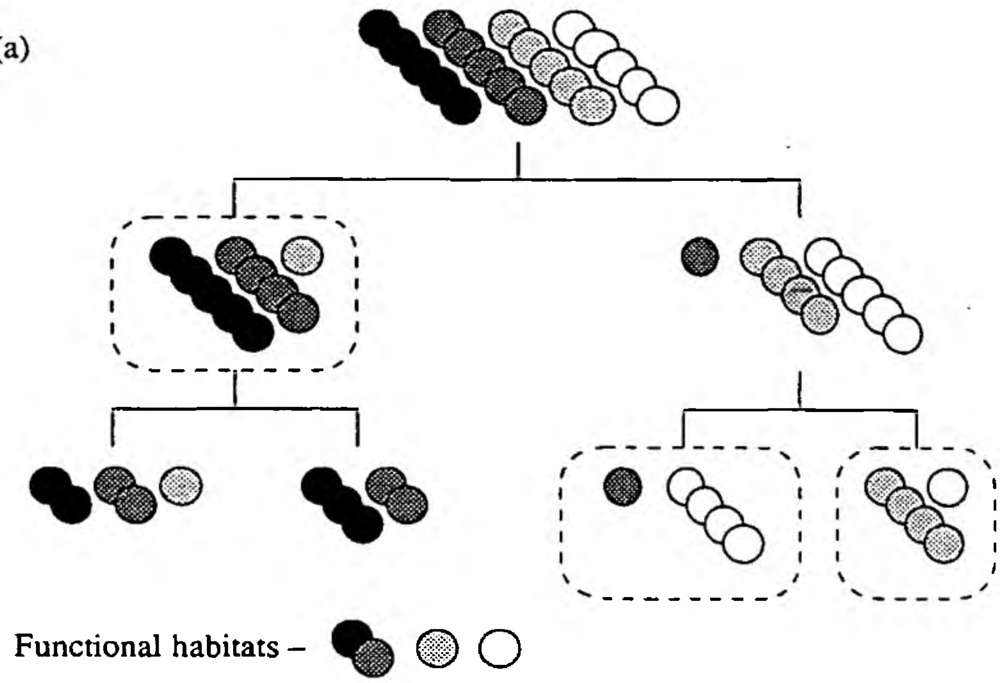
(a)



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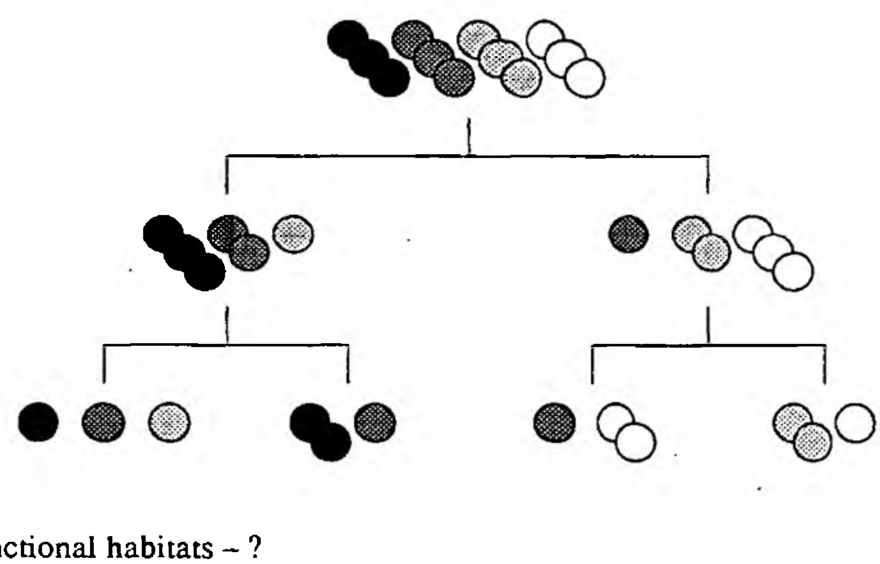

FIG. 1. Effect of replication. Three functional habitats are confidently inferred from the classification with 5 replicates of each potential habitat (a). The classification with 3 replicates of each potential habitat (b) cannot confidently be interpreted, since single 'outliers' are then more important.

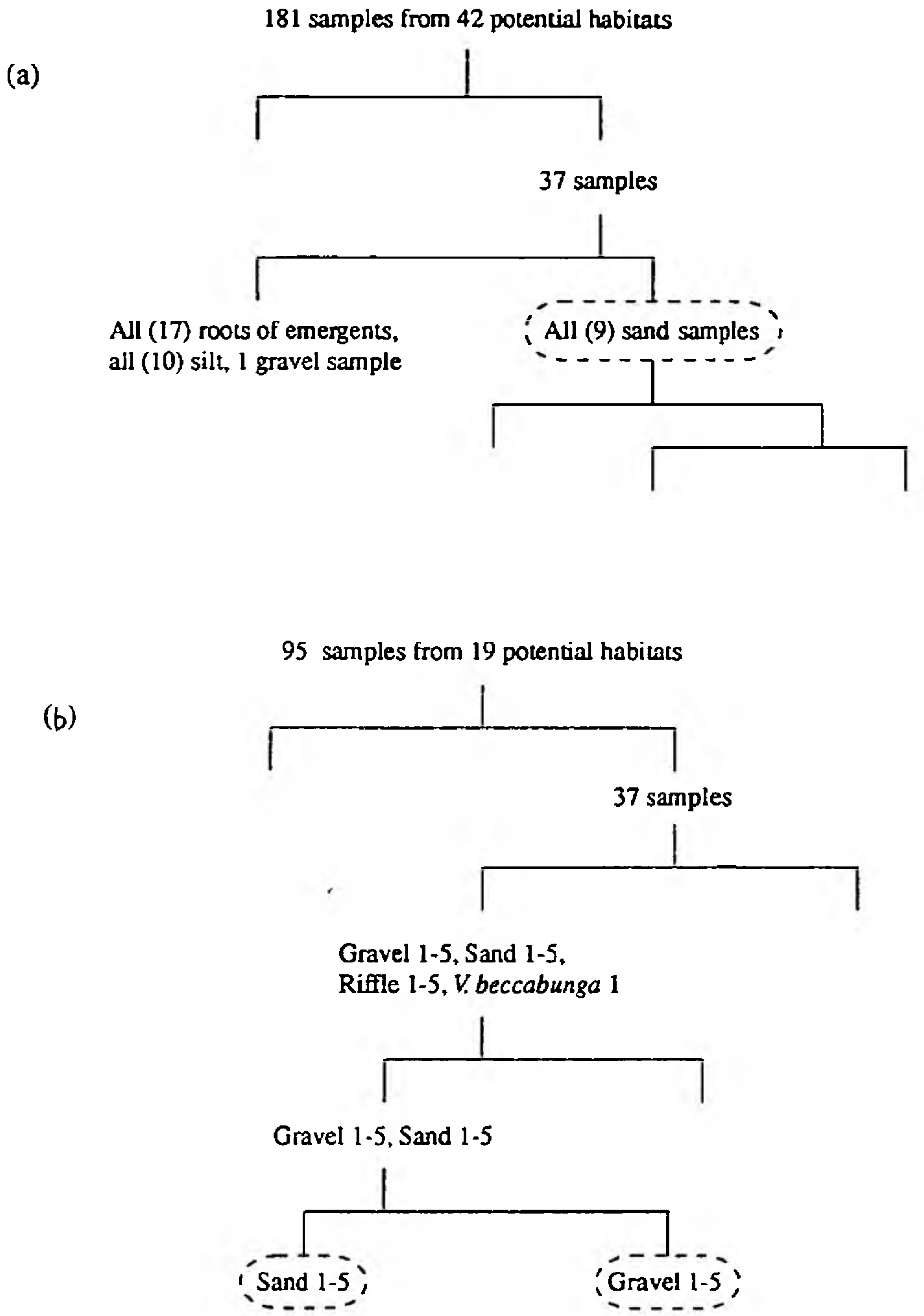

FIG. 2. Elements of the TWINSPAN classification relating to 'sand' replicates. (a) Separation of sand samples from silt and root samples on the River Welland. (b) Separation of sand samples from gravel samples on the River Wissey.

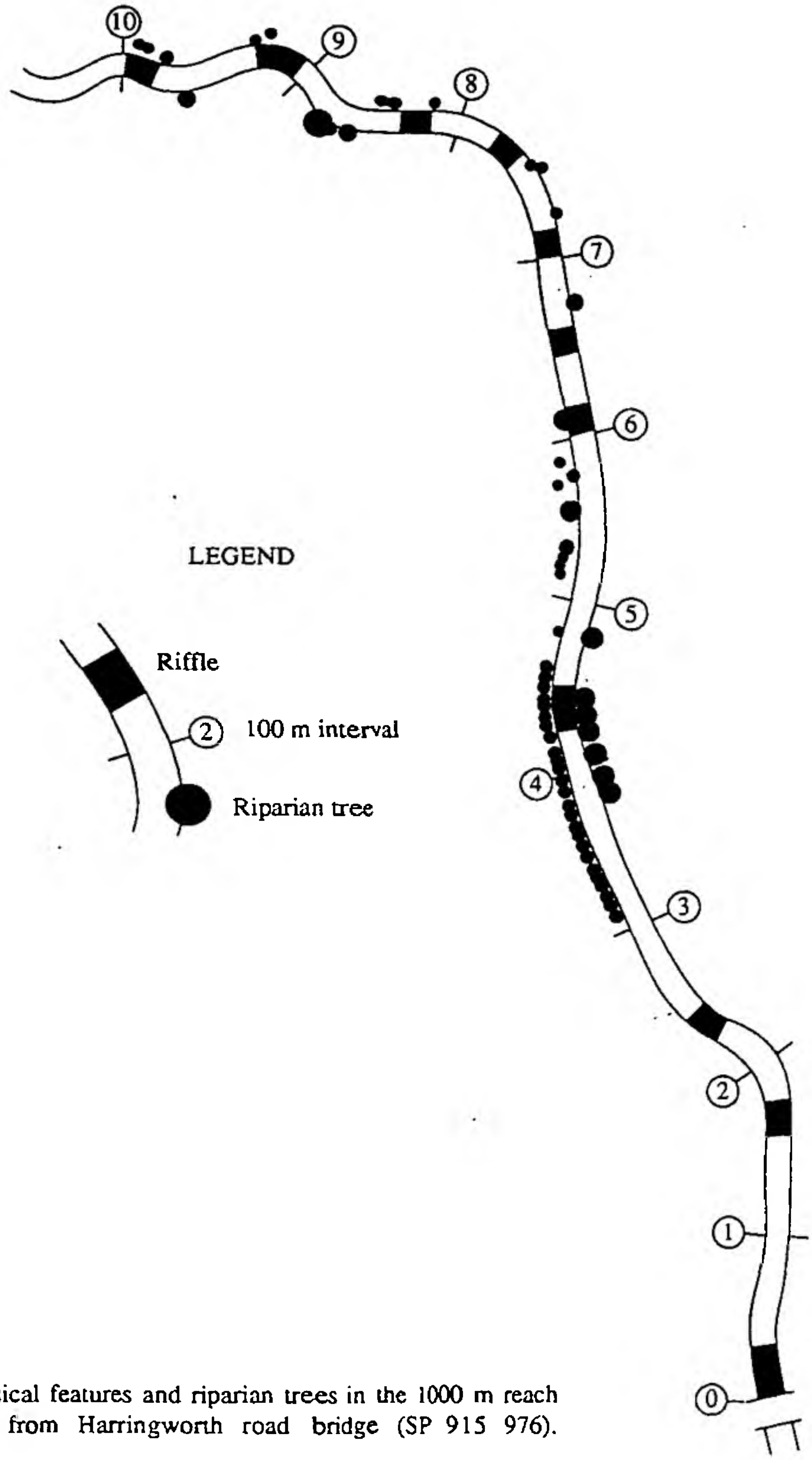

FIG. 3. Physical features and riparian trees in the 1000 m reach downstream from Harringworth road bridge (SP 915 976).

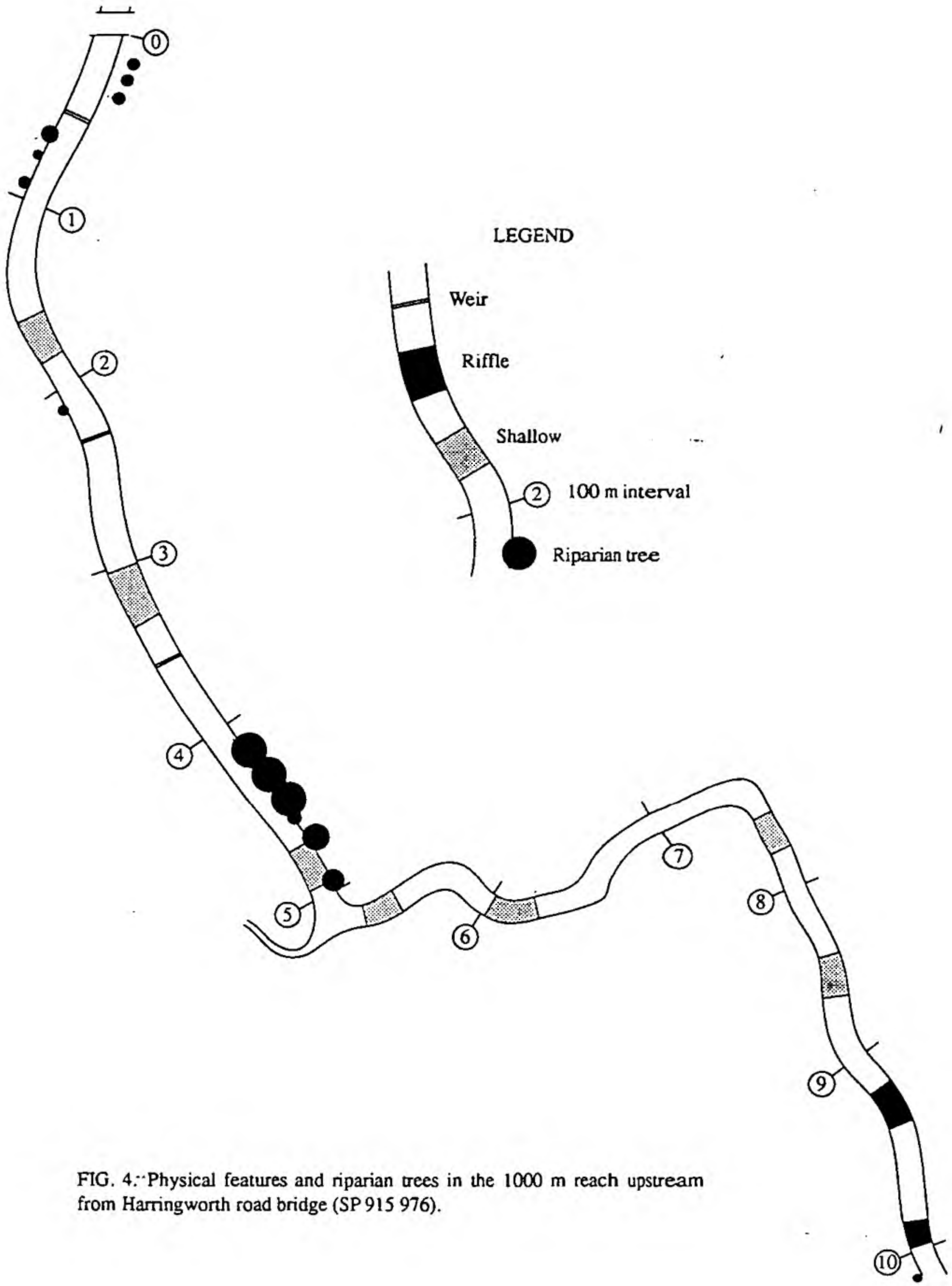

FIG. 4: Physical features and riparian trees in the 1000 m reach upstream from Harringworth road bridge (SP 915 976).

TABLE 1. Occurrence of functional habitats over the Harringworth study reach. Sections of 100 m numbered sequentially from the road bridge in each direction.

	Downstream										Upstream									
	9-10	8-9	7-8	6-7	5-6	4-5	3-4	2-3	1-2	0-1	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Gravel	X	X	X	X	X	X	X	X	X	X	X	X			X	X		X	X	X
Riffle - substrate	X	X	X	X		X	X	X	X	X										X
- *Fontinalis*			X	X				X		X										X
Silt - with leaf litter					X	X	X	X	X			X								
- without leaf litter		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
'Reeds'	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rorippa (or similar)	X	X	X	X	X		X	X	X	X	X	X		X		X	X	X	X	X
Phalaris	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Agrostis (or similar)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Run - *Nuphar*																				
Pool - *Nuphar*																				
- *Elodea*	X																			
- *Cladophora*	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other submerged spp.	X	X	X	X	X	X	X	X	X	X	X			X	X				X	X

APPENDIX C

RECOMMENDATIONS FOR RIVER WELLAND - SEPTEMBER 1991

Anglian Region are planning a scheme for conservation enhancement of the middle reaches of the River Welland, which was channelised during arterial drainage schemes in the late 1960s. The research which led to the current project was based largely on the Welland and so input to the planning stage of the restoration work has been made, with agreement of the Project Leader. The physical features of the channel and functional habitats were surveyed for 1 km either side of Harringworth road bridge (SP 915 976). Recommendations for channel restoration were made from an assessment of existing functional habitats and the predicted characteristics of the reach. The report is reproduced in the following pages.

1. CONTEXT

The River Welland was subject to arterial drainage works in the late 1960s. The channel was widened and deepened throughout for a long flood return period, with a single-stage trapezoidal section. The maintenance regime in recent years has been applied sensitively, on a little-and-often basis, and with regard for conservation issues.

There remains a need for active rehabilitation of the channel at some sites, in accord with the environmental duties of the National Rivers Authority. Capital funding has provisionally been allocated for channel restoration at Harringworth. The objective of this report is to suggest a strategy for the work, based upon the functional habitat methodology which has been developed on the river.

2. BACKGROUND

The 'River Welland Environmental Survey' (Anglian Region Operational Investigation A13–38A) sought to find an objective basis for site assessment and conservation practice. The project considered existing information and the results of specific further research, to produce recommendations for future management policy. Some of the information and recommendations are summarized below.

2.1 Information

Classification of samples from a large number of subjectively-defined 'potential habitats' revealed fifteen 'functional habitats', which support distinct assemblages of macroinvertebrate species. Particulate substrates, marginal and instream macrophytes each contribute strongly to the list of habitats which are important to macroinvertebrate diversity.

Quantitative samples of macroinvertebrates were taken from three substrate/depth/flow conditions at five sites. Macroinvertebrate biomass was ten times higher in the physical substrate of riffles or pools than in runs. Runs had a greater proportion of highly productive types but the absolute biomass of those was only half that in riffles and pools. With the ratio of channel area between riffles, pools and runs of 1:1:2, the restoration of a riffle system where it is lacking should bring a five-fold increase in macroinvertebrate biomass and at least a two-fold increase in their production.

Extensive series of riffles and pools are not common in Anglian Region, due in part to the naturally-low gradient of the rivers and in part to canalisation or serial impoundment. The Welland is one of the least affected in both these respects; but prior channel modification has compromised the riffle system in some places.

The distance between riffles on unmanaged rivers is related to channel width; and thence to discharge. Riffle spacing was correlated with annual mean discharge (Figure 1) on the River Welland, where most of the riffles are those which have re-formed after dredging. The appropriate length for riffles was also correlated with discharge, albeit less strongly (Figure 2).

The steep single-stage banks have allowed little development of marginal vegetation. There is typically a thin strip of shallow water, dominated by a single plant species. Sites with more extensive margins support a range of herbaceous and tall emergent macrophytes, representing several of the macroinvertebrate functional habitats.

2.2 Recommendations

Functional habitats should be used as a basis for conservation assessment of the channel and to identify priorities for enhancement. Work on the River Kym (a Great Ouse tributary) showed that a survey of functional habitats provided as much information towards appropriate management as a biological survey, at lesser cost.

The correlation of riffle spacing with discharge should be used to quantitatively assess the present riffle system of a reach. Rehabilitation of the riffle system should be considered if necessary. The numerical relationship of riffle parameters to discharge will indicate restoration which is appropriate – and likely to be augmented rather than eroded by subsequent flood events.

Competence of the present channel design should be taken into account in future management, since sorting of the coarse material necessary to riffle formation should occur at least during biennial floods. Encouragement of riffles may require alteration of the channel section or explicit placement of coarser fractions.

The margins are an important source of conservation interest and in many places, reinstatement of a marginal shelf may be the first priority for conservation enhancement. Diverse margins presently exist where the bank has failed, or where deposition has occurred. If the channel section can be altered to incorporate wider margins, or the design is relaxed prior to further maintenance, this will enhance its conservation value.

Effectiveness of the lowland river corridor as a conservation feature is greatly enhanced by the presence of trees, which were generally removed during the capital scheme. Inhibition of aquatic macrophyte growth by shading reduces the hydraulic roughness of the channel. The status of riparian trees along the Welland should be investigated and enhanced, with benefit both to conservation value and channel maintenance costs.

3. SURVEY

Macroinvertebrate functional habitats were recorded over 100 m sections of a 2000 m reach centred on the road bridge at Harringworth (SP 915 976). The results are shown in Table 1 – for precise location of 100 m sections see Figures 3 and 4. Macrophyte species were also recorded individually, over 500 m sections (Table 2). The location and extent of riparian trees and hydraulic features (riffles & weirs) are given in Figures 3 & 4.

Riffles – and therefore '*Fontinalis* in riffle' – were absent from the upstream section 0-900 m. The predictive relationship suggests a mean riffle spacing of 106 m at Harringworth. Nine or ten riffles are therefore expected to occur in each 1000 m. The downstream section meets this expectation (Figure 3), while the upstream section shows only two riffles due to serial impoundment by weirs (Figure 4). Considering the substantial positive effect of riffles and their associated pools on macroinvertebrate species richness and biomass, reinstatement of riffles to the upstream section should be the first priority for action.

There are a series of localised shallow areas, with coarser substrate, on the upstream section. These suggest that the process of erosion and deposition still occurs at high discharge, and that they may be the appropriate sites for riffle restoration. With the two existing riffles, which are above the influence of the weirs, they provide the predicted number of riffle sites for the upstream 1000 m.

Distinct assemblages of macroinvertebrate species are associated with silt, with and without leaf litter. Previous management has included the systematic removal of trees from a major proportion of the river corridor. 'Silt with leaf litter' as a functional habitat (Table 1) was restricted to the sections which had significant coverage of riparian trees (Figures 3 and 4).

The habitats represented by marginal macrophyte species (*Phalaris, Agrostis* etc., *Rorippa* etc.) were present on both the upstream and downstream sections. Macrophytes rooted below the water level (*Rorippa* etc.) were less abundant on the upstream section, where the depth of water tolerable for their growth is restricted to small areas, often within stands of tall emergents. *Phalaris* and *Agrostis* were abundant throughout – they are typically rooted above normal water level and so are not sensitive to the depth of the wetted margin.

Tall emergents (*Sparganium erectum, Glyceria maxima*) were present throughout the reach. *Phragmites* was not found on the reach at Ketton where the functional habitats were originally determined. It was present only in the downstream section at Harringworth but has a patchy distribution through the main river as a whole, so that may not be significant.

Submerged macrophytes were present throughout the downstream 1000 m and in some of the upstream 100 m sections. With the exception of *Cladophora*, they were less varied and less abundant in the upstream 1000 m. There they are forced to root in fine sediment and under some depth of often turbid water. They must therefore be more susceptible to mechanical displacement and have a less favourable light environment.

4. RECOMMENDATIONS

Note that for the most part, the suggested procedural details are based on familiarity with the local conditions, rather than specialist knowledge.

4.1 Riffle restoration (upstream 0-900 m)

During a period of moderate discharge –

• Remove the three weirs which lie in the first 500 m upstream section. There is a considerable accumulation of silt behind the structures, which could have an adverse effect downstream if the removal is carried out during low flows. The removal of the weirs is necessary for proper restoration towards a natural (not 'wild') state. Anglers (Uppingham & District Angling Society) should be made aware of the substantial benefits to productivity, since the raised water level associated with the weirs is favoured by them.

During normal discharge thereafter –

• Compare the particle size distribution of the local shallows (Figure 4, ~~A-G~~) with that of the well-developed riffles on the downstream section (Figure 3). Determine whether additional coarse material is required to simulate the natural riffle condition.

• Each riffle should account for a portion of the drop in water level through the reach, not forming surrogate weirs but not submerged as at present. The mean length of the riffles should be around 18 m, from the relationship between riffle length and discharge. The local shallows which are the proposed riffle sites have formed under unusual conditions, especially the lowermost two which are associated closely with weirs. Schedule adjustments as necessary, from their appearance at the reduced water level.

• Calculate the competence of the stream during biennial floods. Pay particular attention to the location of material which is predicted not to be sorted during such flows.

• Adjust the 'riffle material' of the local shallows to the appropriate dimensions, importing coarse material if necessary.

4.2 Enhancement of margins (upstream 0-900 m)

• If removal of the weirs for riffle restoration is acceptable, the position and aspect of the margins will be improved without further intervention. Development of the riffle-pool system will generate areas of shallow water for colonisation by herbaceous macrophytes.

• If the weirs remain, central and lateral shoals which have formed in the channel should be retained, since they provide the only existing location for marginal plants other than the tall emergents.

• The margins could be made more extensive with the present water level by adjusting the channel section to include a shallow shelf or shallower bank slope. This would require extra land unless restricted to sites where the bank has failed previously.

6.3 Tree planting (upstream 100-400, 500-1000 m & downstream 600-1000 m)

• No specific recommendations. This would provide refugia from *Cladophora* overgrowth in summer, reduce the roughness of the channel by inhibiting excess macrophyte growth and enhance the conservation value of the river corridor as a whole. Tree planting need not prevent access for channel maintenance plant, if planned in consultation with the engineers responsible for flood protection.

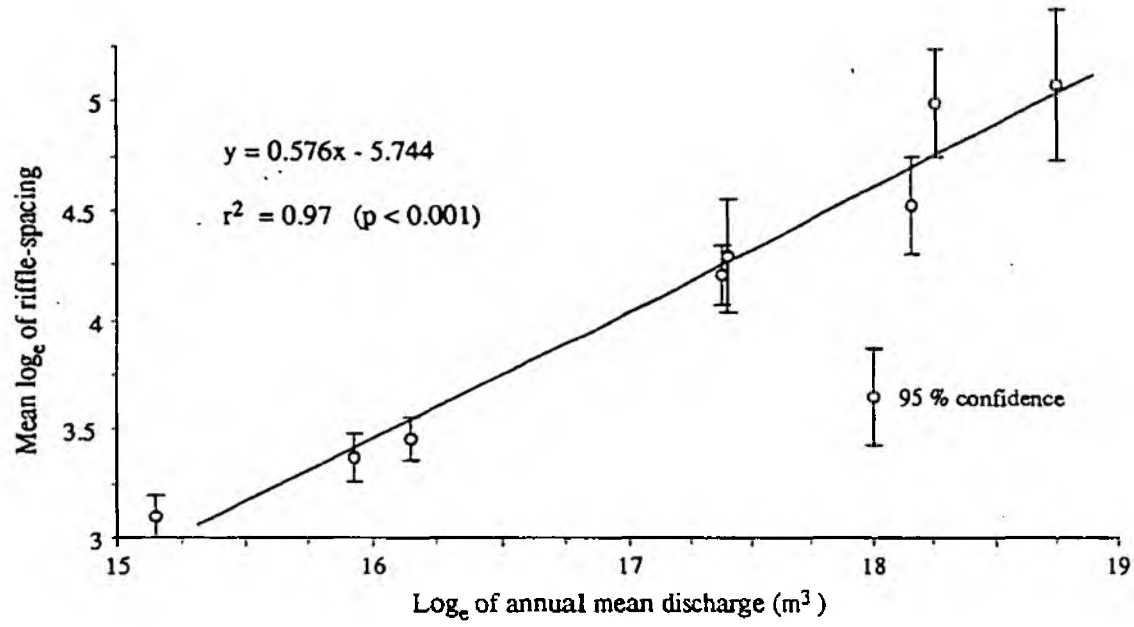

Figure 1 Relationship of riffle-spacing to discharge

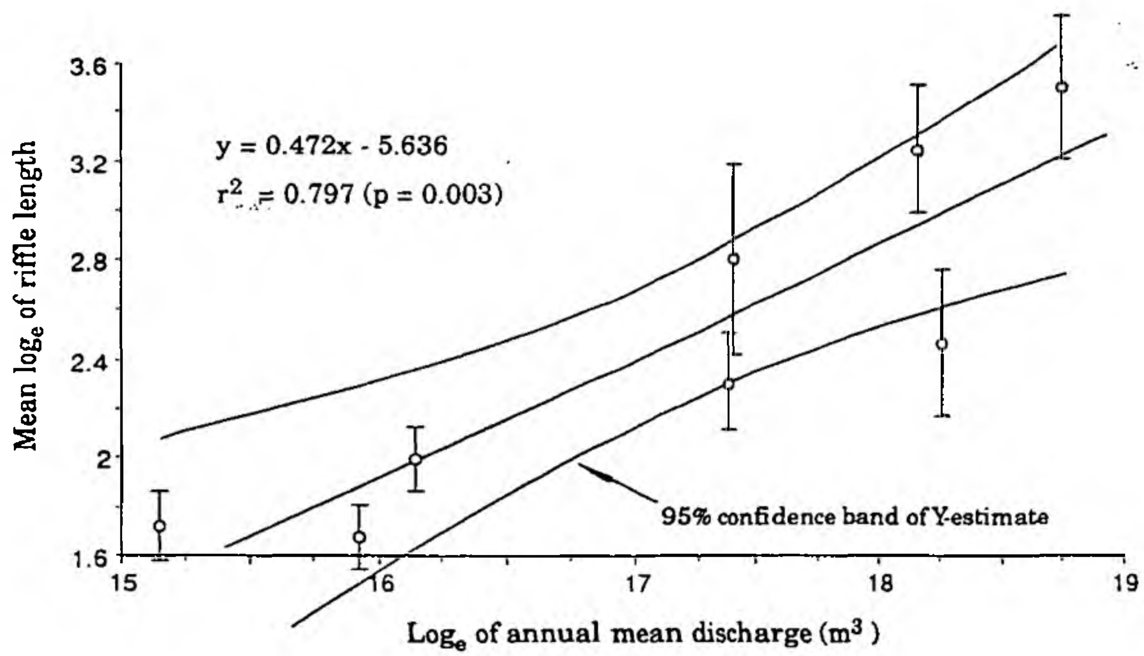

Figure 2. Relationship of mean riffle length to discharge

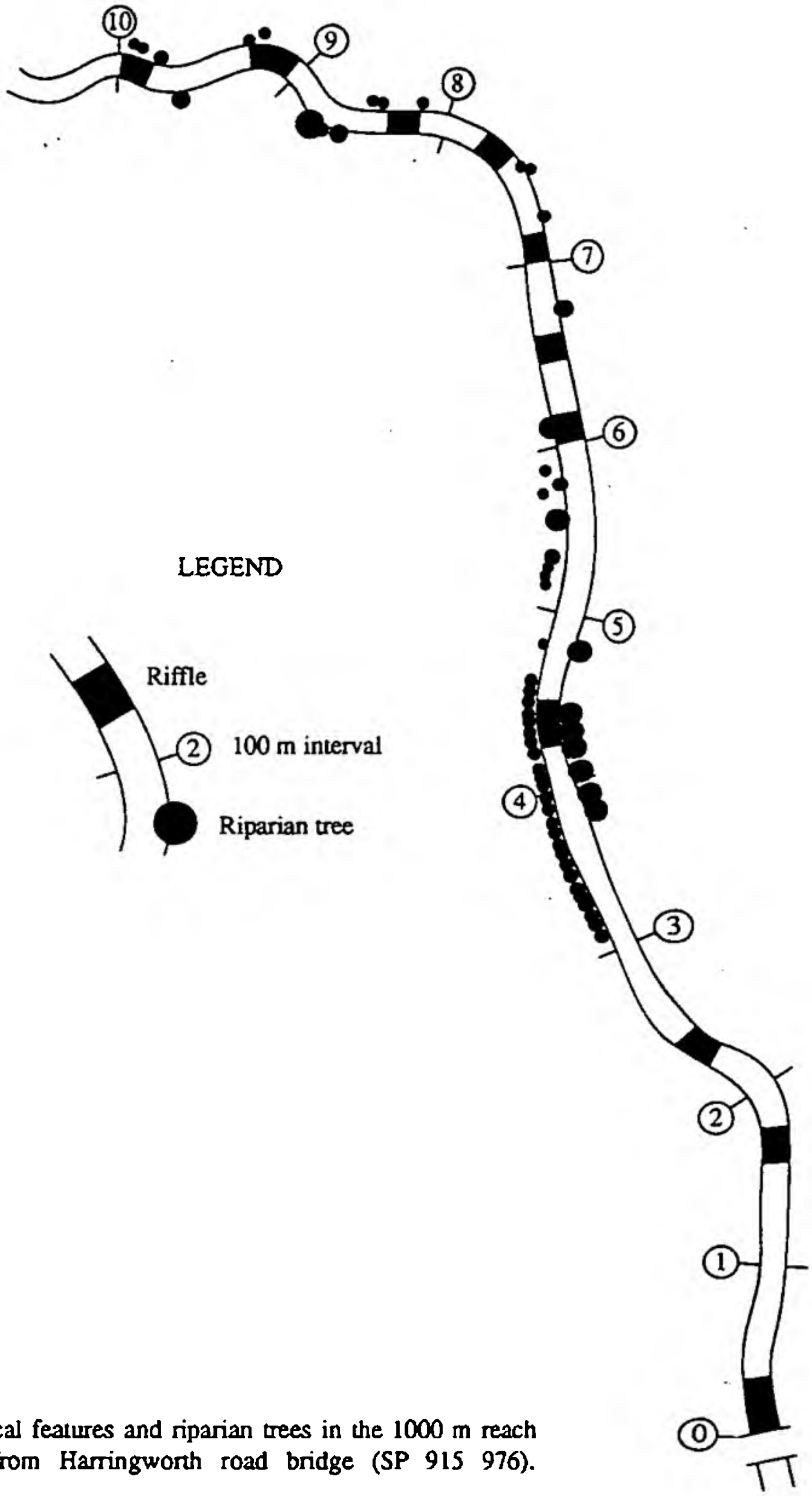

FIG. 3. Physical features and riparian trees in the 1000 m reach downstream from Harringworth road bridge (SP 915 976).

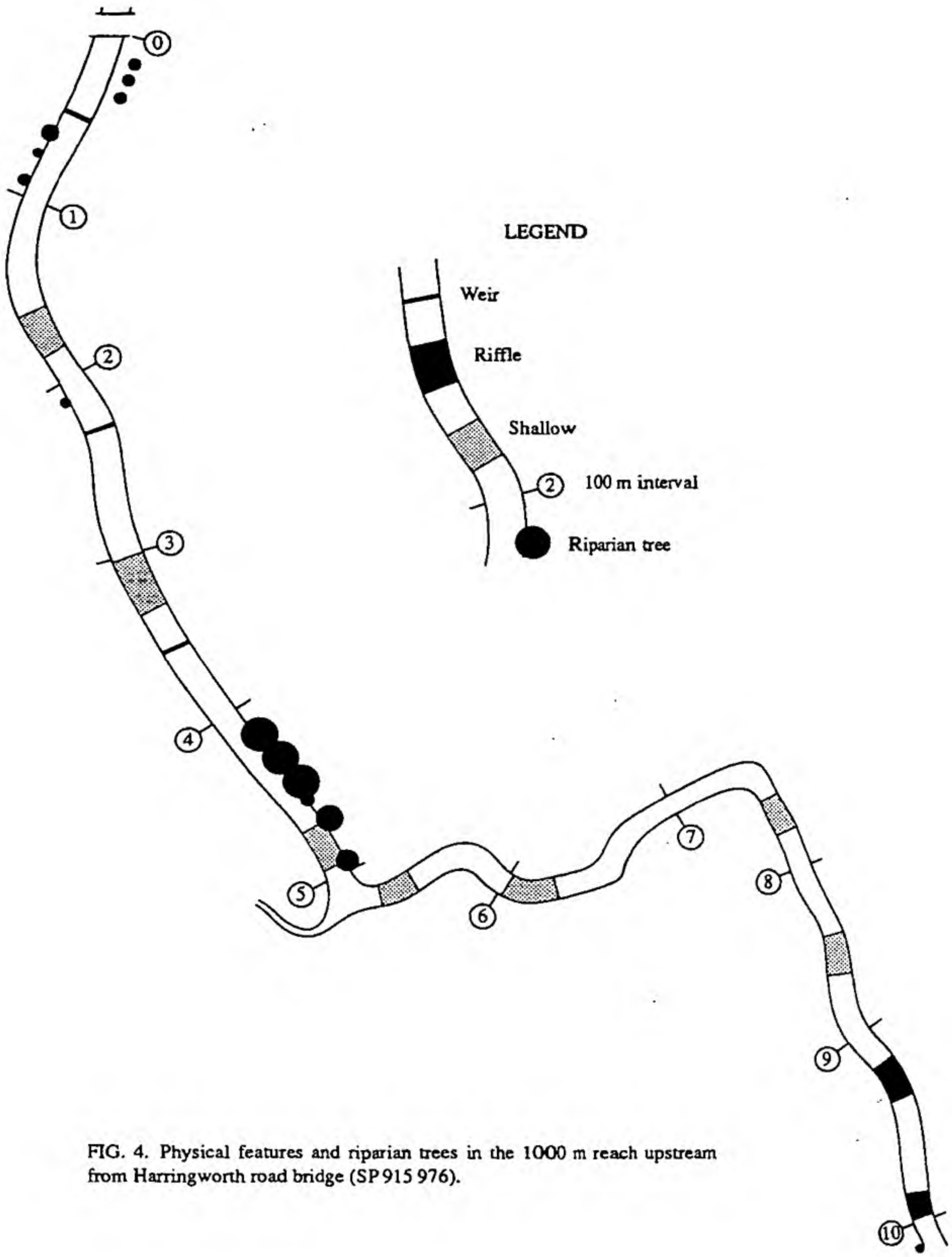

FIG. 4. Physical features and riparian trees in the 1000 m reach upstream from Harringworth road bridge (SP 915 976).

TABLE 1. Occurrence of functional habitats over the Harringworth study reach. Sections of 100 m numbered sequentially from the road bridge in each direction.

	Downstream										Upstream									
	9-10	8-9	7-8	6-7	5-6	4-5	3-4	2-3	1-2	0-1	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Gravel	X	X	X	X	X	X	X	X	X	X	X	X			X	X		X	X	X
Riffle - substrate	X	X	X	X		X	X	X	X	X										X
- *Fontinalis*			X	X				X		X										X
Silt - with leaf litter					X	X	X	X	X			X								
- without leaf litter		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
'Reeds'	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rorippa (or similar)	X	X	X	X	X		X	X	X	X	X	X		X		X	X	X	X	X
Phalaris	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Agrostis (or similar)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Run - *Nuphar*																				
Pool - *Nuphar*																				
- *Elodea*	X																			
- *Cladophora*	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other submerged spp.	X	X	X	X	X	X	X	X	X	X	X			X	X				X	X

Table 2. Macrophyte abundance

	d/s 5-10	d/s 0-5	u/s 0-5	u/s 5-10
Herbaceous marginal				
Apium nodiflorum	F	F	F	F
Myosotis scorpioides	F	F	O	F
Rorippa amphibia	F	F	R	O
R. nasturtium-aquaticum	R			R
Veronica beccabunga	F	F		O
Mentha aquatica	R			R
Polygonum amphibium		O		
Submerged				
Potamogeton pectinatus	A	F		R
P. lucens			R	
P. perfoliatus	O	R		
P. crispus	R	R	R	
Sparganium emersum	O	R		
Callitriche stagnalis agg.	R	R	R	
Myriophyllum spicatum	O	R	R	
Fontinalis antipyretica	O	O		R
Cladophora glomerata	A	A	A	A
Emergent				
Carex acutiformis			O	
Sparganium erectum	A	A	A	F
Schoenoplectus lacustris	F	F	A	F
Phalaris arundinacea	A	A	A	A
Glyceria maxima	A	A	A	A
G. fluitans		R		
Sagittaria sagittifolia	R	R	R	
Agrostis stolonifera	A	A	A	A
Juncus inflexus	R	R	O	O
Phragmites communis	R	F		

(Subjective estimate of abundance – Abundant ... Frequent ... Occasional ... Rare)