River Wissey Investigations: Linking Hydrology and Ecology

Main Report Part II

University of Birmingham

Project Report OI\526\4\A

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Statement of use
This report is intended for use by water resources and conservation staff in determining the relationships between flows and ecology of rivers. It should be read in conjunction with the other Operational Investigations reports from this project (ie. Executive Summary; Summary of a Recommended Approach to Setting Flows for Ecological Objectives; and Manual for Using Macroinvertebratesto Assess In-River Needs).

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CONTENTS.

1. INTRODUCTION.

A detailed investigation of the ecology and hydrology of the River Wissey was initiated in 1991 following concerns about the impact of falling flows in the river on the flora and fauna. There was particular concern for the detrimental effects of low flows on the brown trout population for which the river is renowned. An intensive program of field surveys during 1991 and 1992 was supplemented by the collation of existing information on the river. This yielded a substantial amount of detailed data which was used to assess the past and current physical and ecological status of the Wissey, and, through an integrated analysis of macroinvertebrate survey records and physical habitat data, to describe the relationships between macroinvertebrate distributions and habitat characteristics. The results of these studies are reported in "River Wissey Investigations: Linking Hydrology and Ecology" (NRA, 1994).

Following the 1991/1992 study, two important questions were raised relating to the implications of the results. First, the data collected during these surveys were not representative of "normal" river conditions, taken as they were under extreme low flows. It was unknown whether the results would apply under moderate to high flow conditions. Secondly, it was queried as to whether the observed habitat / fauna relationships described for the Wissey would be directly or indirectly applicable to other chalk streams. In 1994, an extension of the project was granted by the Environment Agency (then the National Rivers Authority) with the aim of answering these questions. This involved i) additional surveys of the Wissey under normal flow conditions, ii) integration of results of these surveys with a) the original River Wissey data set and b) additional survey data from the River Babingley (NRA 1995) and nine other chalk streams collected by the NRA during late 1992/1993. This Report presents the results of this work, draws conclusions regarding the use of macroinvertebrates as indicators of habitat quality in relation to flow, and forms the basis for a generalised methodology which uses macroinvertebrates for habitat assessment.

The Report volumes which form the output of the project are detailed in Table 1.1. In addition to the Main Report, these include:

- an Summary of a Recommended Approach to Setting Flows for Ecological Objectives. This Summary is written for those involved in the management of river flows, and recommends the development of River Flow Objectives, through the definition of Ecologically Acceptable Flow Regimes which meet Ecological Objectives set for each sector of river.

- a Manual for using Macroinvertebrates to Assess In-river Needs which provides a step-by-step guide towards the setting of sector-scale Ecological Objectives using field survey and historical macroinvertebrate data.

- an Executive Summary of the River Wissey Investigations which summarises the results of the project and the recommendations for management specific to the River Wissey.

Table 1.1 Output from the River Wissey investigations.

Main Report: Part I (1994): a descriptive assessment and evaluation of ecological impacts during the 1991-92 low-flow years.

Annex A:	River corridor and wetlands; the diatom community and EA fish survey data; water chemistry; and channel-bed sediments and surface water-groundwater interactions.
Annex B:	Aquatic macrophytes and their influence on hydraulics and sedimentation.
Annex C:	PHABSIM analyses.
Annex D:	Macroinvertebrates: distribution and use in habitat assessment, based on survey data from 1991-1992 and NRA data, 1964-1991.

Main Report: Part II (1997) this volume: containing i) a description of the physical habitat and ecological changes recorded on the River Wissey over the 1991-'94 period; ii) analysis of the relationships between macroinvertebrates, physical habitat and flow; iii) development of a recommended method for use in assessing in-river flow needs using macroinvertebrates, and iv) an assessment of the transferability of macroinvertebrate habitat preference information between chalk streams.

Manual for using Macroinvertebrates to Assess In-river Needs (1997): the use of macroinvertebrates to assess in-river flow needs.

Summary of a Recommended Approach to Setting Flows for Ecological Objectives (1997).

Executive Summary of the River Wissey Investigations (1997).

The research detailed in these reports has been contributed to by a large number of people over the last seven years. We would like to thank all those who were involved in the field, laboratory and report production. The individuals concerned are named in the Main Report Part I, but we would especially like to thank here Miss E Linton and Dr P Wood, who contributed most valuable field and laboratory assistance to the second phase of the project.

2. AIMS AND OBJECTIVES.

This second part of the Main Report describes the results of field surveys of the River Wissey and ten other Anglian rivers, and the analysis of these results. This Report has three main aims:

i) To describe in detail the relationships between macroinvertebrates, habitat and flows on the River Wissey and assess the efficiency of macroinvertebrates as habitat describers;

ii) To assess the transferability of taxa-habitat preference functions developed for the River Wissey to other chalk streams; and

iii) To develop a methodology for field surveying, sample processing and data analysis which may be applied to other chalk stream sites in order to gain the optimum amount of information on the relationship between the macroinvertebrate fauna, habitat quality and flows.

A series of objectives were set in order to address these aims. These fall into three categories:

1 Maximising information on the River Wissey.

a) To collect seasonal information from selected sites on macroinvertebrate distributions and habitat characteristics in a "normal" flow year, to extend the data base compiled during the 1991/1992 surveys;

b) To identify the most important habitat characteristics controlling macroinvertebrate distributions;

c) To describe the relationships between macroinvertebrate taxa and hydraulic habitat conditions (water depth and current velocity) in terms of habitat preference functions / preference curves;

d) To assess the efficiency of macroinvertebrate taxa in describing hydraulic habitat conditions by critical testing of taxa preference functions / preference curves between seasons and years.

2 Examining macroinvertebrate distributions in other chalk streams.

a) To identify and rank the habitat factors controlling macroinvertebrate community composition in ten other chalk streams;

b) To use the taxa preference functions / preference curves developed for the River Wissey to predict invertebrate distributions in the ten other Anglian chalk streams using hydraulic habitat data, and critically assess the transferability of the River Wissey information.

3 Developing a methodology for using macroinvertebrates as hydraulic habitat indicators.

a) To use the information obtained from the above to identify the most appropriate sampling strategy and level of taxonomic identification to provide most useful data with minimum effort;

b) To produce a simple-to-use method for the development of preference functions and, preference curves and "surfaces" to link observed macroinvertebrate distributions and hydraulic habitat information;

c) To provide guidelines for interpreting the information obtained from the above method, leading to an assessment of the ecological impact of flows on macroinvertebrate communities.

These objectives are addressed in the following Sections.

3. METHODS.

This Section describes the field methods used in the 1994 surveys and analytical methods used on the full data set. The full details of the site survey field methods are given in Part I of the Main Report. Analytical methods used in this (Part II) Report are modified from those in Part I of the Main Report and full details of the basis of the modified methods are provided below.

3.1 The River Wissey field surveys.

Field surveys and laboratory sample processing followed the same methods as described in the Main Report Part I (NRA, 1994), in this case on a restricted set of three sites: Chalk Hall Farm, Langford Hall (gravel riffle) and Langford Hall (shallow sand run with riffle-type characteristics), abbreviated in some figures and tables to CF, LG and LS respectively. Surveys were undertaken in February, May and October, in each case providing up to 12 macroinvertebrate samples and sets of habitat information from each site. Figure 3.1 shows the locations of the sites and those of the other Wissey main sites referred to in this Report, and Table 3.1 gives the relevant National Grid References.

Table 3.1 River Wissey main site locations and codes.

SITE LOCATION	NGR	CODE
Bodney Bridge	TL828988	BYBR
Chalk Hall Farm	TL835981	CKHF (CF)
Langford Hall (gravel)	TL830950	LHGR (LG)
Langford Hall (sand)	TL830950	LHSD (LS)
Didlington (sand)	TL802945	DDSD
Didlington (gravel)	TL785957	DDGR
Northwold	TL767971	NTWD

3.2 Other Anglian Region chalk streams surveys.

This Report uses additional data from three sites on the River Babingley, collected in 1992 as part of the NRA project "The River Babingley - A Study of In-River Needs"; and data from a survey of twenty-one sites on nine rivers throughout Anglian Region undertaken by the NRA in autumn 1992 / spring 1993. Field and laboratory methods again followed the "Wissey methodology", with the difference that at each site only one transect (instead of three) was surveyed, giving four "cells" defined by at least five sets of habitat data and one macroinvertebrate sample. Figure 3.2 shows the locations of the rivers and Table 3.2 lists the site names and locations.

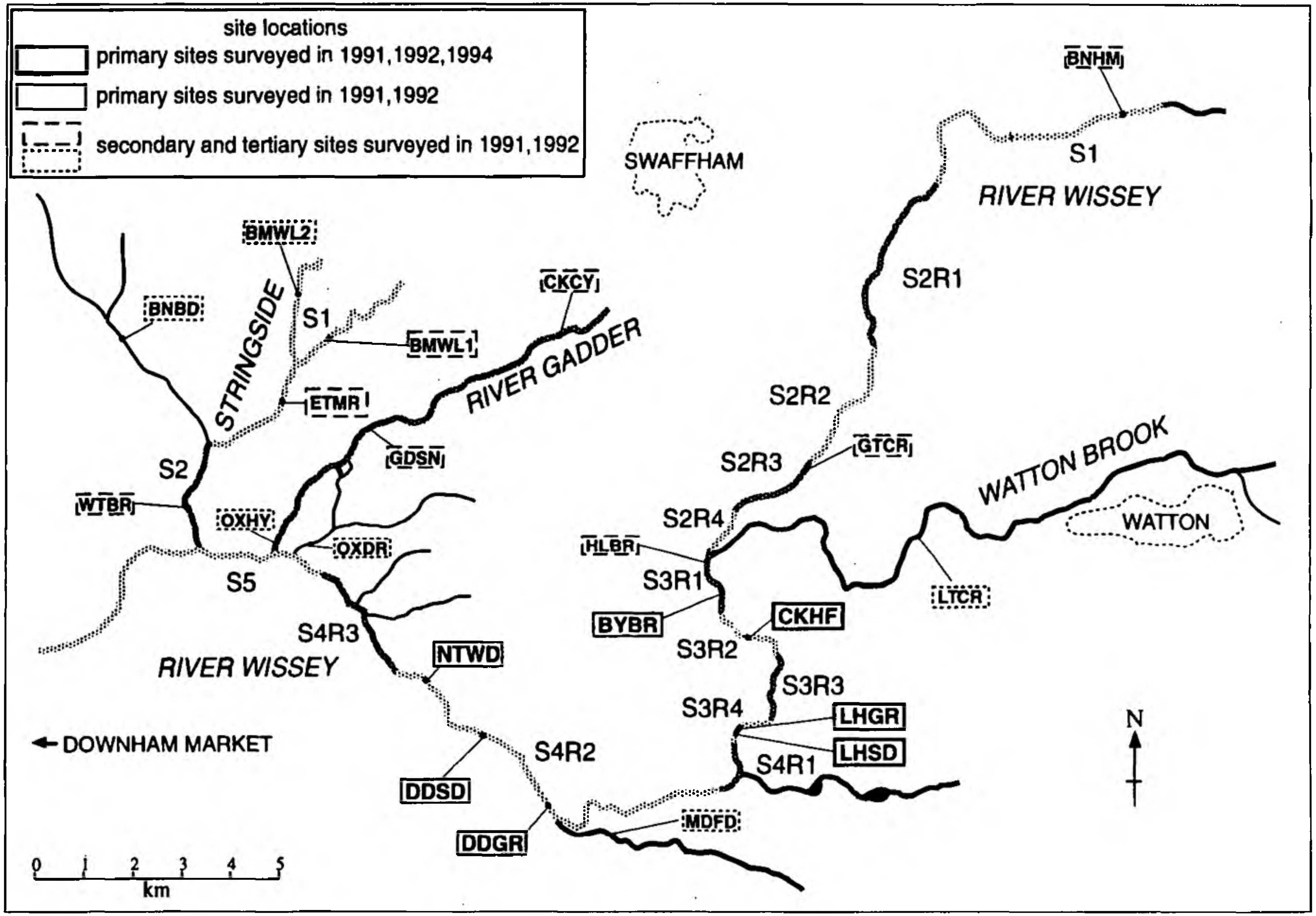


Figure 3.1 RIVER WISSEY: sampling sites, sectors (S) and reaches (R).

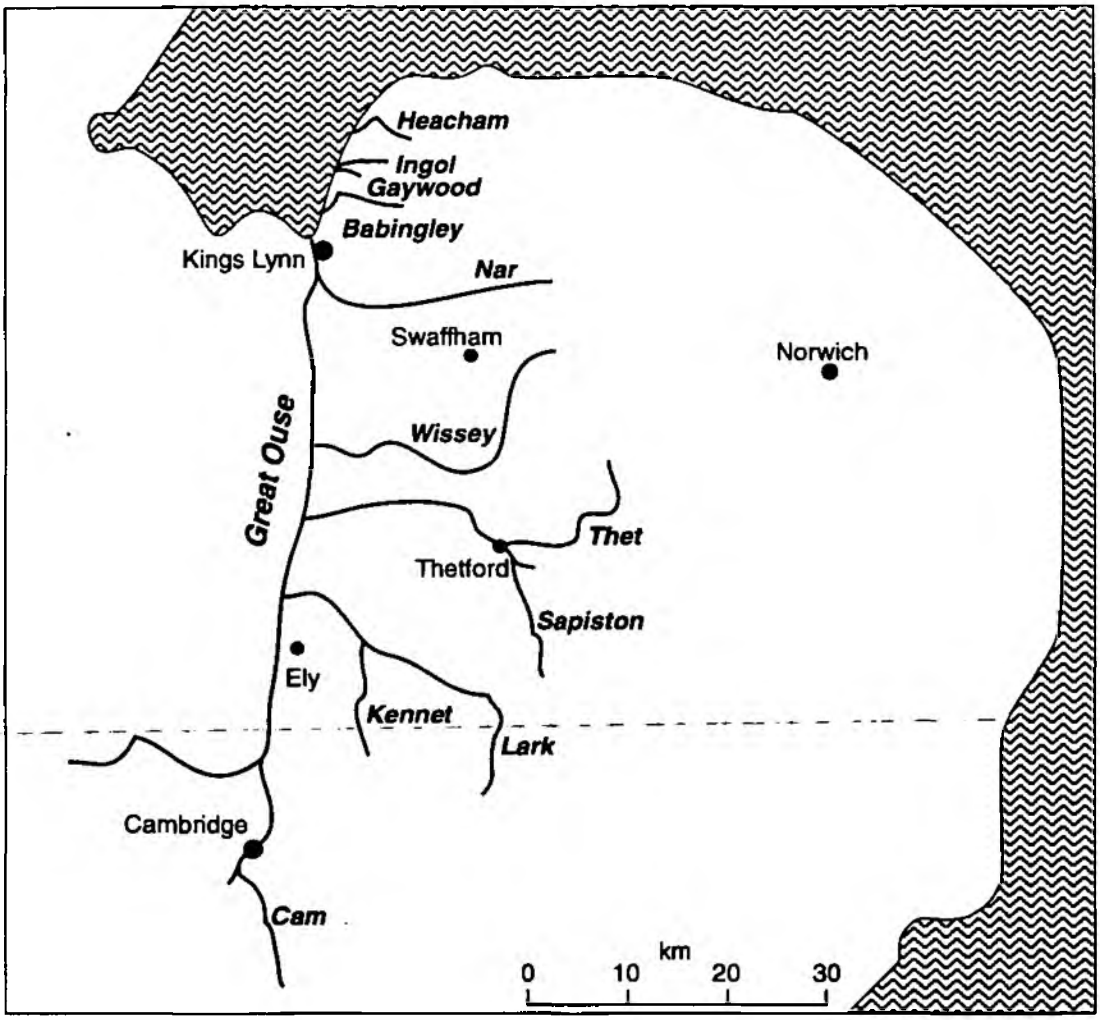


Figure 3.2 Location of Anglian chalk streams including the Rivers Wissey and Babingley.

Table 3.2 The Anglian Rivers survey: site names, codes and locations.

river	sample code	site	NGR	NRA code
Cam	C1	Shortgrove Estate	TL520352	BF27M31
Cam	C2	Springwell Farm	TL518403	BF27M33
Cam	C3	Little Chesterford	TL516415	BF27M34
Cam	C4	King's Mill	TL504427	BF27M35
Cam	C5	Whittlesford Station	TL487475	BF27M36
Gaywood	G1	Grimston	TL795713	BF61M15
Heacham	H1	40m U/S Bridge	TF694373	BF66M17
Heacham	H2	300m U/S Bridge	TF694370	BF66M18
Ingol	I1	Ingoldisthorpe S.T.W.	TF697327	BF65M06
Ingol	I2	Wooton Marsh Farm	TF676333	BF65M07
Kennett	K1	U/S Beck's Bridge	TL663730	BF38M12
Kennett	K2	D/S Beck's Bridge	TL662735	BF38M13
Kennett	K3	Freckenham	TL665723	BF38M14
Lark	L1	Temple Bridge Weir	TL758729	BF37M12
Lark	L2	Lackford Road Bridge	TL789711	BF37M11
Lark	L3	West Stow Country Park	TL796713	BF37M44
Lark	L4	Mill Farm	TL831692	BF37M43
Nar	N1	East Lexham	TF859170	BF58M36
Nar	N2	Castle Acre	TF819148	BF58M35
Nar	N3	West Acre	TF779147	BF58M34
Sapiston	S1	Elmswell New Hall	TL970637	BF41M24
Sapiston	S2	Beaumont's Hall	TL948674	BF41M25
Sapiston	S3	Abbey Farm	TL924717	BF41M26
Thet	T1	West Car Farm	TM023947	BF44M45
Thet	T2	Shropham Fen	TL997930	BF44M46
Thet	T3	East Harling	TL988866	BF44M47

3.3 Data Analysis.

Two main types of statistical analysis have been employed in this report multivariate analyses (which deal with community information, ie. multi- species information), and regression analyses (used to relate single species/families to one or more habitat variables).

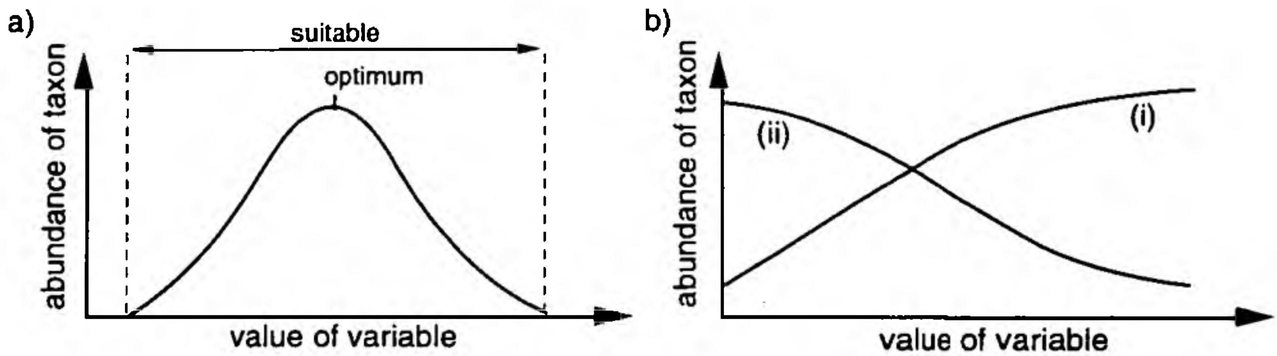
3.3.1 Multivariate analyses.

Classification and ordination techniques were used to i) investigate community differences between samples (spatially and temporally), and ii) relate these differences to a variety of measured habitat characteristics by correlating community scores with habitat variable values. The classification method employed was Two-way indicator species analysis (TWINSPAN, Hill, 1979), whilst the ordination methods were correspondence analysis and detrended correspondence analysis from the Canonical community ordination computer package (CANOCO, ter Braak, 1988). Full details of these multivariate techniques are given in the Part I of the Main Report.

3.3.2 Regression analyses.

Regression analyses used to elucidate the relationships between the distribution of individual species/families or higher taxa and habitat variables. The basis for the choice of regression method is described below.

Taxa can be assumed to be related to habitat variables (such as water depth, current velocity or macrophyte cover) in the form illustrated in (a) below:



ie. at some value of the variable the habitat becomes suitable for the species, after which abundance increases to a point where the habitat is optimal, beyond which point abundance declines again to zero where the value of the variable is such that the habitat is unsuitable again. In most real-life cases the range of the variables observed will mean that only a small portion of the curve is covered (bi) above), or the zero value of the variable is optimal and abundance declines from this optimum as the value of the variable increases from zero (bii).

A second-order polynomial regression is the most suitable model to describe these species-habitat relationships, ie.:

$$\text{abundance} = \mathbf{a} + (\mathbf{b} \times \text{var.}) + (\mathbf{c} \times \text{var.})^2$$

where **a**, **b** and **c** are constants and var. is the value of the variable.

There is frequently a high degree of interdependence between the main habitat variables (depth, current velocity and macrophyte cover) affecting macroinvertebrate distributions in chalk streams. For this reason, <u>multiple</u> regression is required to distinguish the responses of species to individual variables. In the case of depth, velocity and macrophyte cover as key variables, the regression equation thus becomes:

$$\text{abundance} = \mathbf{a} + (\mathbf{b} \times D) + (\mathbf{c} \times D)^2 + (\mathbf{d} \times V) + (\mathbf{e} \times V)^2 + (\mathbf{f} \times M) + (\mathbf{g} \times M)^2$$

where **a** to **g** are constants and D = depth, V = velocity and M = macrophyte cover.

All regression analyses discussed in this Report were performed using the StatView computer package.

In Part I of the Main Report, a variety of methods were tested which related species abundance to flow, based on those used by other workers in developing habitat preferences curves for invertebrates (Gore and Judy, 1981; Orth and Maughan, 1983; Orth and Leonard, 1990). Species habitat preferences were derived from polynomial regression on single variables and also multiple polynomial regression on two variables (depth and current velocity). Using the 1991 and '92 data only, little difference was found in the two methods, and the simpler first method was recommended. However, with the addition of the 1994 data in which the importance of macrophyte cover as a third key variable becomes apparent, the multiple regression method provides a much more accurate model for defining species habitat preferences. It is therefore this method which is used in the later Sections and recommended for general use in the Manual.

4. RESULTS - THE RIVER WISSEY.

Results from the 1994 macroinvertebrate and habitat surveys were added to those from the 1991/1992 surveys. This Section presents the combined results from the seven primary sites: Bodney Bridge, Didlington gravel and sand sites, Northwold, Chalk Hall Farm, Langford Hall gravel and sand sites. The first four sites were surveyed in 1991 and '92 only; the latter three sites in 1991, '92 and '94.

4.1 Physical habitat and macrophyte distribution.

Physical habitat and macrophyte distribution data are presented below for each macroinvertebrate sampling survey: eight surveys - three from May, three from October and two from February.

At the three sites surveyed in all three years, major changes in physical habitat and macrophyte cover were observed in 1994, under relatively high flows, in contrast to the drought years of 1991/1992. The surveys can thus be regarded as covering the extremes of flow conditions.

4.1.1 Seasonal and annual distributions of habitat variables.

The seasonal and annual distributions of the measured habitat variables were contrasted by analysis of percentile distributions from each site and survey. Figure 4.1 illustrates percentile distributions at each survey for water depths, current velocities and percentage cover of the dominant macrophyte *Ranunculus* and total macrophyte cover, for the three sites re-surveyed in 1994. Cell mean values of point measurements are used. Figure 4.2 shows changes in 50th %ile depths, flows and *Ranunculus* cover for the eight macroinvertebrate survey dates. The collected habitat data is presented in full in Appendix 1.

The most apparent annual differences in habitat distributions are the higher depths and macrophyte cover values observed in 1994: depths were greatest in February 1994; macrophyte cover, particularly *Ranunculus* at Chalk Hall Farm and Langford Hall gravel site, is greatest in October 1994 at the end of the growth season. Current velocities are closely related to the ponding and channelling effects of macrophytes, particularly the submerged *Ranunculus*. Thus, at Chalk Hall Farm velocities are relatively high in October 1991 and 1992 where moderate weed growth maintained channelled areas of high velocity between *Ranunculus* clumps; in October 1994 *Ranunculus* growth and marginal weeds were so dense (weed-cutting began in April 1994) that extreme ponding was experienced and velocities were depressed (note depths were correspondingly high for this season).

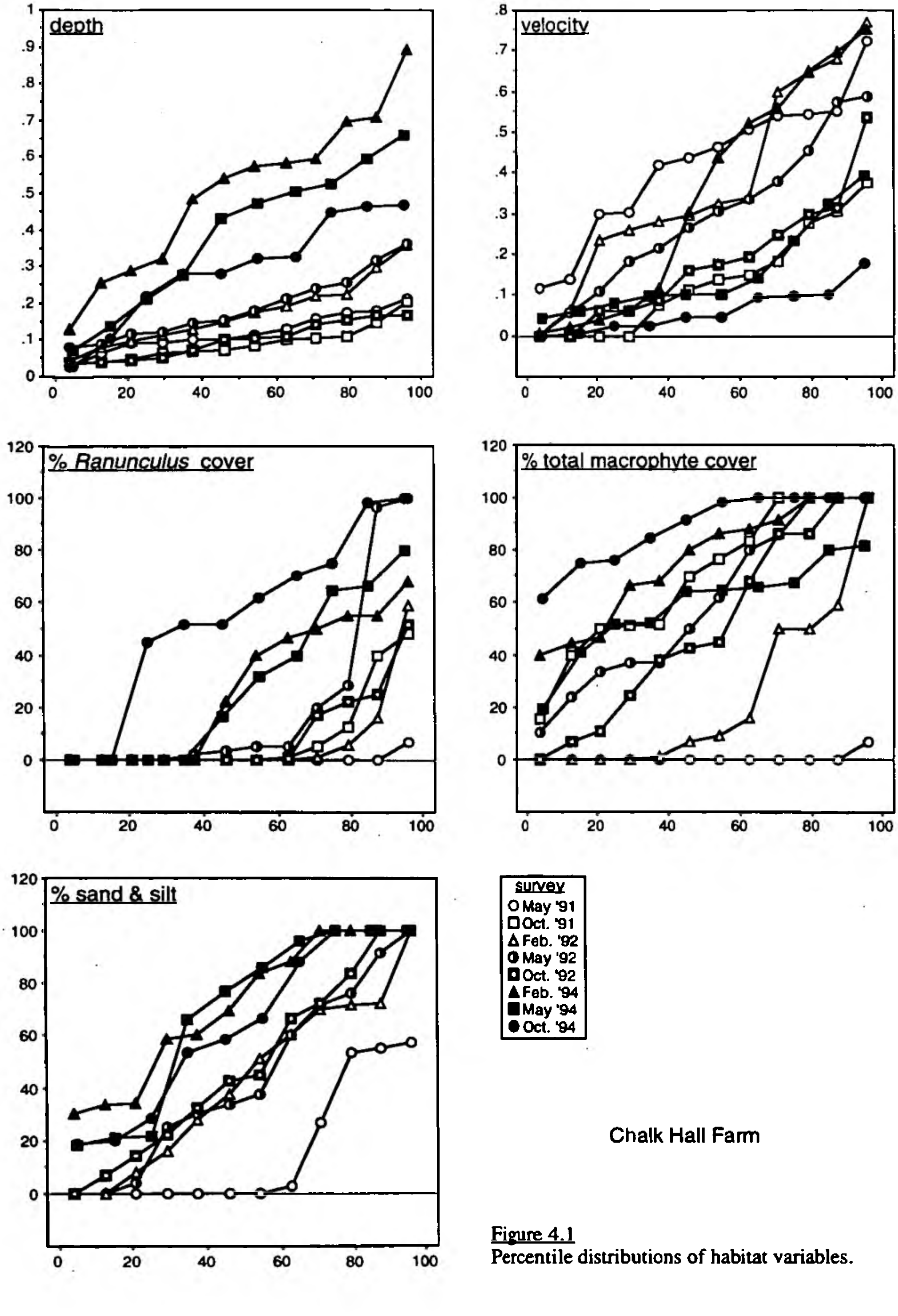


Figure 4.1
Percentile distributions of habitat variables.

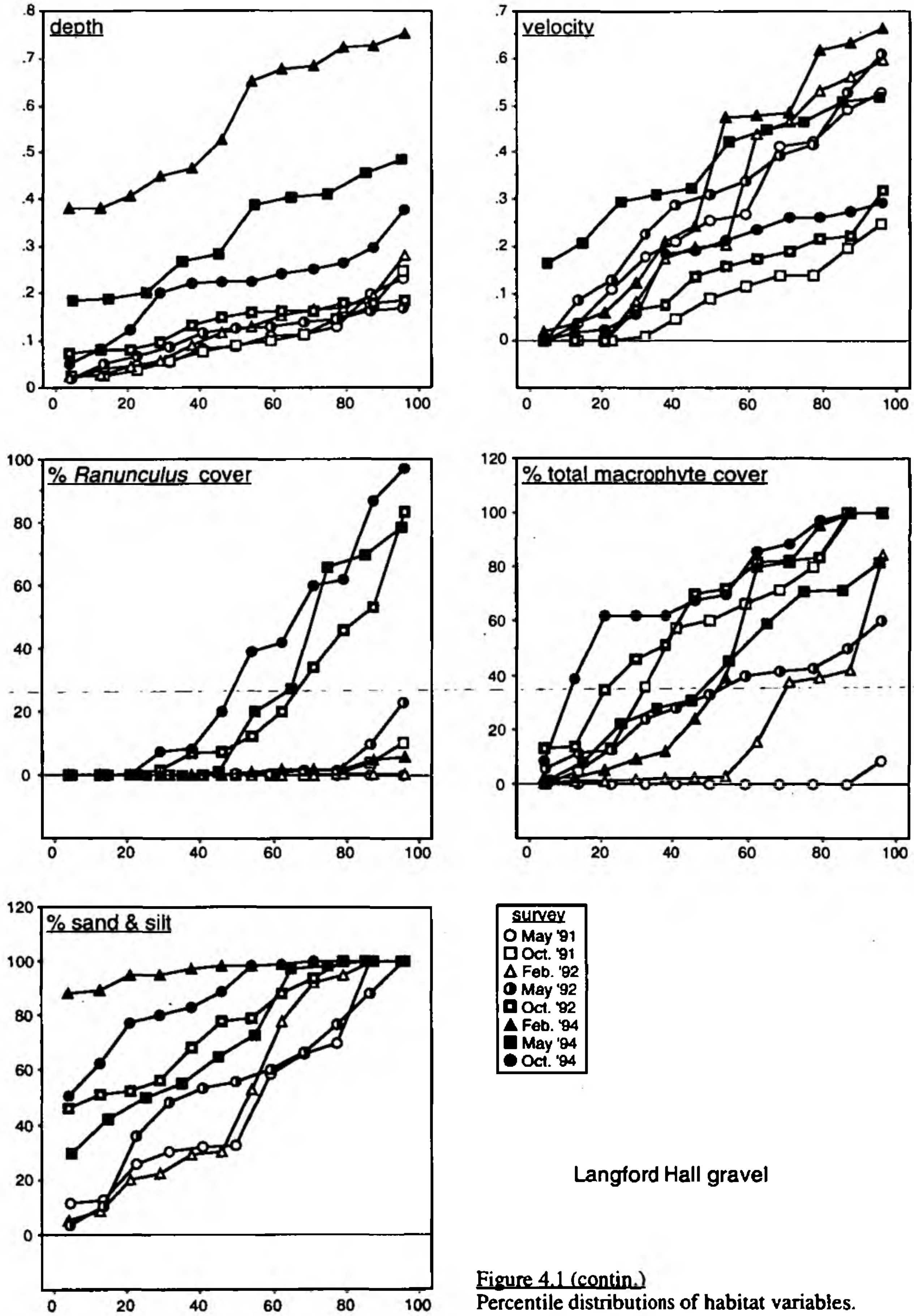


Figure 4.1 (contin.)
Percentile distributions of habitat variables.

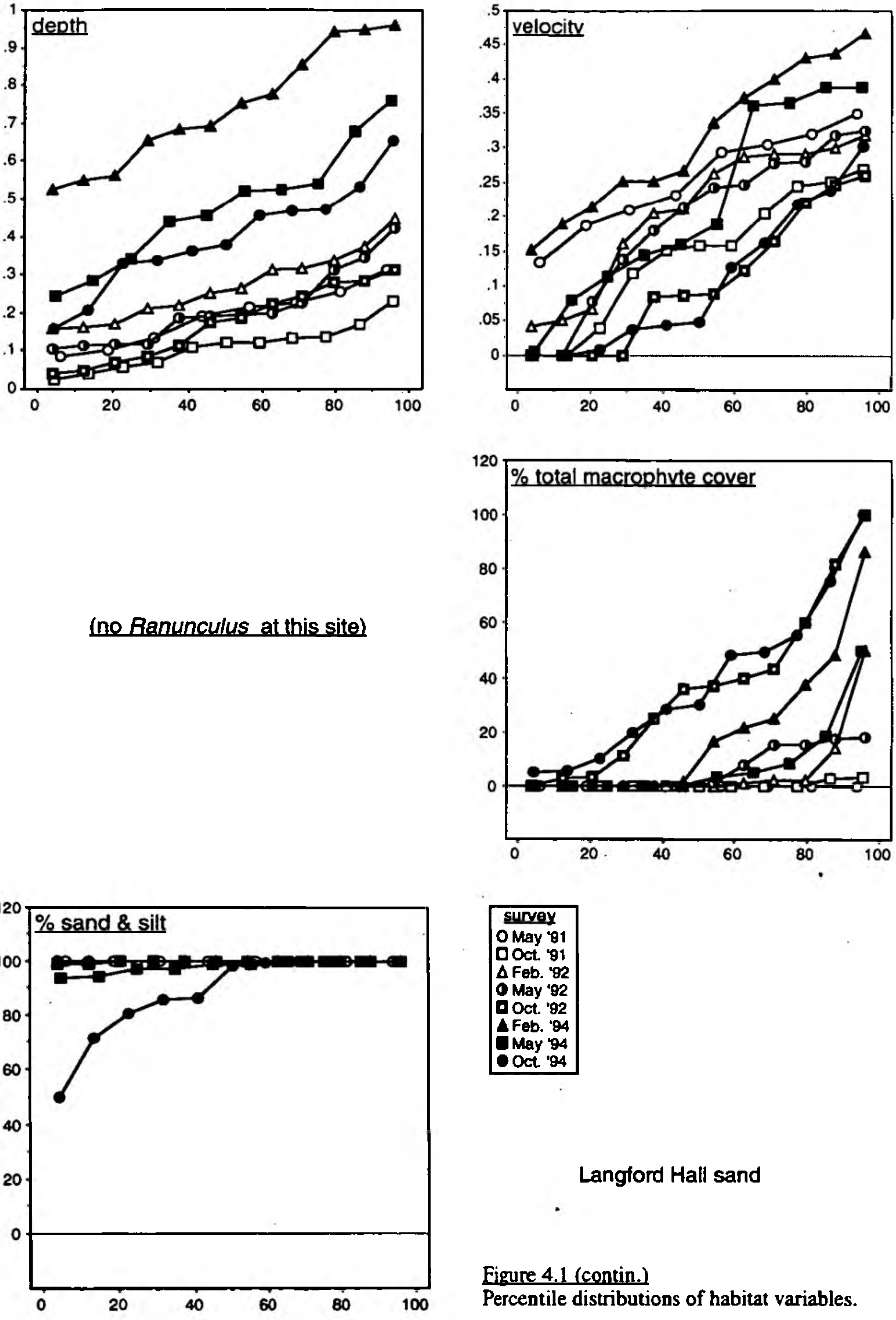


Figure 4.1 (contin.)
Percentile distributions of habitat variables.

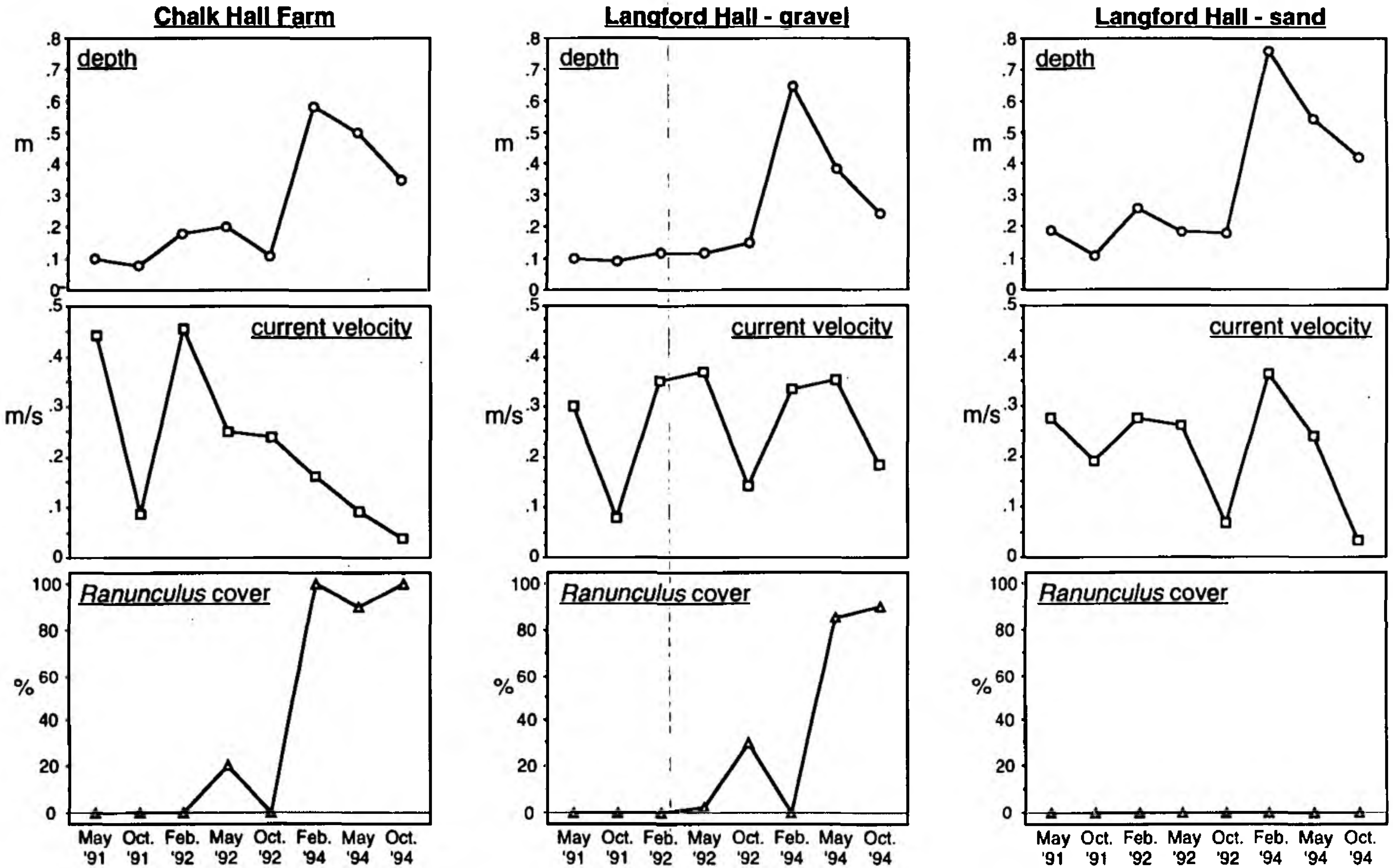


Figure 4.2 Changes in water depth (50th%iles), current velocity (50th %iles) and Ranunculus cover (75th%iles) at three sites over eight surveys.

Percentage cover of fine substrate (sand and silt) appears to increase in 1994 - this is mainly a function of the increased wetted width resulting in a greater area of vegetated margin being included in the surveyed transects. An exceptional case is Langford Hall gravel site in February 1994 where large amounts of sand completely covered the bed which was previously dominated by fine gravels. This appeared to be deposited over the gravel rather than a result of gravel being washed out. Conversely, Langford Hall sand site showed significant amounts of gravel forming a thin veneer over the sand substratum in late 1994 for the first time, where previously the substrate was almost 100% sand.

4.1.2 Hydraulic habitat and flow.

Flows experienced during the surveys varied from very low to very high in comparison with the long-term average. Figure 4.3 indicates the magnitude of the flows recorded at the time of each survey in relation to the range of mean daily flows for each month calculated from 1962-1995 data.

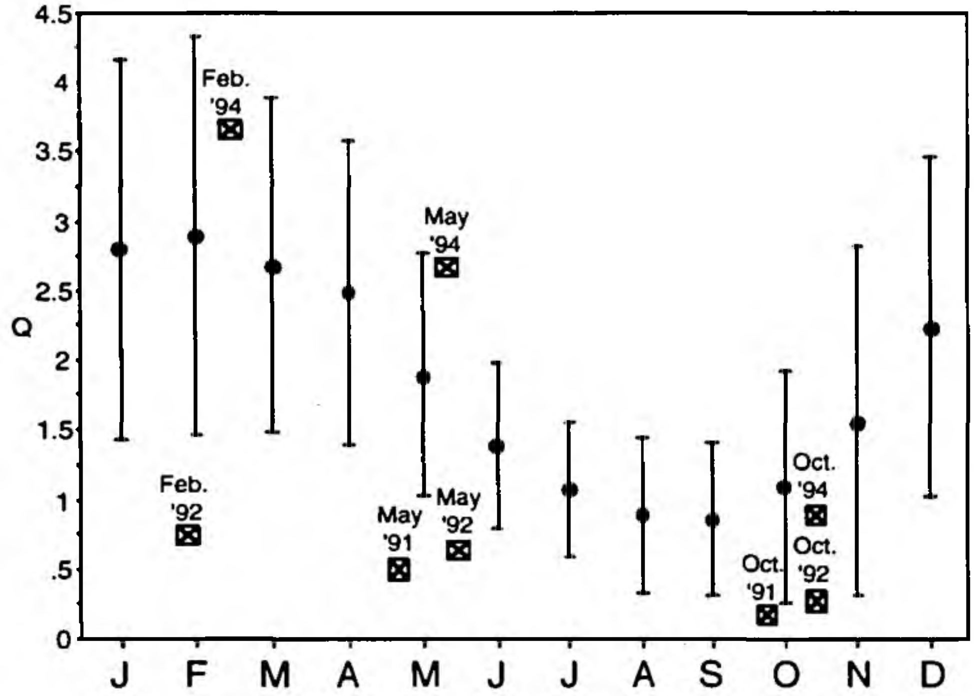
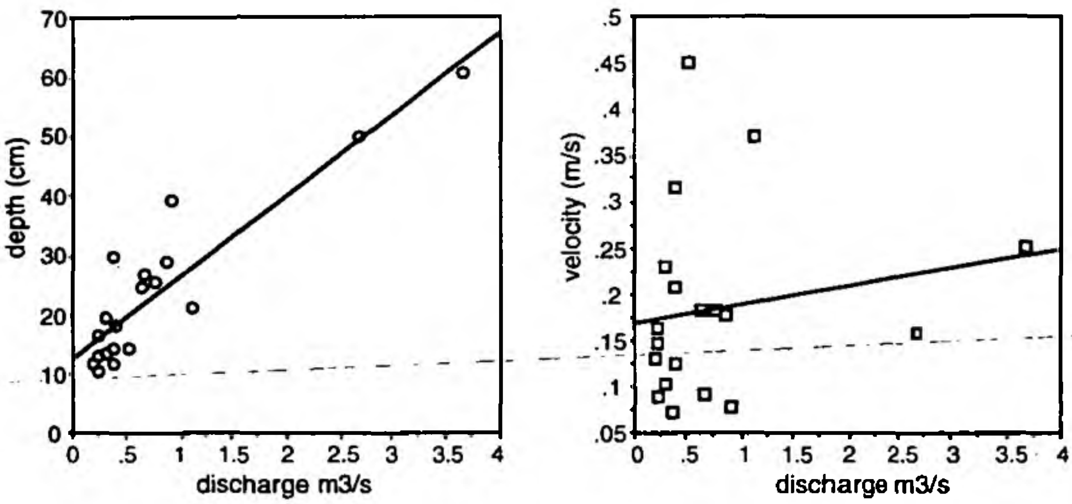


Figure 4.3 Mean and standard deviations of daily flows recorded at Northwold for each month, 1962-1995, with flows experienced during the 1991-1994 macroinvertebrate surveys superimposed.

In attempts to model the relationships between habitat variables and flow, simple relationships between transect depth, velocity and flow were not achievable because of the dominant influence of macrophytes, which in the 1994 surveys caused significant ponding. By including macrophyte cover in depth/velocity/flow multiple regression equations, acceptable relationships were established (see Figure 4.4), which allowed changes in transect mean depth and velocity at different flows to be predicted. These are used in Section 4.7 where macroinvertebrate / habitat relationships are linked to flow. The regression equations for each site linking habitat variables and flow are given in Appendix 2, and predicted cell depths and velocities for a range of flows tabulated in Appendix 3.



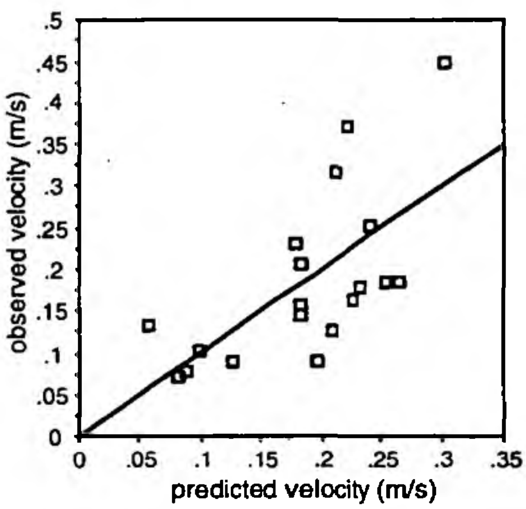


Figure 4.4 relationships between depth, velocity and discharge as measured at Northwold GS, using data from lower transect at Chalk Hall Farm, 1991,1992 and 1994 surveys. Above left: depth v. discharge; above right: velocity v. discharge - poor relationship due to the ponding effects of macrophytes in some surveys; right: fit between predicted and observed velocities where velocity is related to both discharge and total macrophyte cover using multiple regression.

4.2 Macroinvertebrate abundance, taxa richness and diversity.

A total of around 280,000 individuals were collected from the seven main sites over the eight surveys; 120 taxa were recorded. Of these, around 146,000 individuals were collected from the three sites: Chalk Hall Farm, Langford Hall gravel and Langford Hall sand, which supported 116 of the 120 taxa. The individual cell abundances of all taxa collected in the 1991 and 1992 surveys were given in Part 1 of the Main Report, Annex D. Data from the 1994 surveys are given in Appendix 4 of this report. For all surveys (1991-'94), overall site values for abundance, numbers of taxa, and Shannon-Weiner diversity index (average of individual cell values for each site and survey) are tabulated in Appendix 5, and the average cell abundances of all taxa and average values of the habitat variables in Appendix 6.

Considerable variability was noted in the numbers of taxa and individual animals recorded between sites, seasons and years. Figure 4.5 illustrates the overall totals of numbers of taxa and abundances recorded at the three main sites.

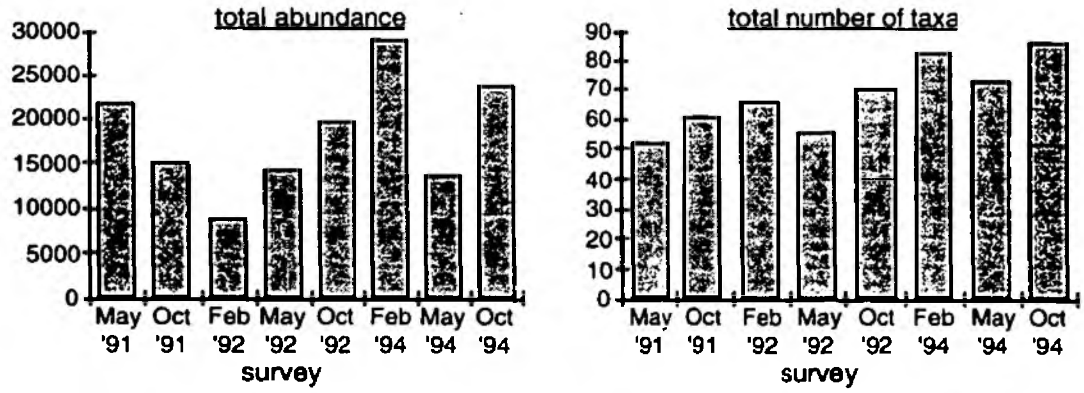


Figure 4.5 Total numbers of individuals and taxa collected from three River Wissey sites (Chalk Hall Farm, Langford Hall gravel site, Langford Hall sand site) over eight surveys.

With the exception of abundance in May, both abundance and numbers of taxa within each season were slightly higher in 1992 than 1991, and substantially higher in 1994. This appears to correlate flows experienced in the three years.

It appears that seasonal patterns are interrelated with year-on-year differences. The correlation between total abundance, number of taxa and diversity with flow, is also illustrated in Figure 4.6. At all sites the overall numbers of taxa and individuals are generally higher in 1994 than in 1991/1992. This is most distinct in February. In the low flow years, February appears to be a poor month particularly in terms of total abundance, whereas in 1994 (high flow) this month showed most individuals.

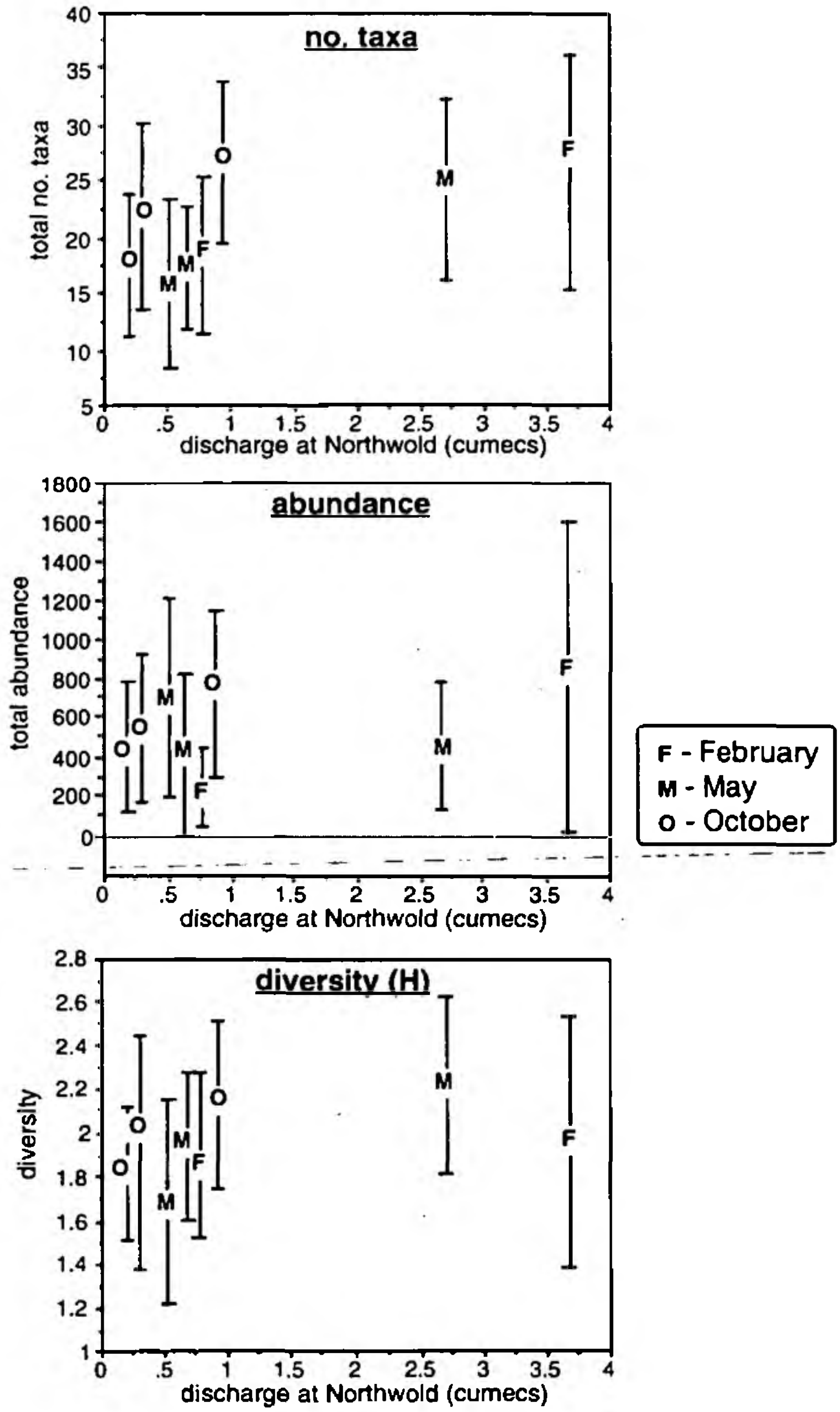


Figure 4.6 Changes in numbers of taxa, abundance and diversity with discharge, using pooled data from Chalk Hall Farm, Langford Hall gravel and sand sites, over eight surveys.

The observed seasonal and year-on-year pattern is possibly related to the importance of marginal, emergent weed beds as macroinvertebrate habitat - in the low flow years this habitat type was most available later in the year as emergent weeds encroached on the channel; in the high flow year, February flows over-topped the banks providing large areas of wetted bank which were well colonised with macroinvertebrates. It therefore appears that the fauna rapidly exploit newly-available habitat. However, if this explanation were the only one, the marginal cells would display this pattern more clearly than the centre channel cells, which was not found to be the case: Figure 4.7 illustrates in more detail the site averages of total abundance and number of taxa, and distinguishes between centre channel and marginal cells. The marginal cells do not appear to show significantly greater between-year differences in abundance / number of taxa than the mid-channel cells.

Chalk Hall Farm and Langford Hall gravel site - the gravel and *Ranunculus*-dominated sites - show greater numbers of both individual animals and numbers of taxa than Langford Hall sand site which is sand-dominated. The centre channel cells support more taxa and individuals than the marginal cells at Chalk Hall Farm and Langford Hall gravel site, whereas at Langford Hall sand site marginal cells support highest numbers of animals. This suggests that gravel/*Ranunculus* habitat is most important for macroinvertebrate diversity and abundance, followed by emergent vegetation in silted margins, and lastly (poorest) bare sand.

4.3 Macroinvertebrate community relationships with habitat characteristics.

Investigation of the qualitative relationships between macroinvertebrate community type and measured habitat variables was undertaken using correspondence analysis - a multivariate statistical technique which leads to an arrangement of sample communities in an ordination diagram, where samples with similar faunal characteristics are plotted closely together, while dissimilar samples are plotted further apart. Relationships between sample communities from different sites, seasons and surveys can be interpreted from these plots and, by correlating ordination axis scores with the habitat variables, the links between community type and the in-stream environment can be inferred.

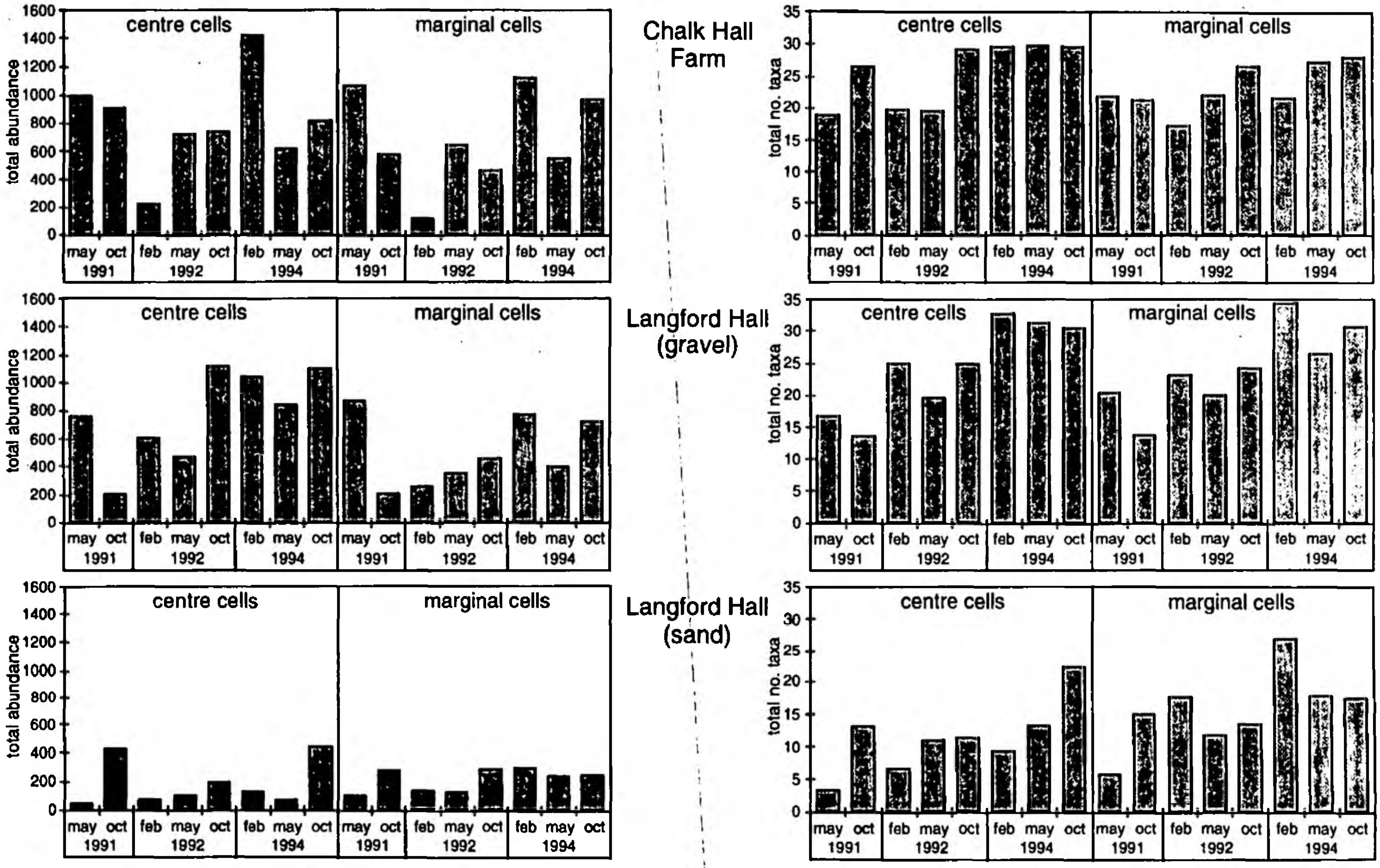


Figure 4.7 Macroinvertebrate abundance and numbers of taxa recorded at three sites over eight surveys on the River Wissey. Centre channel and marginal cells are differentiated.

4.3.1 Community comparisons between sites by survey.

For each of the eight surveys, the relationships were investigated between macroinvertebrate communities and the measured variables using data from all sites, ie seven sites for the 1991/1992 surveys and three sites for the 1994 surveys. Figure 4.8 displays ordination plots of the data by season, with cell points from different sites highlighted by symbols. Arrows indicate the direction of correlation between habitat variables and ordination axes.

Between-site differences were most apparent in May, and least so in February. This is illustrated by the greater separation of points in the ordination plots from these seasons (axes are scaled the same in all plots to allow comparison). In each season the primary separation of site types was between the deep, sandy-bottomed Langford Hall sand and Didlington sand sites and the other shallower, gravel-bed sites. Secondary distinctions between the sites of the latter group were most clearly related to macrophyte cover, with seasonal and annual differences related to between-site variations in *Ranunculus* growth. Thus, for instance, in May 1991 the Northwold site has a distinct fauna related to the fact that only at this site was there substantial weed growth, whereas in May 1992 Northwold, Chalk Hall Farm and Didlington gravel site all supported similar, reduced, macrophyte cover and possessed more uniform macroinvertebrate communities.

4.3.2 Community comparisons between surveys by site.

Ordination analyses were performed on the data from each of the three sites sampled over eight surveys (Chalk Hall Farm, Langford Hall gravel and sand sites). In the plots from these ordinations (Figure 4.9), sample points from each survey are highlighted. These results showed that:

- seasonal and annual variability is greater than within-site variability, ie. groups of samples from each survey are more clearly separated than were those from each site.

- seasonal variability in community composition is correlated with *Ranunculus* development at Chalk Hall Farm and Langford Hall gravel site (this macrophyte is absent at Langford Hall sand site); and also with velocity at Langford Hall gravel and Langford Hall sand sites (but not Chalk Hall Farm where high velocities are maintained late in the season - the former two sites tend to become ponded).

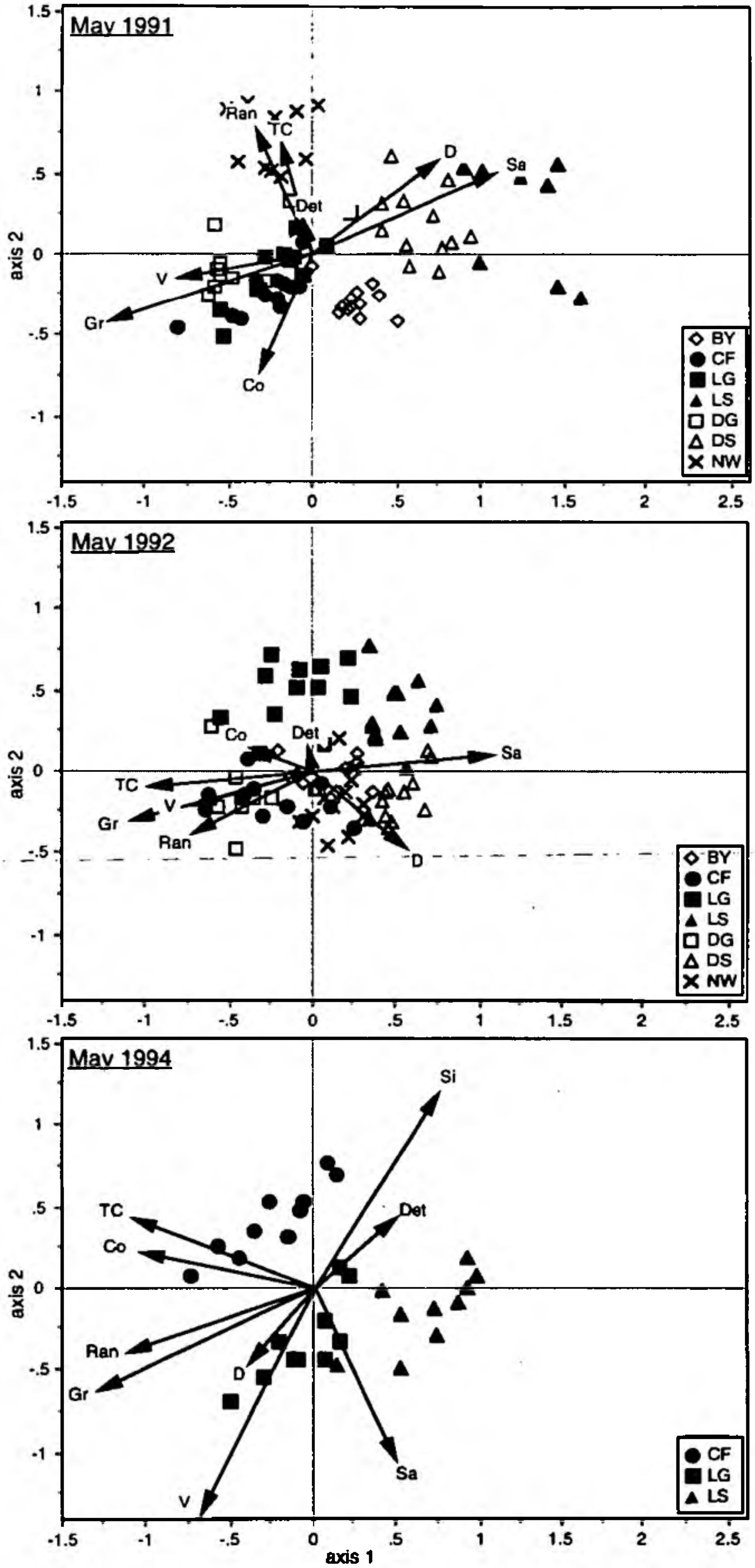


Figure 4.8 Detrended correspondence analyses of sample (cell) data: May. Closeness of points (representing cells) indicate similarity of macroinvertebrate community. Arrows indicate strength (by length) and direction of correlation with ordination axes and hence sample communities. Variable codes: D=mean depth, V=mean velocity, Co=%cobble, Gr=%gravel, Sa=%sand, Si=%silt, Ran=%*Ranunculus*, Det=%detritus, TC=%total macrophyte cover.

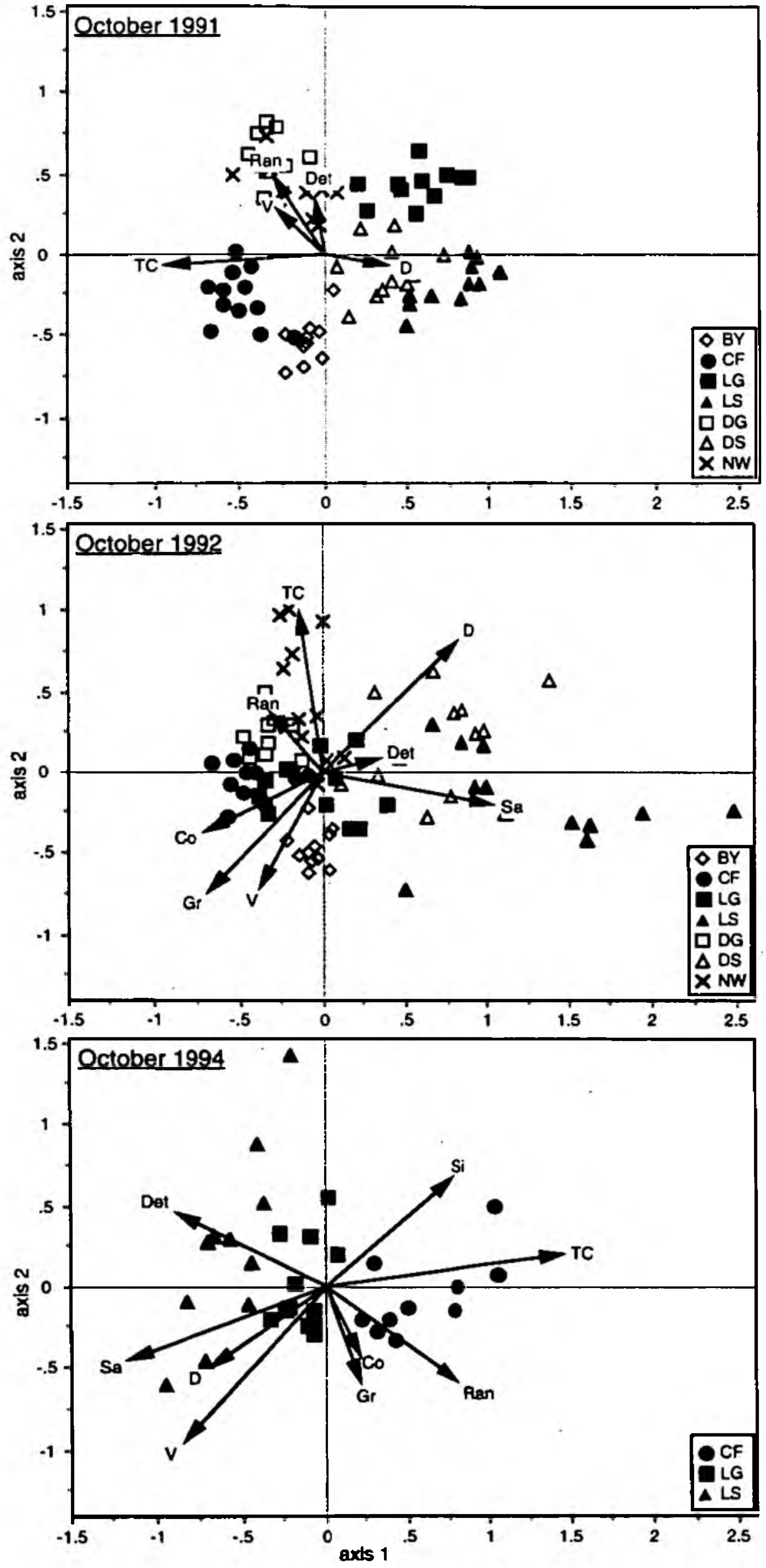


Figure 4.8 (contin.). Detrended correspondence analyses of sample (cell) data: October. Closeness of points (representing cells) indicate similarity of macroinvertebrate community. Arrows indicate strength (by length) and direction of correlation with ordination axes and hence sample communities. Variables: D=mean depth, V=mean velocity, Co=%cobble, Gr=%gravel, Sa=%sand, Si=%silt, Ran=%*Ranunculus*, Det=%detritus, TC=%total macrophyte cover.

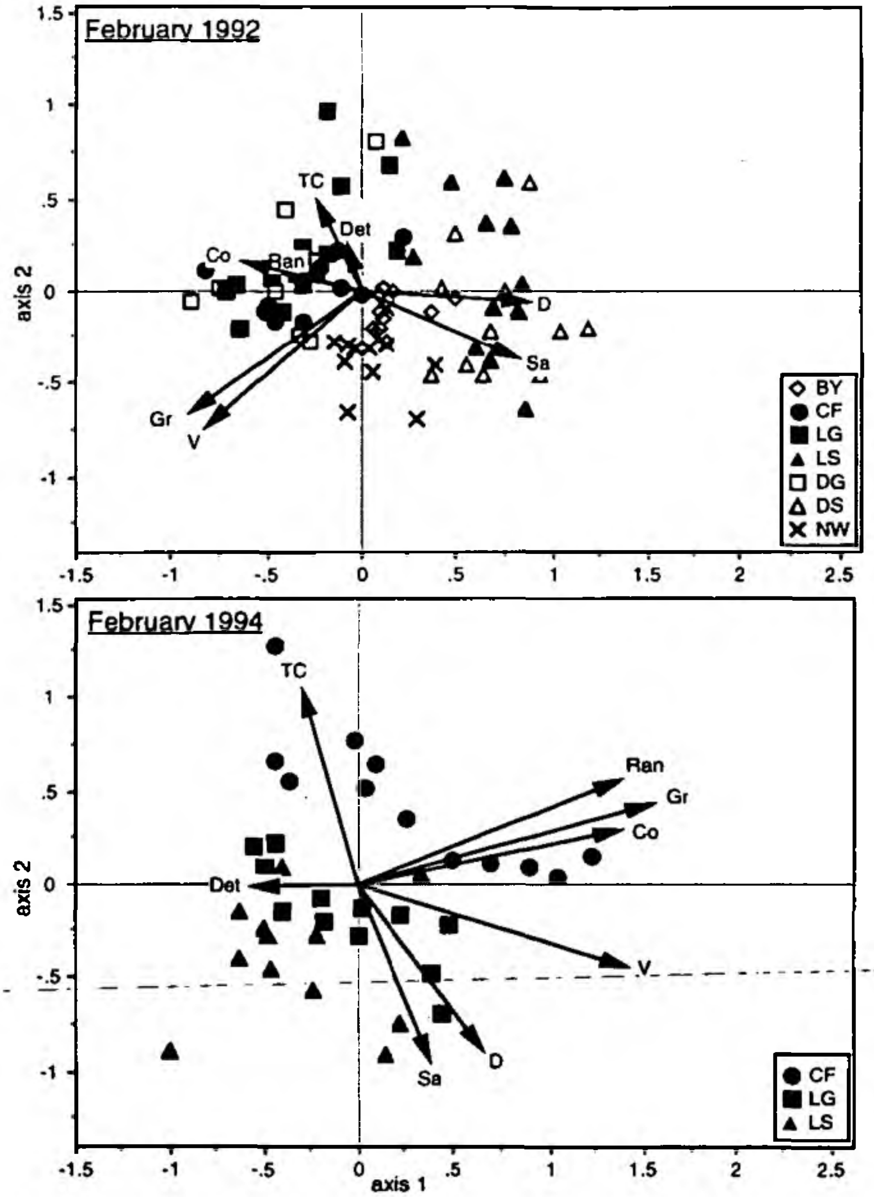


Figure 4.8 (contin.). Detrended correspondence analyses of sample (cell) data: February. Closeness of points (representing cells) indicate similarity of macroinvertebrate community. Arrows indicate strength (by length) and direction of correlation with ordination axes and hence sample communities. Variables: D=mean depth, V=mean velocity, Co=%cobble, Gr=%gravel, Sa=%sand, Si=%silt, Ran=%*Ranunculus*, Det=%detritus, TC=%total macrophyte cover.

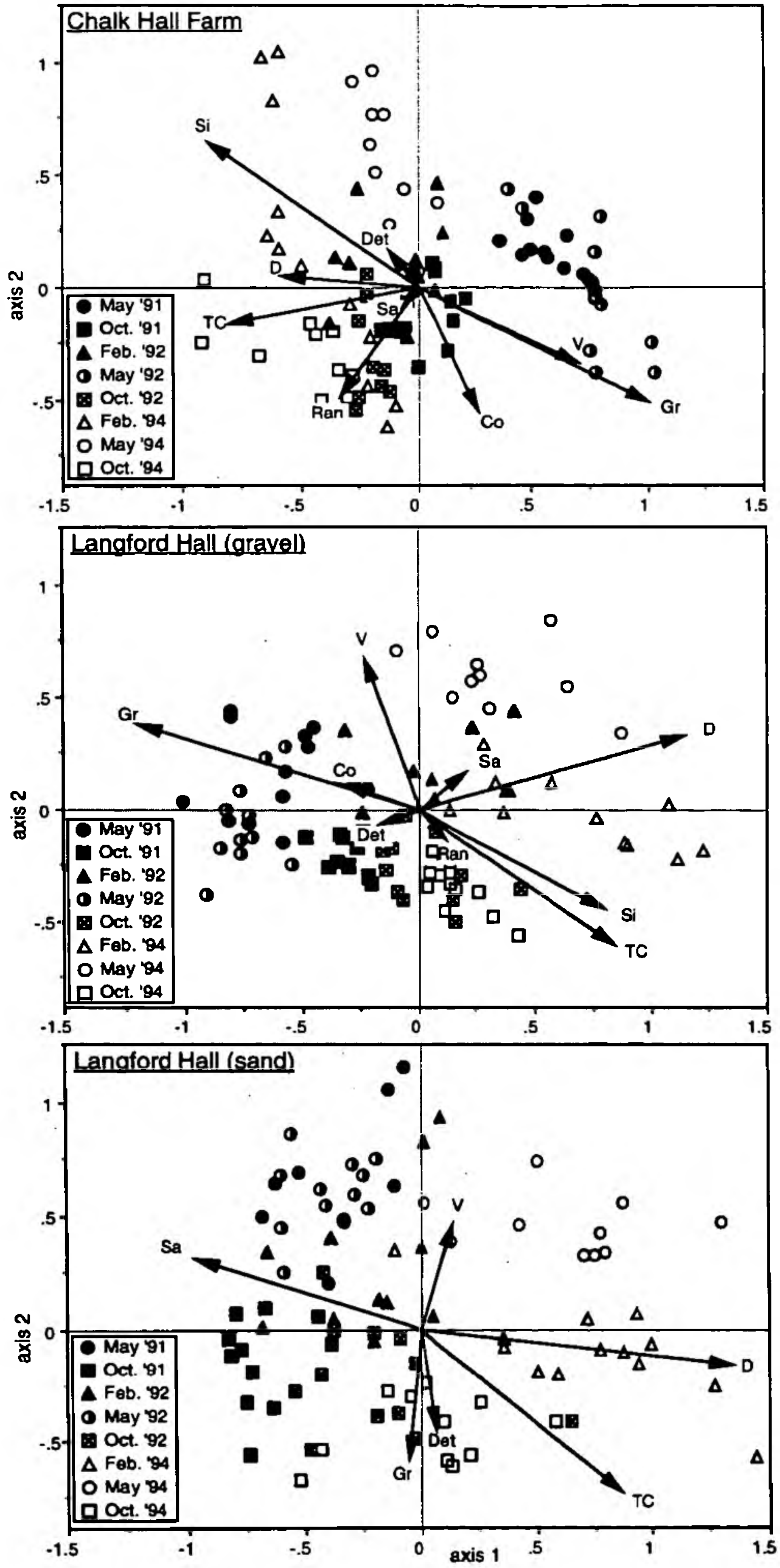


Figure 4.9 Detrended correspondence analyses of cell data from three sites surveyed over 3 years. Codes to variables are as in Figure 4.8.

- between-year variability in community composition is related at each site to depth and total cover, reflecting the increased depths in 1994 and increased wetted margins supporting rich emergent vegetation growth.

- within-survey variability is related more evenly to all the variables, illustrating the variety of cell conditions at each survey. Directional variability is only noticeable at Chalk Hall Farm where the cells show a range of conditions from high velocity/low silt to low velocity/high silt.

The conclusions regarding the relative importance of the habitat variables are: i) <u>seasonally</u> *Ranunculus* growth and to some extent depth and velocity are important; ii) <u>year-on-year</u> total cover (both instream and marginal growth), depth and velocity are important; and iii) <u>spatially</u> at any one survey, velocity, depth, siltation and total cover are controlling factors. Note that siltation and total cover are highly autocorrelated due to a) accumulation of fines around instream macrophyte beds and b) colonisation by weeds of silted margins. For this reason silt was removed as a variable in some of the analyses.

As a result of the above analyses, depth, velocity and total cover were chosen for inclusion in the following investigations of the relationships between individual taxa and habitat variables.

4.4 Relationships between individual macroinvertebrate taxa and habitat.

Having established the important habitat variables in controlling macroinvertebrate community composition using multivariate methods, the relationships between individual taxa and these variables were investigated. The aim of the analyses in this Section was to determine whether:

- significant relationships existed between the distributions of individual taxa and habitat variables (especially the flow-dependent variables - depth and current velocity);
- taxa are related to habitat variables more strongly in some seasons than others;
- taxa are related to habitat variables more strongly in some years than others;
- year-on-year changes in taxa abundances are related to changes in the habitat variables;
- relationships between taxa abundance and habitat variables can be used to predict abundance within and between seasons and years;
- species level or family level identification is necessary to establish significant relationships.

In order to answer the above questions, a series of regression analyses were performed relating taxon abundances to the habitat variables. 501 sets of cell data were available: approximately 84 per survey for the years 1991/1992, and 36 for 1994 (ie seven and three sites respectively, with 12 cells per site). Regression analyses compared ln-transformed abundances (after adding 1 to all counts) with the three variables (depth, velocity, macrophyte cover) using the multiple polynomial regression method, as described in Section 2.

The later parts of this Section deal with the selection of "indicator taxa", ie. those with strong, predictable habitat preferences, and the presentation of habitat preference information for these indicator species.

4.4.1 Seasonal relationships.

The ability of macroinvertebrate taxa to differentiate between habitat type at different seasons was tested by a) describing the relationship of each taxon with each of three variables: depth, velocity, total macrophyte cover, using multiple polynomial regression, and b) using these derived relationships to back-predict the expected abundance of taxa in the sampled cells, and testing the significance of the fit between predicted and observed abundances (in this case using simple linear regression).

Data from 1992 only was used in this analysis as this was considered most suitable for the following reasons: i) data from seven sites were available (whereas only 3 in 1994), and ii) minor surveying and taxonomic problems in the 1991 survey were eliminated.

Both family level and species level data were tested by summing the abundances of species from each family before data transformation. Where only one species was recorded from a family this species was used alone. All taxa (species and families) recorded in at least 20% of samples in at least one season were included in the analysis.

Table 4.1 presents a summary of the results in the form of significances of fit between a) the taxa and the three variables; and b) the predicted abundances generated from these relationships and observed abundances, for each season. It is apparent that:

- The distribution of most taxa can be at least partly explained by the 3 variables in one or more seasons;

- The selected habitat variables best explain the distribution of most taxa in May and October;

- As might be expected from the previous observation, whilst the three variables are able to predict the distribution of taxa abundances within all three seasons on which the models for the predictions are based (ie February predictions based on February data; October predictions based on October data), these predictions are most successful again for May and October;

- Predictions between-season are relatively poor (ie predictions of the distribution of a taxon in one season using predictions based on the relationship measured in another season); indeed negative relationships are seen for some taxa between predicted and observed abundances. This might be explained by taxa which actively prefer different conditions in different seasons - ie preferring high flow velocities in some seasons while avoiding them in others, as a consequence in life cycle characteristics.

- Family level data show almost as good a fit to the habitat data as do species data in those cases where a family is dominated by one common species (the importance of taxonomic level is discussed further later in this Section).

Table 4.1 Regressions of cell abundances on cell depth, velocity and macrophyte cover characteristics within and between seasons, using 1992 survey data. A: Significance of fits of regressions using data from each season. B, C and D: Significance of fits of regressions between predicted and observed abundances, using predictions based on February, May and October data respectively and observed abundances from each season. ns = not significant; * = significant with probability of the null hypothesis being correct (no relationship) of less than 10%, ** less than 1%. *** less than 0.1%.

	A			B - Feb.			C - May			D - Oct.		
	Feb	May	Oct	Feb	May	Oct	Feb	May	Oct	Feb	May	Oct
Planariidae	ns	**	***	**	ns	***	ns	***	*	ns	ns	***
Ancylus fluviatilis	***	**	ns	***	*	ns	ns	***	ns	ns	*	*
Ancylidae	***	**	ns	***	*	ns	ns	***	ns	ns	*	*
Potamopyrgus jenkinsi	**	ns	ns	***	ns	*	ns	**	ns	***	ns	**
Hydrobiidae	*	ns	ns	***	ns	*	ns	**	ns	*	ns	**
Physa fontinalis	*	ns	*	***	ns	**	ns	*	*	ns	ns	***
Planorbis vortex	ns	ns	*	*	ns	ns	ns	*	**	ns	ns	***
Planorbiidae	ns	ns	*	*	ns	ns	ns	**	ns	ns	ns	***
Sphaeriidae	ns	*	***	*	ns	ns	ns	***	*	ns	ns	***
Oligochaeta	**	***	***	***	ns	***	ns	***	**	*	ns	***
Piscicola geometra	ns	ns	ns	**	*	ns	*	*	ns	ns	ns	**
Thermozyon tessulatum	ns	ns	ns	ns	ns	*	ns	**	ns	ns	ns	**
Glossiphonia complanata	ns	ns	*	*	ns	*	ns	**	*	ns	**	***
Helobdella stagnalis	ns	ns	**	**	ns	ns	ns	*	*	ns	ns	***
Glossiphonidae	ns	ns	**	*	ns	**	ns	**	ns	*	ns	***
Erpobdella octoculata	**	***	**	***	***	**	**	***	ns	**	***	***
Asellus aquaticus	*	***	***	***	***	**	**	***	*	*	**	***
Asellidae	*	***	***	***	***	**	**	***	*	*	**	***
Gammaridae	*	***	***	***	***	***	**	***	ns	**	***	***
Baetis sp.	**	**	**	***	ns	ns	*	***	ns	ns	***	***
Baetidae	**	**	**	***	ns	ns	ns	***	ns	ns	***	***
Ephemerella ignita	ns	***	ns	*	ns	ns	ns	***	ns	ns	**	**
Ephemera danica	***	***	***	***	***	***	***	***	***	***	***	***
Ephemeridae	***	***	***	***	***	***	***	***	***	***	***	***
Caenis sp.	ns	*	ns	*	ns	ns	ns	***	ns	ns	ns	ns
Caenidae	ns	*	ns	*	ns	ns	ns	***	ns	ns	ns	ns
Zygoptera	*	ns	***	***	ns	***	ns	*	*	ns	ns	***
Corixidae	***	ns	**	***	ns	ns	ns	*	ns	*	ns	***
Haliplidae l.	ns	***	ns	*	-	ns	-	-	-	ns	-	ns
Haliplidae	ns	ns	ns	*	ns	ns	ns	*	ns	ns	ns	ns
Dytiscidae	ns	ns	ns	**	ns	ns	ns	*	ns	ns	ns	*
Gyrinidae lv.	*	ns	ns	***	*	ns	**	**	ns	ns	ns	*
Elmis aenea l.	ns	***	***	*	**	***	ns	***	***	ns	***	***
Elmis aenea a.	ns	***	***	*	*	***	ns	***	ns	ns	***	***
Limnius volkmari lv.	**	***	***	***	***	ns	***	***	*	ns	*	***
Limnius volkmari ad.	ns	*	***	ns	ns	**	ns	***	ns	ns	*	***
Oulimnius sp. lv.	*	ns	***	***	ns	***	*	**	ns	ns	ns	***
Elmidae	**	***	***	***	***	***	***	***	***	ns	***	***
Sialis lutaria	**	**	*	***	***	ns	***	***	*	ns	**	***
Polycentropus flavomaculatus	ns	**	***	*	**	***	ns	***	***	ns	***	***
Polycentropodidae	ns	**	***	*	**	***	ns	***	***	ns	***	***
Hydropsyche pellucidula	***	ns	***	***	ns	ns	*	*	ns	ns	ns	***
Hydropsyche siltalai	*	***	ns	***	***	*	**	***	ns	ns	ns	**
Hydropsychidae	***	***	***	***	***	ns	***	***	ns	ns	***	***

Table 4.1 (continued)

	A			B - Feb.			C - Mar			D - Oct.		
	Feb	May	Oct	Feb	May	Oct	Feb	May	Oct	Feb	May	Oct
Limnephilus lunatus	***	**	ns	***	**	ns	***	***	ns	**	*	*
Halesus radiatus	ns	***	-	*	-	-	-	-	-	-	-	-
Limnephilidae	**	**	ns	***	***	ns	***	***	ns	**	*	*
Athripsodes cinereus	*	*	***	***	ns	***	*	***	ns	***	ns	***
Athripsodes bilineatus	ns	***	*	*	***	**	*	***	***	*	***	***
Mystacides azurea	*	ns	ns	***	ns	ns	ns	*	ns	ns	ns	**
Leptoceridae	*	**	**	***	*	**	**	***	**	***	***	***
Goera pilosa	***	ns	*	***	*	***	***	**	***	***	*	***
Goeridae	***	ns	*	***	*	***	***	**	***	***	*	***
Lepidostoma hirtum	-	*	ns	ns	-	-	-	***	ns	-	ns	**
Sericostoma personatum	*	*	ns	***	*	ns	ns	***	ns	ns	ns	*
Tipulidae	ns	ns	***	**	ns	**	ns	*	**	ns	ns	***
Chironomidae	ns	ns	***	*	ns	*	ns	*	ns	ns	ns	***
Simuliidae	***	**	***	***	ns	***	ns	***	ns	ns	*	***

4.4.2 Year-on-year changes.

A primary aim of the study was to understand and predict the changes in macroinvertebrate communities observed year-on-year in relation to flow through habitat variables. This is at least as important in the context of flow management as understanding spatial distributions within-year, although more difficult to determine as data from several years are required. This study provided information from 3 years of contrasting flows.

For the October sample set (the period of lowest flows), data files were constructed of the between-year changes in cell characteristics - mean depth, velocity and total macrophyte cover; and changes in macroinvertebrate abundances, using data from the two gravel sites surveyed in all years (Chalk Hall Farm and Langford Hall gravel site), and taxa present in at least 20% of all samples. Pairs of changes were generated by subtracting values from one year from another: '92-'91, '94-'91 and '94-'92.

Responses of macroinvertebrates to changes in the variables were tested by multiple linear regression of change in (ln+1 transformed) abundance on the three variables. Table 4.2 gives the results in the form of the significances of fit of the taxa abundance changes to the three variables, and indicates the direction of change to which these are related for each variable, positive (increase) or negative (decrease).

It is apparent that most taxa are responding to year-on-year changes in at least one variable; the majority respond positively to increase in depth and velocity - this accords with the general increase in abundance and diversity observed in the higher flow year of 1994.

Table 4.2 Summary of regressions of between-year changes in cell abundances on between-year changes in depth, velocity and macrophyte cover. sig.: significance of multiple regression; depth, velocity, macrophytes: direction of relationships between abundances and the three variables where these are indicated as significant elements of the multiple regressions. ns = not significant; * = significant with probability of the null hypothesis being correct (no relationship) of less than 10%, ** less than 1%, *** less than 0.1%.

	sig.	depth	velocity	macrophytes
Planariidae	***	ns	+	ns
Bithynia leachi	**	ns	-	ns
Hydrobiidae	*	+	-	-
Physa fontinalis	**	ns	+	ns
Planorbis contortus	*	ns	ns	+
Planorbis vortex	*	ns	ns	ns
Glossiphonia complanata	*	+	-	ns
Helobdella stagnalis	**	-	ns	-
Gammaridae	***	+	ns	-
Baetis sp.	***	+	+	ns
Baetidae	***	+	+	ns
Ephemera danica	***	+	ns	-
Ephemeridae	***	+	ns	-
Caenis sp.	*	-	+	ns
Caenidae	*	-	+	ns
Leutra sp.	*	ns	+	ns
Haliplidae l.	*	ns	ns	ns
Haliplidae	*	ns	ns	ns
Elmis aenea l.	**	ns	+	ns
Elmis aenea a.	***	-	+	-
Limnius volkmari lv.	***	+	ns	-
Limnius volkmari ad.	**	ns	+	ns
Oulimnius sp. lv.	*	ns	+	ns
Oulimnius sp. ad.	***	-	ns	-
Elmidae	**	ns	ns	-
Sialis lutaria	*	+	-	ns
Hydropsyche pellucidula	***	+	+	ns
Hydropsyche angustipennis	ns	ns	ns	ns
Hydropsyche siltalai	***	ns	+	+
Hydropsychidae	***	+	+	ns
Athripsodes cinereus	***	ns	+	+
Leptoceridae	**	ns	+	+
Goera pilosa	**	+	+	ns
Goeridae	**	+	ns	ns
Sericostoma personatum	**	+	+	ns
Tipulidae	***	ns	ns	-
Simuliidae	***	+	+	ns

4.4.3 Prediction of year-on-year change from spatial distribution data.

Section 4.4.1 showed how macroinvertebrate spatial (within-survey) distributions can be described by habitat variables (but not successfully between seasons); section 4.4.2 shows that invertebrates also respond to annual changes in these factors. The ability of a model based on one season to predict the distribution of taxa in the same season but between years was also tested. Functions describing the preference of taxa for particular variables may be transferable between years only if the taxa are behaving with "fixed" preferences; alternatively taxa may distribute in a more plastic fashion in relation to available habitat, in which case preference functions will not be transferable where available habitat is variable year-on-year.

Multiple regression was used to explain macroinvertebrate abundances from October samples from 1991, 1992 and 1994 using depth, velocity and macrophyte cover data. Data from the three sites sampled in all years were used, and taxa occuring in at least 20% of the sample set included. Predictions of abundance were made for each year using data from the same and each other year, and tested against observed abundances. Table 4.3 shows the significance of fit of linear regressions of observed against predicted abundances.

Predictions between-year were only acceptable for a few taxa - notably the Elmid beetles. Predictions based on the October 1994 data were most successful when applied to other years - either because of the greater abundances in 1994 allowed a better significance of fit despite large variability in the data, or alternatively taxa showed more pronounced habitat partitioning in the low flow years of 1991/92.

Table 4.3 Significance of regressions of observed on predicted cell abundances, comparing predictions based on regressions from each year with observed abundances from the same and other years (October data only).

regression of predicted abundances based on data from:	all yrs	1991		1992		1994	
regressed upon observed abundances from:	all yrs	1991	1992&'94	1992	1991&'94	1994	1991&'92
Planariidae	***	***	*	***	*	**	ns
Dendrocoelidae	***	**	ns	**	ns	*	*
Ancylus fluviatilis	**	**	ns	*	ns	*	ns
Ancylidae	**	**	ns	*	ns	*	ns
Potamopyrgus jenkinsi	***	***	ns	***	*	***	ns
Bithynia leachi	***	*	ns	***	ns	***	*
Hydrobiidae	***	***	ns	***	**	***	ns
Lymnaeidae	*	***	ns	**	*	***	ns
Physa fontinalis	***	***	*	***	*	***	*
Planorbis contortus	***	***	*	***	ns	***	ns
Planorbis vortex	***	***	ns	*	ns	***	ns
Planorbiidae	***	***	*	*	ns	***	ns
Sphaeriidae	***	***	*	**	ns	***	ns
Oligochaeta	***	***	ns	***	ns	**	ns
Piscicola geometra	***	-	-	**	*	**	ns
Thermozyon tessulatum	**	ns	ns	**	ns	***	ns
Glossiphonia complanata	***	***	ns	**	ns	**	**
Helobdella stagnalis	***	*	ns	**	ns	**	ns
Glossiphonidae	***	***	ns	**	ns	**	**
Erpobdella octoculata	***	***	**	***	ns	***	**
Asellus aquaticus	***	***	**	***	***	***	ns
Asellidae	***	***	**	***	***	***	ns
Gammaridae	***	***	ns	***	**	***	ns
Baetis sp.	***	***	ns	***	***	***	*
Baetidae	***	***	ns	***	***	***	*
Ephemera danica	***	***	**	***	*	***	**
Ephemeridae	***	***	**	***	*	***	**
Caenis sp.	***	**	ns	**	*	**	ns
Caenidae	***	**	ns	**	*	**	ns
Leutra sp.	***	-	-	-	-	***	-
Zygoptera	***	*	*	**	***	***	ns
Corixidae	**	*	ns	**	ns	**	ns
Haliplidae l.	**	*	ns	*	ns	ns	ns
Haliplidae	**	*	ns	*	ns	*	ns
Dytiscidae l.	***	*	ns	**	ns	***	ns
Dytiscidae	***	**	ns	*	ns	***	ns
Gyrinidae lv.	**	**	ns	***	ns	**	ns
Elmis aenea l.	***	**	ns	***	**	***	***
Elmis aenea a.	***	**	*	***	*	***	*
Limnius volkmari lv.	***	***	ns	***	ns	***	*
Limnius volkmari ad.	***	*	ns	***	ns	*	*
Oulimnius sp. lv.	**	**	ns	*	ns	**	*
Oulimnius sp. ad.	***	**	*	***	*	*	ns
Elmidae	***	***	ns	***	*	**	**

Table 4.3 (continued).

regression of predicted abundances based on data from:	all yrs	1991		1992		1994	
regressed upon observed abundances from:	all yrs	1991	1992&'94	1992	1991&'94	1994	1991&'92
Sialis lutaria	***	***	*	**	ns	***	ns
Polycentropus flavomaculatus	*	*	**	*	ns	**	ns
Polycentropodidae	*	*	**	*	ns	**	ns
Hydropsyche pellucidula	***	**	ns	***	ns	***	*
Hydropsyche angustipennis	*	*	ns	*	ns	**	ns
Hydropsyche siltalai	***	***	ns	*	**	-	-
Hydropsychidae	***	***	ns	***	*	***	**
Limnephilus rhombicus	***	-	-	-	-	***	-
Limnephilidae	***	*	ns	***	ns	***	ns
Athripsodes cinereus	***	***	*	**	ns	***	**
Mystacides azurea	*	*	ns	**	ns	*	ns
Leptoceridae	***	***	ns	**	ns	***	**
Goera pilosa	***	**	ns	***	ns	**	ns
Silo nigricornis	*	ns	ns	-	-	*	ns
Goeridae	**	**	ns	***	ns	*	ns
Sericostoma personatum	***	*	ns	*	ns	***	ns
Tipulidae	***	***	ns	***	**	***	ns
Chironomidae	***	***	ns	*	ns	*	ns
Simuliidae	***	***	ns	***	**	***	***
Tabanidae	***	*	ns	**	*	***	ns

4.4.4 Taxonomic level.

In the above analyses a combination of taxonomic levels were used: the original level of identification was variable - difficult groups were only identified to genus/family; plus in some analyses taxa were grouped into families to test the level of response to the measured variables (as described earlier). An aim of this study is to define at what taxonomic level predictable responses to habitat variables can be described. The results of the previous sections allow some conclusions to be drawn.

In most instances, families were found to be represented by one very common and abundant species and one or two rare species (eg *Ephemera danica* and *E. vulgata*; *Asellus aquaticus* and *A. meridianus*). In these cases, using family level data made negligible difference to the results. In other instances, two or more co-dominant species share similar habitat preferences, eg the *Hydropsyche* species - in which case combining counts may improve the predictive ability of the results by increasing the number of counts and reducing errors inherent in using rarer taxa. In other instances, however, where two or more relatively abundant species have contrasting habitat preferences, combining counts is not advisable - eg *Potamopyrgus jenkinsi* and *Bithynia sp.* (Hydrobiidae).

4.4.5 Selection of "indicator taxa".

Selection of taxa used in Sections 4.4.1 to 4.4.3 was based mainly on frequency, ie all taxa present above arbitrarily chosen threshold frequencies designed to eliminate those for which statistical analysis was unsuitable. However, the results of the analyses described above allowed selection of a subset of taxa which appear to respond most strongly to the measured habitat variables and can be regarded as good habitat "indicators". These taxa are not necessarily the most selective of habitat conditions, but may be those which are least influenced by other, unmeasured variables, and are relatively common.

In order to select taxa as "indicators" of habitat, the results of sections 4.4.1 to 4.4.3 were collated. Table 4.4 brings together criteria considered most important in identifying indicator taxa. These criteria are indicated in the table by letter codes, which are explained below. Asterisks (*) in the table indicate highly significant fits (p<1%) in the relevant category. For the first four criteria:

A: Highly significant fits between observed abundances and predicted abundances within each of all three seasons (February, May and October), where predictions are based on the data from the same season. (Tests used 1992 data only.)

B: Highly significant fits between observed abundances and predicted abundances in all three years, using October data, where tests compare observed abundances with predictions made from data from the same year.

C: Highly significant fits between year-on-year change in abundance and year-on-year change in habitat variables. (Tests used changes between 1991 & 1992, 1991 & 1994, and 1992 & 1994.)

D: Highly significant fits between predicted abundances from October data from each year and observed abundances in October surveys from other years.

Taxa indicated in bold text fulfilled all four of the above criteria, and were considered the best habitat indicators. These were:

Baetis sp.	Elmidae
Baetidae	Hydropsychidae
Ephemera danica	*Athripsodes cinereus*
Ephemeridae	Simuliidae

Six taxa were chosen for further consideration and are discussed in the later parts of this report: these were the above list but omitting *Baetis* sp., *Ephemera danica* as these could be used as indicators at the family level.

Table 4.4 Criteria for selecting indicator species. See text for explanation of letter codes.

	A	B	C	D	E	F
Planariidae		*	*		*	*
Potamopyrgus jenkinsi		*				*
Bithynia leachi			*			
Hydrobiidae		*				
Lymnaeidae		*				
Physa fontinalis		*	*	*	*	*
Planorbis contortus		*				
Planorbis vortex						*
Planorbiidae					*	*
Sphaeriidae		*				
Oligochaeta	*	*			*	*
Helobdella stagnalis			*			
Glossiphonidae					*	*
Erpobdella octoculata	*	*		*		*
Hydrachnellidae					*	
Asellus aquaticus	*	*		*		*
Asellidae	*	*		*		*
Gammaridae	*	*	*			*
Baetis sp.	*	*	*	*		*
Baetidae	*	*	*	*	*	*
Ephemera danica	*	*	*	*		*
Ephemeridae	*	*	*	*	*	*
Ephemerellidae					*	
Zygoptera				*		*
Dytiscidae						*
Elmis aenea l.		*	*	*		*
Elmis aenea a.		*	*	*		*
Limnius volkmari lv.	*	*	*			*
Limnius volkmari ad.			*			
Oulimnius sp. lv.						*
Oulimnius sp. ad.			*			
Elmidae	*	*	*	*	*	*
Sialis lutaria	*	*				*
Hydropsyche pellucidula		*	*			*
Hydropsyche siltalai			*			
Hydropsychidae	*	*	*	*	*	*
Polycentropodidae					*	
Limnephilidae					*	
Athripsodes cinereus	*	*	*	*		
Leptoceridae	*	*	*		*	
Goera pilosa			*			*
Goeridae			*			*
Sericostoma personatum			*			
Tipulidae		*	*			*
Chironomidae						*
Simuliidae	*	*	*	*	*	*

The final two criteria listed in Table 4.4 were alternative methods of indicator taxa selection suggested for use in the methodology presented in the Manual accompanying this Report. The use of these criteria is discussed further in Section 6.3 of this Report.

Criterion **E** is based on analysis of EA biological monitoring and flow data, which is explained further in Section 4.7. Taxa indicated here were recorded in at least 10% greater frequency in samples from high-flow years than samples from low flow years, or *vice versa*.

Criterion **F** was determined from a multiple polynomial regression of taxon abundance against the habitat variables, similar to the method used in Sections 4.1 and 4.3 above, but here simply combining all October data from all years and all sites. Taxa indicated as fulfilling this criterion showed highly significant relationships ($p<1\%$) between (ln+1) abundance and the three variables. Regression equations linking taxa and the habitat variables are given in Appendix 7.

Using these two criteria alone, five of the six taxa selected using the detailed analysis described above would be chosen (excluding Athripsodes cinereus), plus five other taxa:

Planariidae	Oligochaeta
Physa fontinalis	Glossiphonidae
Planorbiidae	

These are notably all common and abundant taxa, which do not necessarily posess strong habitat preferences but exhibit significant regression relationships due to their frequent non-zero occurrence. This problem is addressed in Section 6.3, where the development of the methodology for the Manual is discussed.

4.5 Habitat preferences of "indicator" taxa.

Having ascertained which taxa show strong relationships with the habitat variables, these relationships can be usefully described in a number of ways which allow the nature of the relationships to be viewed and used to predict the distribution of the taxa under different combinations of the habitat variables. Three methods of presenting the habitat preference information are given below.

4.5.1 Habitat preference functions.

These are the regression equations linking abundance with habitat. For the six "indicator taxa" defined in the previous Section the equations were:

Baetidae:

$(\ln+1)$ abundance = $1.06 + 4.63D - 7.66D^2 + 5.46V - 6.47V^2 + 0.046M - 0.00033M^2$

Ephemeridae:

$(\ln+1)$ abundance = $1.91 + 5.73D - 3.06D^2 + 4.20V - 9.75V^2 - 0.020M + 0.00009M^2$

Elmidae:

$(\ln+1)$ abundance = $2.96 - 7.33D + 5.56D^2 + 12.07V - 19.41V^2 + 0.0071M + 0.00003M^2$

Hydropsychidae:

$(\ln+1)$ abundance = $- 0.51 + 4.27D - 6.48D^2 + 7.88V - 11.66V^2 + 0.0060M + 0.00005M^2$

Athripsodes cinereus:

$(\ln+1)$ abundance = $0.28 - 1.37D + 1.32D^2 + 2.92V - 0.54V^2 + 0.0057M - 0.00002M^2$

Simuliidae:

$(\ln+1)$ abundance = $- 1.76 + 3.80D - 6.52D^2 + 15.13V - 19.86V^2 + 0.031M + 0.000004M^2$

Where D = depth (m), V = current velocity (ms^{-1}) and M = % macrophyte cover. R-squared values for the regressions were: Baetidae = 0.17, Ephemeridae = 0.34, Elmidae = 0.34, Hydropsychidae = 0.19, Athripsodes cinereus = 0.10, Simuliidae = 0.29. These are all relatively small r-squared values, reflecting the high degree of cell-to-cell variability around the overall, highly significant, trends in response to the habitat variables.

4.5.2 Predicted abundance curves.

Habitat preference information can be presented graphically by predicted abundance curves. These are graphs of expected abundance against the values of a habitat variables.

For the River Wissey indicator taxa, predicted abundance is related to three habitat variables, therefore a series of curves are required to express the predicted abundance for every combination of variables. Figure 4.10 displays habitat preference curves for Elmidae, showing predicted (ln+1) abundance against depth at three different velocities (left) and against velocity at three different depths (right). Depth and velocity curves are given for three macrophyte cover scenarios (top, middle and bottom).

4.5.3 Habitat suitability curves.

Habitat suitability curves are a more commonly used method of presenting habitat preference information. In habitat suitability curves, predicted abundance is re-scaled to a percentage suitability value, such that the "optimum" value of the variable gives 100% habitat suitability. Suitability curves have the advantage over predicted abundance curves in that suitability is a <u>relative</u> measure, and therefore transferable between sites; whereas abundance is subject to very localised, site-specific factors.

In order to convert predicted abundance curves to suitability curves, an optimum value must be ascertained. The optimum value is the combination of depth, velocity and macrophyte cover giving maximum predicted abundance. This poses a problem where the preference curves for one or more variables predict maximum abundance at the maximum value of one or more variable - ie the optimum is outside the range of measured variable values and beyond reasonable extrapolation. A possible method of determining the maximum abundance by taking the maximum observed cell abundance, however, this value will be highly dependent on conditions at the time of survey.

The method of determining maximum abundance which was used in this investigation was as follows: 1) An optimum <u>flow</u> was defined as the standard summer low flow (the 1.5 year low flow), which was found from analysis of long-term mean daily flow records (see Section 4.8). 2) The expected depth and velocity combinations at all sites were calculated for flows at and below this value using regression equations relating depth, velocity and flow (see Section 4.1.2). 3) Abundances of the indicator taxa were predicted for each depth and velocity combination, assuming macrophyte cover to be the average of that recorded over the surveys. 4) The maximum abundance predicted at any depth / velocity / macrophyte combination at any site within each sector was found for each taxon. These sector-specific values were then used to re-scale the predicted abundance curves to suitability values. <u>Suitability values were therefore defined as percentages of the maximum expected within the sector, within the normal range of end-of-summer low flows.</u>

Suitability curves for Elmidae in Sector 3 of the River Wissey are shown in Figure 4.11. Curves for other indicator taxa are given in Appendix 8.

Note that in calculating suitability, predicted (ln+1) abundances were first back-transformed to actual abundances before dividing by the predicted sector maximum abundance and multiplying by 100 to give percentage suitabilities.

4.5.4 Suitability surfaces.

In both the predicted abundance and habitat suitability curves given in the previous Sections, it is apparent that to be able to "read off" a value for any combination of habitat variables requires a large number of curves due to the complex suitability relationships resulting from their multiple regression basis. A simpler method of displaying depth / velocity suitability information is suggested to be the "suitability surface". Suitability surfaces consist of a matrix of depth and velocity combinations. Areas of the matrix are shaded to indicate bands of increasing suitability. Figure 4.12 illustrates the development of a suitability surface (in this case for Baetidae). Separate surfaces are required for different macrophyte cover values. Appendix 9 presents suitability surfaces for three macrophyte cover scenarios for each of the indicator taxa, whilst Appendix 10 includes a set of suitability surfaces for Baetidae for 0% to 100% macrophyte cover (separate surfaces for 0%, 10%, 20%...100%).

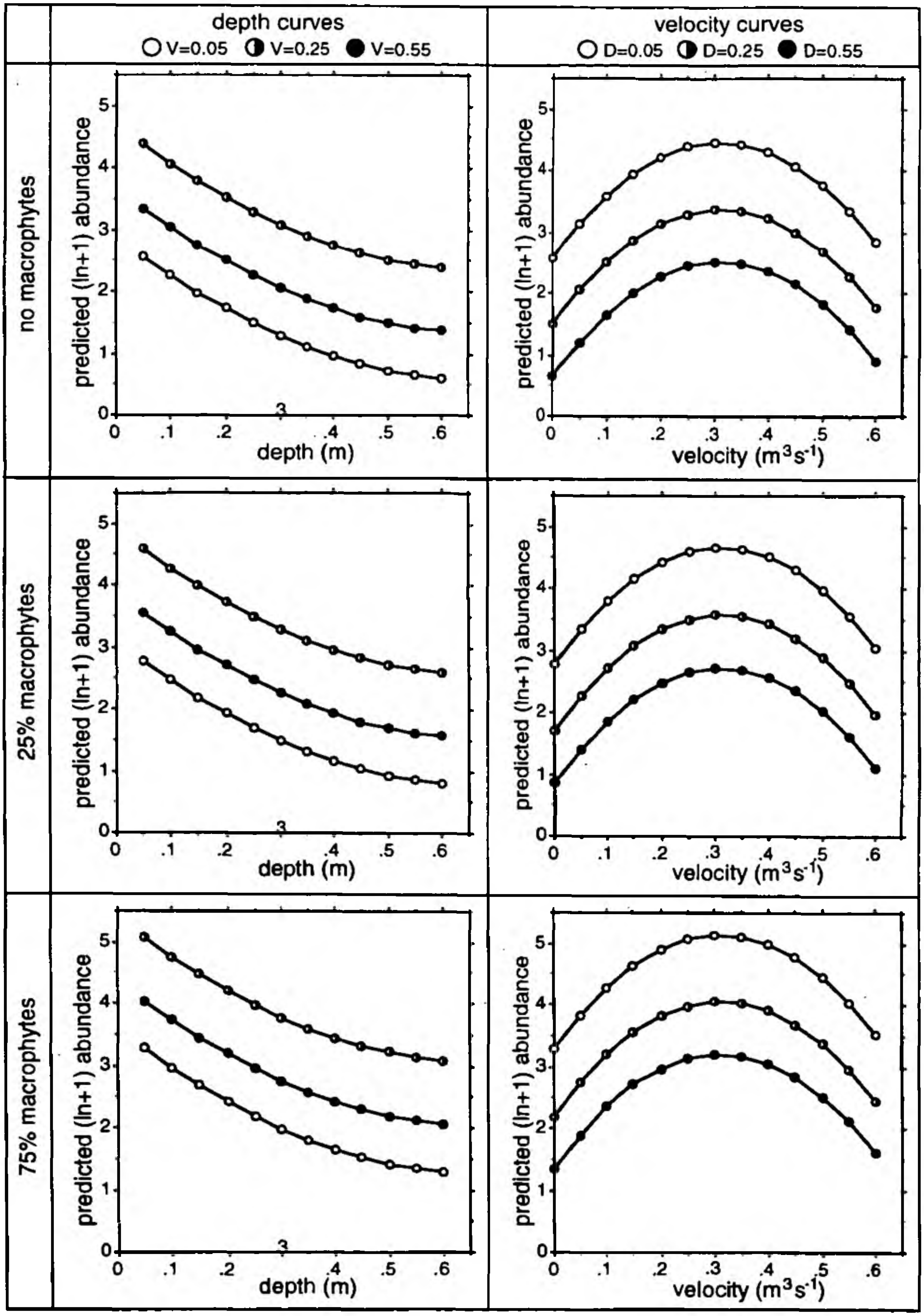


Figure 4.10 Predicted abundance curves for Elmidae on the River Wissey. Three sets of curves are shown: for no, 25% and 75% macrophyte cover (top, middle and bottom). Depth predicted abundances (left) are shown at three velocities, and velocity predicted abundances (right) at three depths. Curves are based on multiple polynominal regression of October cell abundances on depth, velocity and macrophtye cover.

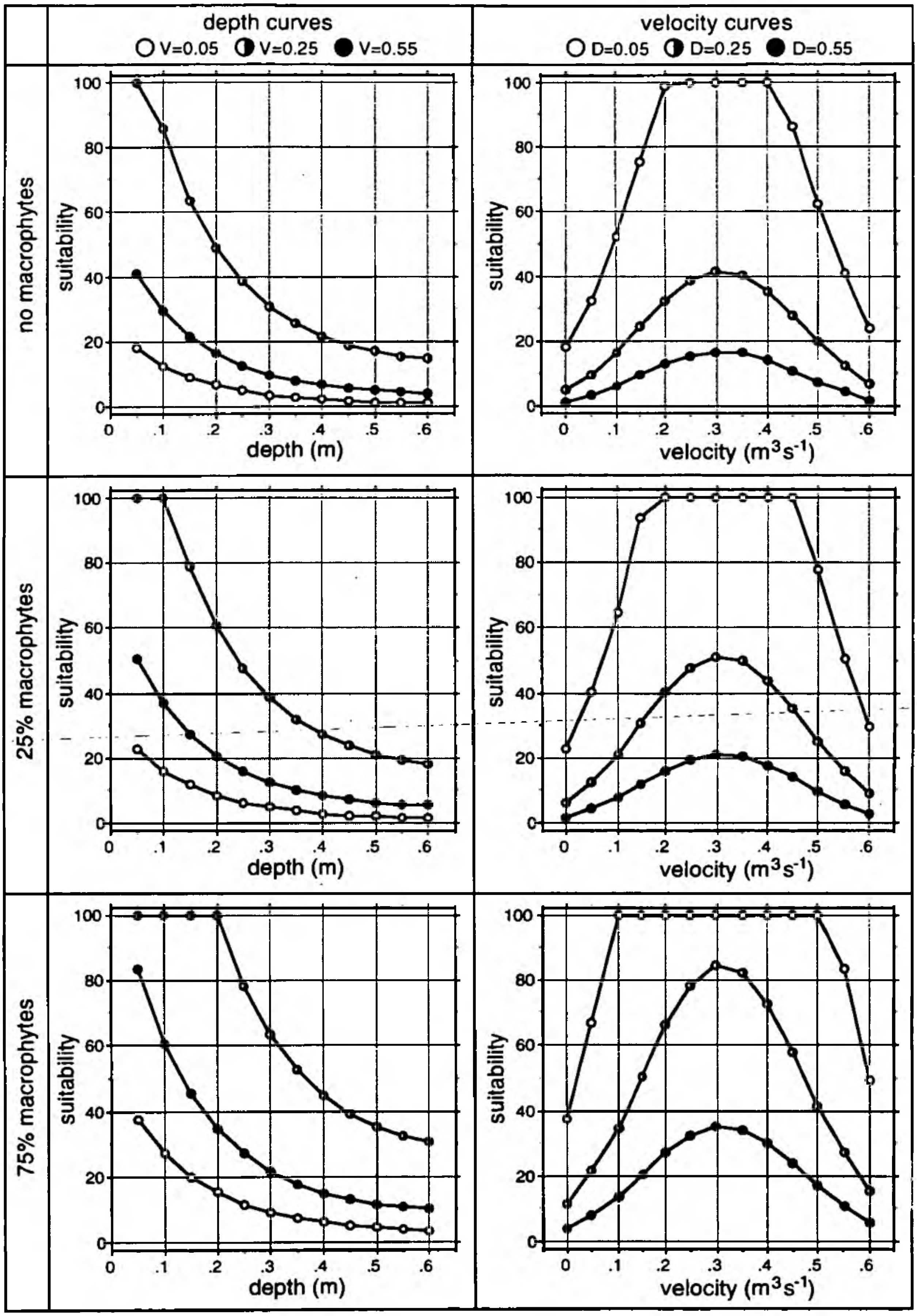


Figure 4.11 Suitability curves for Elmidae in Sector 3 of the River Wissey. Three sets of curves are shown: for no, 25% and 75% macrophyte cover (top, middle and bottom). Depth suitabilities (left) are shown at three velocities, and velocity suitabilities (right) at three depths. Suitabilites were derived by dividing predicted abundances by the maximum abundance predicted at any macrophyte/depth/velocity combination in the sector under flows from zero to the standard summer low flow (the optimum for the sector).

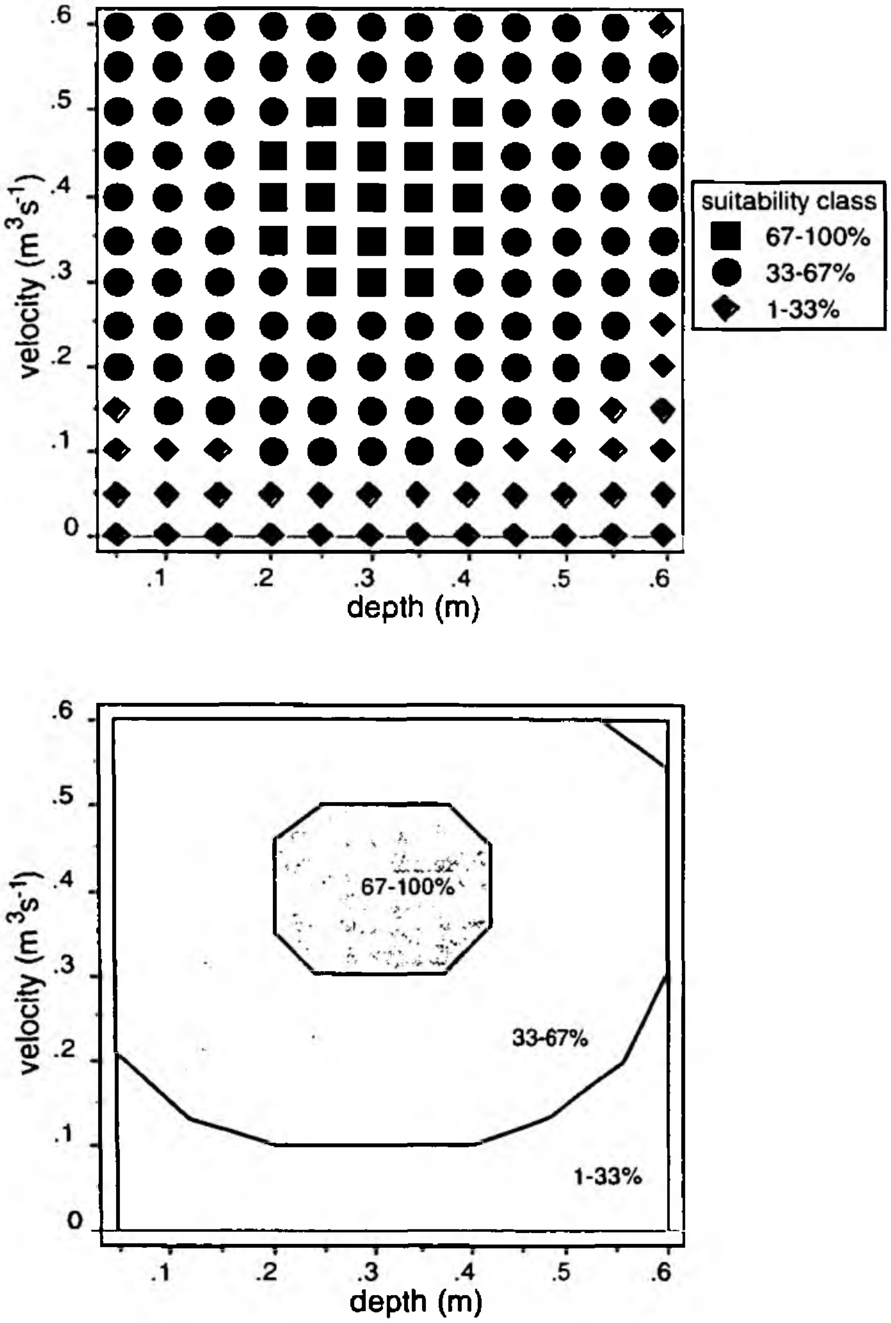


Figure 4.12 Development of suitability surfaces. This example illustrates suitabilities for for Baetidae in Sector 3, under 25% macrophyte cover. Top: suitabilities for each depth/velocity combination are calculated, divided into classes (in this case 1-33%, 33-67% and 67-100%) and plotted as a scatter plot. Bottom: points are replaced by shaded bands for each suitability class.

4.6 Habitat suitability predictions for indicator taxa.

In order to test the predictive efficiency of the habitat suitability relationships derived for the indicator taxa, these were used to predict habitat suitability for sites sampled in the October surveys based on cell habitat characteristics, and predictions compared with observed cell abundances.

Two sets of predictions were tested: 1) Habitat suitabilities for each cell were calculated using the habitat preference functions (predicted abundance equations), by using actual cell depth, velocity and macrophyte cover values, predicting abundance based on these data and converting the results to predicted suitability values. 2) Habitat suitabilities were calculated in the same way but using site average macrophyte cover to the nearest 10%. In the first method, the resulting predicted suitabilities would equate to those obtained if an infinite number of suitability curves or surfaces were consulted so that the exact combinations of depth, velocity and macrophyte cover could be utilised. In the second method, the resulting suitabilities would be those obtained from a set of suitability surfaces based on 10% increments of macrophyte cover and only cell depths, velocities and a measure of average site macrophyte cover were used.

Figure 4.13 illustrates how suitability values would be obtained for one site using the second method described above. For the Langford Hall gravel site, cell values of depth and velocity at each survey were plotted on suitability surfaces for one indicator species (Baetidae) in the appropriate sector (S3). Surfaces were for macrophyte cover values closest to the observed average site cover at each survey. In the figure, the plotted points are marked by symbols indicating the actual abundance of Baetidae observed (shown as percentage classes of the optimum predicted abundance). It can be seen that, based on this relatively small number of sample points, cells falling into the high (>67%) suitability band generally had high abundances of Baetidae, whilst those falling into the lower suitability bands had generally lower abundances.

The results of the two test methods are shown for all sites in Figure 4.14, in which for each site and survey, the proportion of cells falling into each suitability band are indicated in the left-hand bars of the histograms, whilst the proportion of cells containing each of three observed abundance bands are indicated in the right-hand bar. Although the distribution of abundances and suitabilities rarely shows an exact match (note that frequently the range of abundances classes is greater than the range of suitabilities, reflecting the greater observed between-cell variability than predicted), the trends in relative suitability between sites and between surveys is correctly predicted in most cases. A chi-squared test of observed abundance class scores against predicted suitability class scores using pooled data from sites and surveys for each taxon showed significant fits in all cases (Table 4.5).

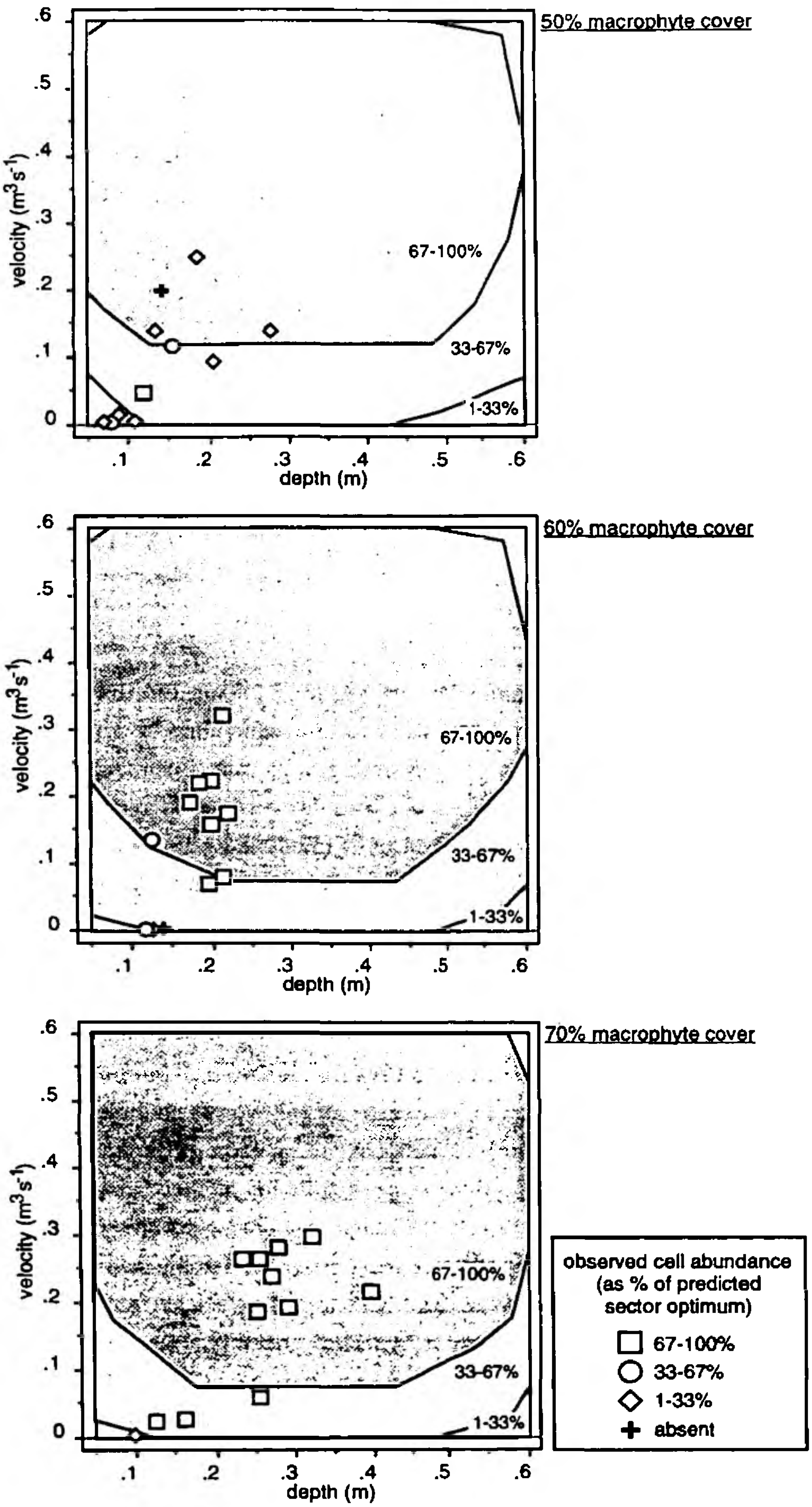


Figure 4.13 Cell abundances of Baetidae in Langford Hall gravel sites in October 1991, '92 and '94, superimposed on suitability surfaces for Baetidae under macrophyte cover percentages (to the nearest 10%) equivalent to the site average cover at each survey. Observed abundances of Baetidae at cell points (depth/velocity combinations) are indicated by symbols; abundances were converted to percentages of the predicted sector optimum (= 59 individuals per cell).

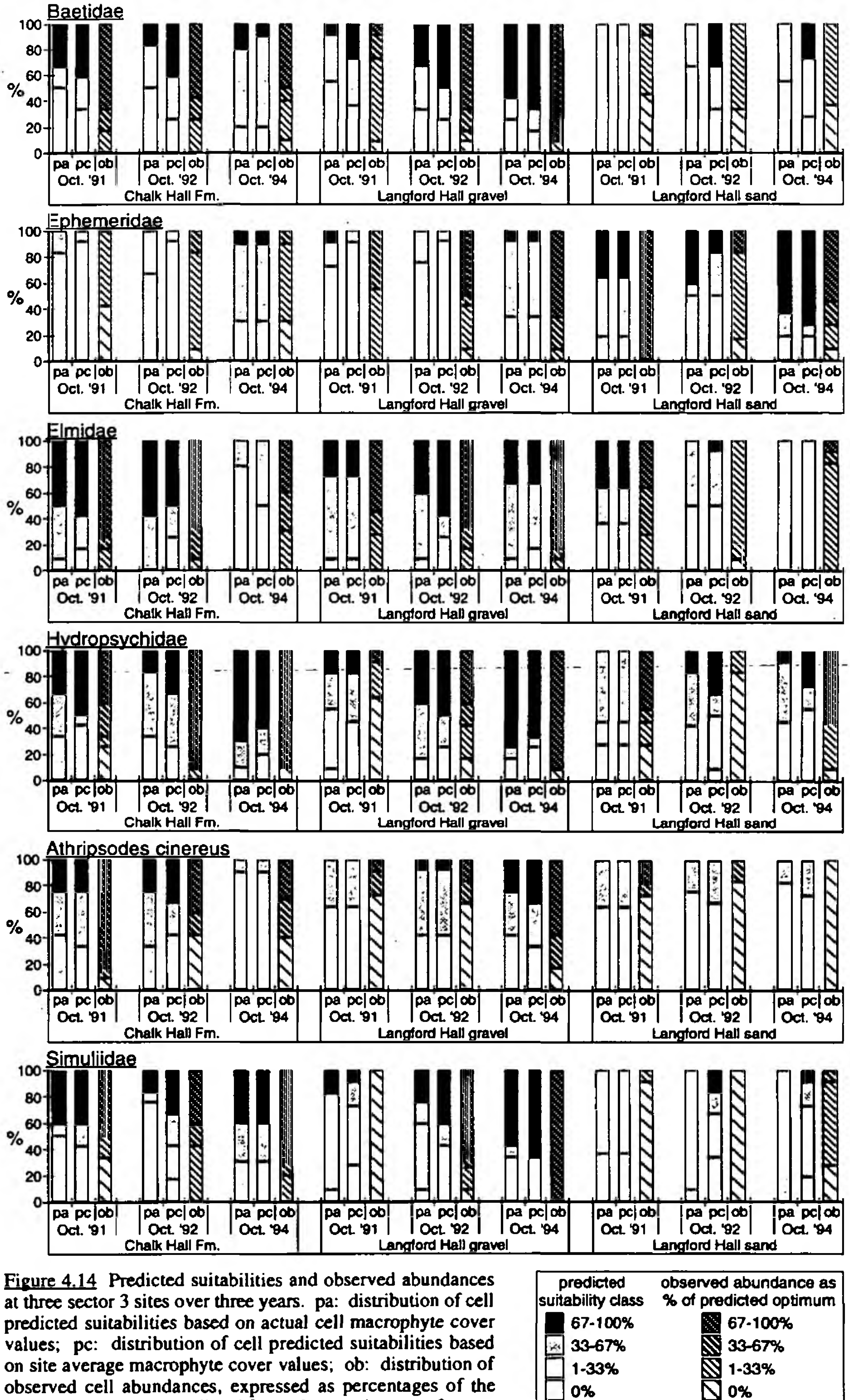


Figure 4.14 Predicted suitabilities and observed abundances at three sector 3 sites over three years. pa: distribution of cell predicted suitabilities based on actual cell macrophyte cover values; pc: distribution of cell predicted suitabilities based on site average macrophyte cover values; ob: distribution of observed cell abundances, expressed as percentages of the optimum abundance predicted for each taxon in sector 3.

Table 4.5 Tests of observed abundance against predicted habitat suitability for all indicator species in three sites from Sector 3, over three October surveys. actual macr. = predicted suitabilities based on actual cell macrophyte cover; site class macr. = predicted suitabilities based on average site macrophyte cover to the nearest 10%.

	actual macr.		site class macr.	
indicator	chi-square	prob.	chi-square	prob.
Baetidae	40.8	< 0.1%	34.2	< 0.1%
Ephemeridae	27.6	< 0.1%	31.9	< 0.1%
Elmidae	23.8	<1%	29.6	< 0.1%
Hydropsychidae	30.4	<1%	29.7	<1%
Athripsodes cinereus	17.6	<1%	17.3	<1%
Simuliidae	47.0	< 0.1%	45.3	< 0.1%

From Figure 4.14 and Table 4.5 it is apparent that the habitat suitability predictions based on site average macrophyte cover were almost as accurate as those based on actual cell macrophyte values. The suitability surface method of predicting site suitability is therefore recommended as a practical option for determining habitat suitability.

4.7 Community habitat suitability predictions from individual taxa preferences.

Section 4.5 considered various ways of describing relationships between individual taxa and flow-related variables, and identifies taxa showing strong preferences for particular combinations of these variables. Whilst these indicator taxa showed the strongest habitat preferences, a range of other taxa also showed significant preferences as determined in Section 4.4. In this Section a wider range of taxa are considered and, using preference functions derived from a multiple regression on three variables using all the October data, predictions of this larger group of taxa are compared with recorded abundances at each October survey. Using this method an prediction of the broader community at each of the main sites can be obtained.

Taxa selected for inclusion in this Section were all those showing significant relationships between abundance and depth, velocity and macrophyte cover based on all October data from the primary sites. (The regression equations for these taxa are given in Appendix 7). For each taxon, cell values were used to predict (ln+1) abundance. Average values from these cell predictions were calculated for each site and each survey; the results are illustrated in Figure 4.15 for sites Chalk Hall Farm, Langford Hall gravel and Langford Hall sand sites.

The results of the "community" predictions show a reasonable degree of success in the prediction of the community composition. The dashed lines in the figures represent the line of exact fit between predicted and observed (ln+1) abundance. Whilst observed and predicted values rarely coincide exactly, it is apparent that the method is able to predict in most cases a) the difference in relative abundance of many taxa between sites and b) the difference in relative abundance between years. For instance, Gammaridae, Baetidae and Elmidae are predicted to be dominant taxa in the gravel sites whilst at the sand site these are predicted to be less abundant, whilst larger numbers of Ephemeridae are expected - this general between-site trend is observed. For many taxa the differences between sites and years tend to be in the same rank order but greater in the observed than in the predicted results. Taxa frequently showing poor fits between observed and predicted abundance include Potamopyrgus jenkinsi and Oligochaeta, which commonly exhibit very aggregated distributions, occurring at very high abundances in small patches.

It can be concluded that this community approach may have some value in predicting the likely rank abundance of dominant taxa at a site and survey, and may be useful in predicting major differences between sites and years.

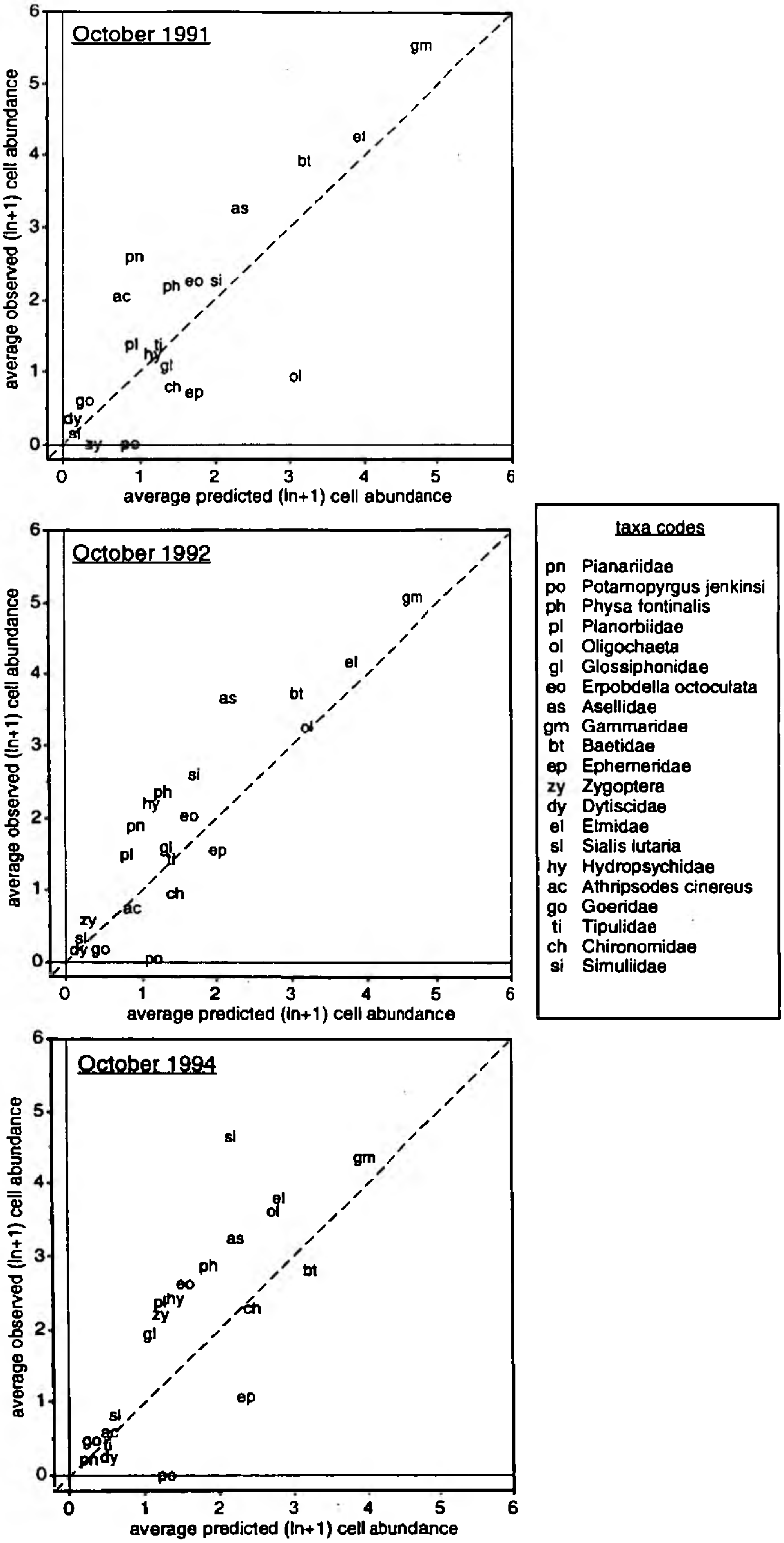


Figure 4.15 Observed and predicted abundances of selected taxa at Chalk Hall Farm, for October 1991, '92 and '94.

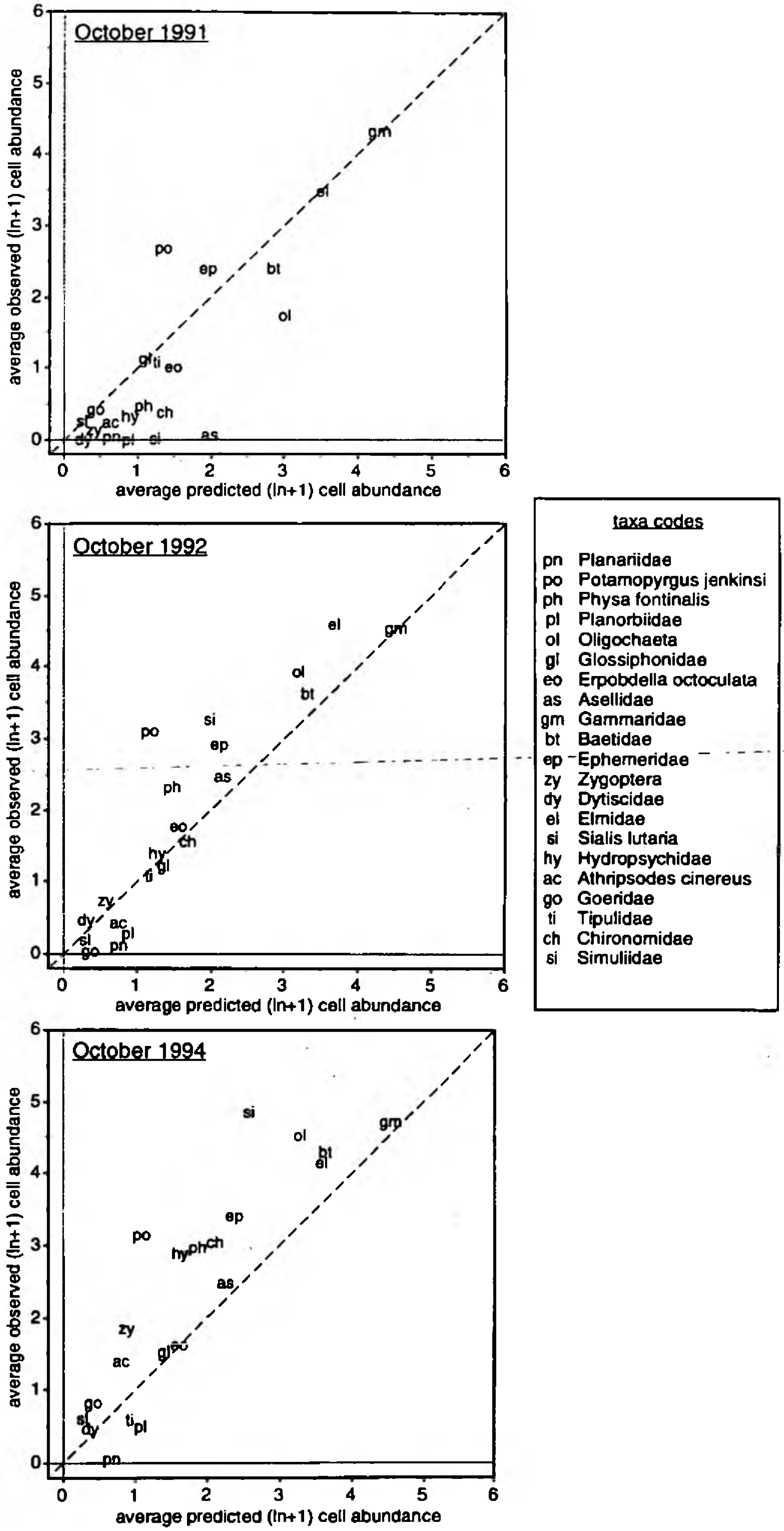


Figure 4.15 Observed and predicted abundances of selected taxa at Langford Hall gravel site, for October 1991, '92 and '94.

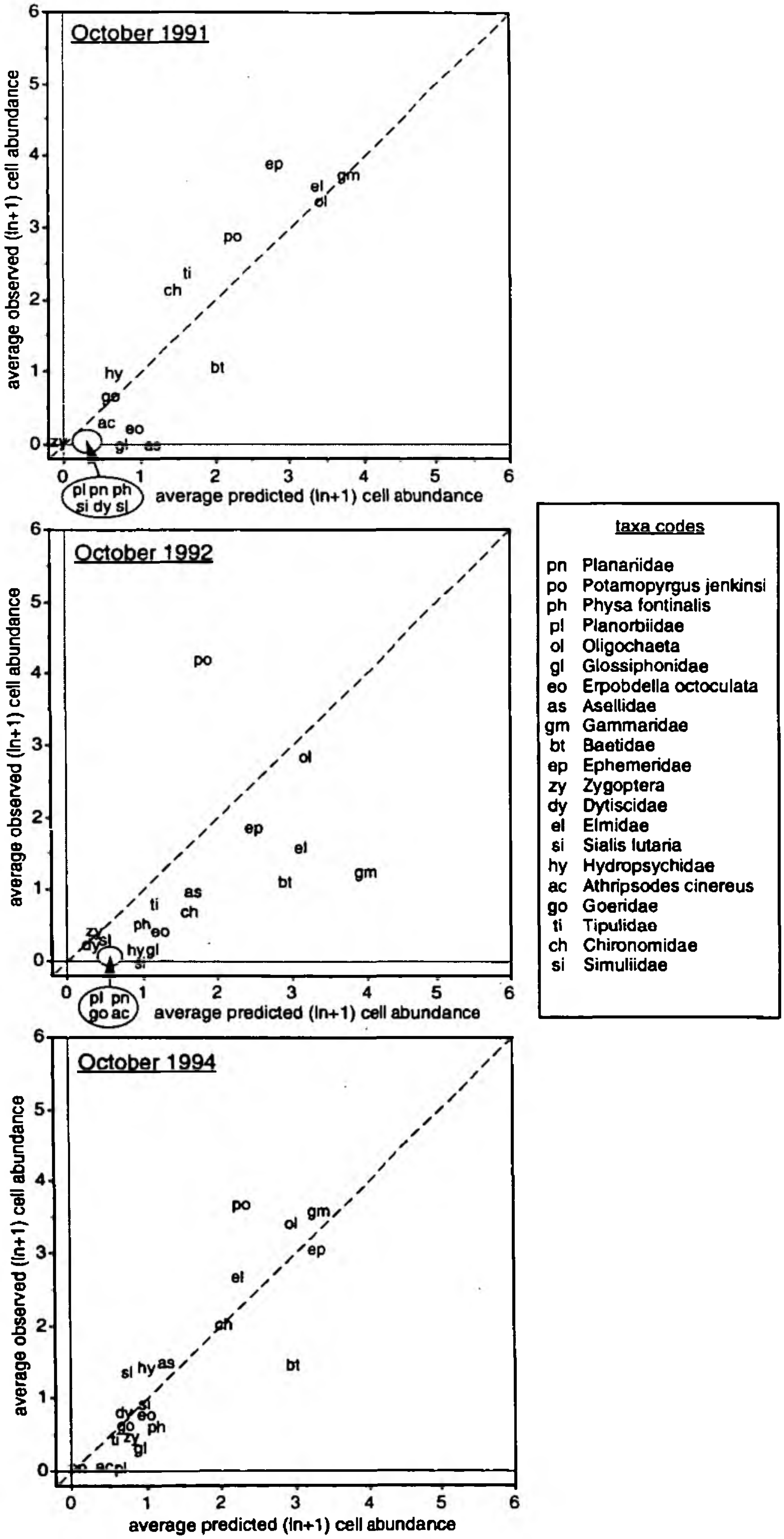


Figure 4.15 Observed and predicted abundances of selected taxa at Lanford Hall sand site, for October 1991, '92 and '94.

4.8 Relationships between macroinvertebrates, hydraulic habitat characteristics and flow.

The assumption that flow influences the distribution of macroinvertebrate taxa is based on the observation that the range of depths and velocities at a site are determined by the interaction of flow and habitat structure (channel form, substrate and macrophyte distribution). For the River Wissey sites the relationship between depth and velocity distribution and flow was determined over a series of surveys.

4.8.1 Habitat and flow relationships.

As introduced in Section 4.12, problems were encountered in relating depth and particularly velocity to flow due to the interactive effects with macrophytes. For this reason, multiple regressions of depth and velocity on flow and macrophyte cover were used to obtain satisfactory relationships. To illustrate the effectiveness of this procedure, simple and multiple regression results for Chalk Hall Farm are contrasted below. (Tables of the regression coefficients for all sites are given in Appendix 2):

Chalk Hall Farm relationships between transect depths (D, in cm), velocities (V, in m s^{-1}), discharge (Q, in $m^3 s^{-1}$) and macrophyte cover (M, %).

upper transect

$D = 11.74 + 8.89Q$ $\quad r^2 = 0.801$
$V = 0.271 + 0.0340Q$ $\quad r^2 = 0.0461$

$D = 8.17 + 8.64Q + 0.0669M$ $\quad r^2 = 0.835$
$V = 0.425 + 0.0449Q - 0.0029M$ $\quad r^2 = 0.285$

centre transect

$D = 5.67 + 12.7Q$ $\quad r^2 = 0.953$
$V = 0.273 + 0.0342Q$ $\quad r^2 = 0.0452$

$D = 2.76 + 11.6Q + 0.0846M$ $\quad r^2 = 0.933$
$V = 0.407 + 0.0811Q - 0.0039M$ $\quad r^2 = 0.392$

lower transect

$D = 12.9 + 13.7Q$ $\quad r^2 = 0.820$
$V = 0.171 + 0.0194Q$ $\quad r^2 = 0.0294$

$D = 8.58 + 13.0Q + 0.112M$ $\quad r^2 = 0.856$
$V = 0.282 + 0.035Q - 0.0029M$ $\quad r^2 = 0.444$

Un-transformed discharge data were used as these were found to give more significant relationships with the habitat variables than log-transformed data.

4.8.2 Macroinvertebrate habitat suitability changes with flow.

The derivation of a site suitability for a given macroinvertebrate taxon at a particular flow involves the intermediate steps of 1) assessing the distribution of depths and velocities at a site at that flow and 2) predicting the suitability of the habitat for the taxon by use of the preference functions / predicted abundance or suitability curves or surfaces described in Section 4.5.

The predicted depths and velocities under a range of flows for each site in Sectors 3 and 4, using average observed macrophyte cover, are tabulated in Appendix 3. From these predicted combinations of depth and velocity, habitat suitabilities for each indicator taxon were derived. Habitat suitability / flow curves were plotted from these results, and are shown in Figure 4.16.

The the Sector 3 and 4 habitat suitability / flow curves for the indicator taxa illustrate the differences between sites in response of taxa with differing habitat preferences. The differences between curves can be accounted for by physical characteristics of the site which determine the range of depths and velocities found under average flow conditions, and the relative rate of change of depth and velocity with flow. It is clearly apparent that, for instance, the Bodney Bridge site provides better habitat for taxa such as Baetidae and Elmidae than does Langford Hall sand site - this is because under any flow the former site is relatively shallow with high current velocities while the latter is deep with large areas of low current velocity. Observing change in suitability with flow, it can be seen that for Baetidae suitability increases at both sites with flow, whereas for Elmidae suitability increases initially at Bodney Bridge and then declines, and declines slightly in a linear fashion at Langford Hall sand site. This is due to the differing preferences of the two taxa: both taxa prefer higher current velocities, but whilst Baetidae also prefer higher depths, Elmidae decline in abundance with depth. Thus at the deep Langford Hall sand site, which experiences only considerable increase in depth but little change in current velocity with increasing flow, only Baetidae are provided with better habitat availability under higher flows. At Bodney Bridge, which is less ponded and shows rapid increase in current velocities but little change in depth with increasing flow, both Elmidae and Baetidae are favoured by increasing flows initially, until Elmidae lose habitat as depths exceed their optimum value. Suitability / flow patterns for indicator taxa at other sites can also be explained on the basis of the relative rate of increase in depth and velocity, in most cases related to the initial depth and degree of ponding at the contrasting sites.

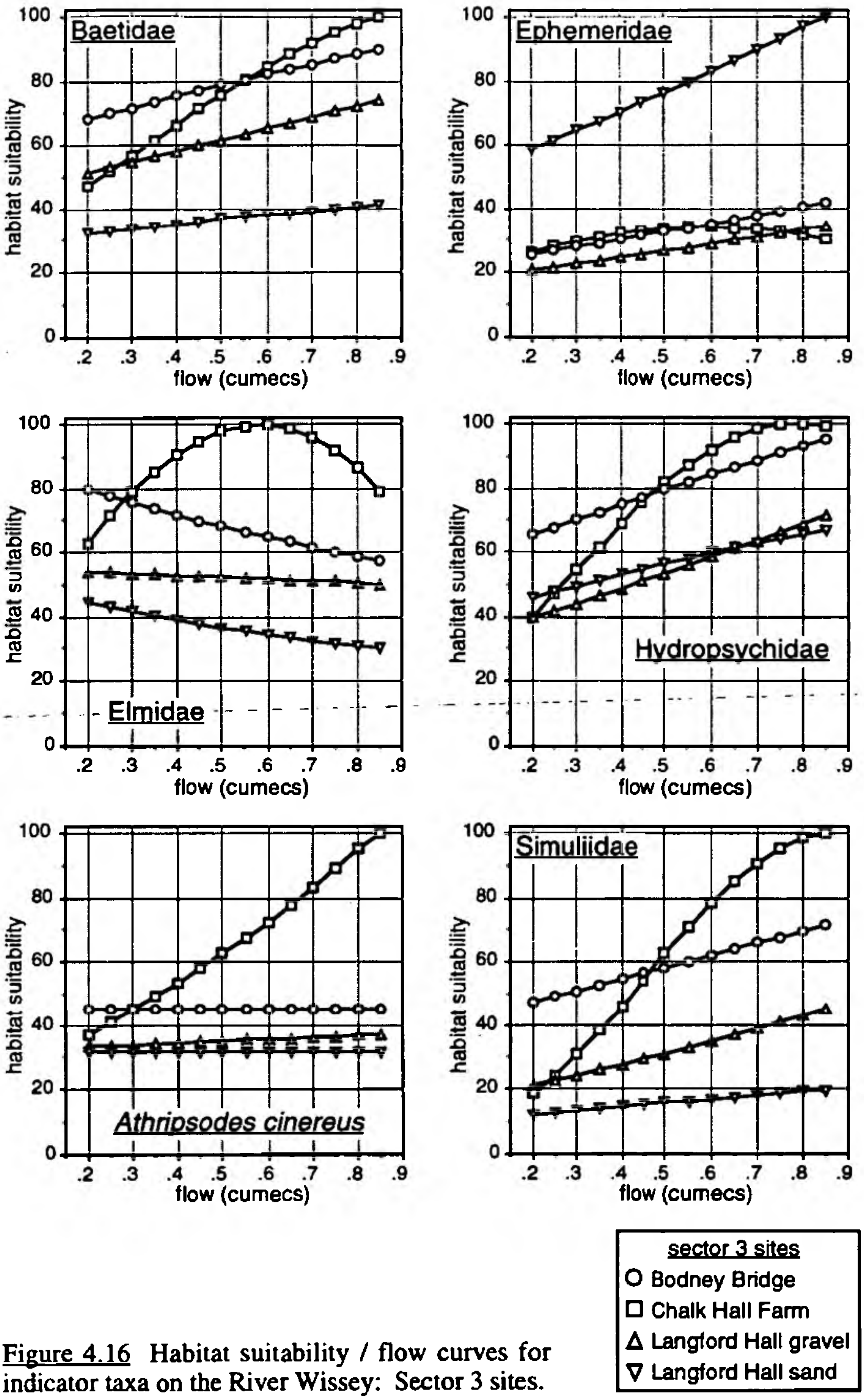


Figure 4.16 Habitat suitability / flow curves for indicator taxa on the River Wissey: Sector 3 sites.

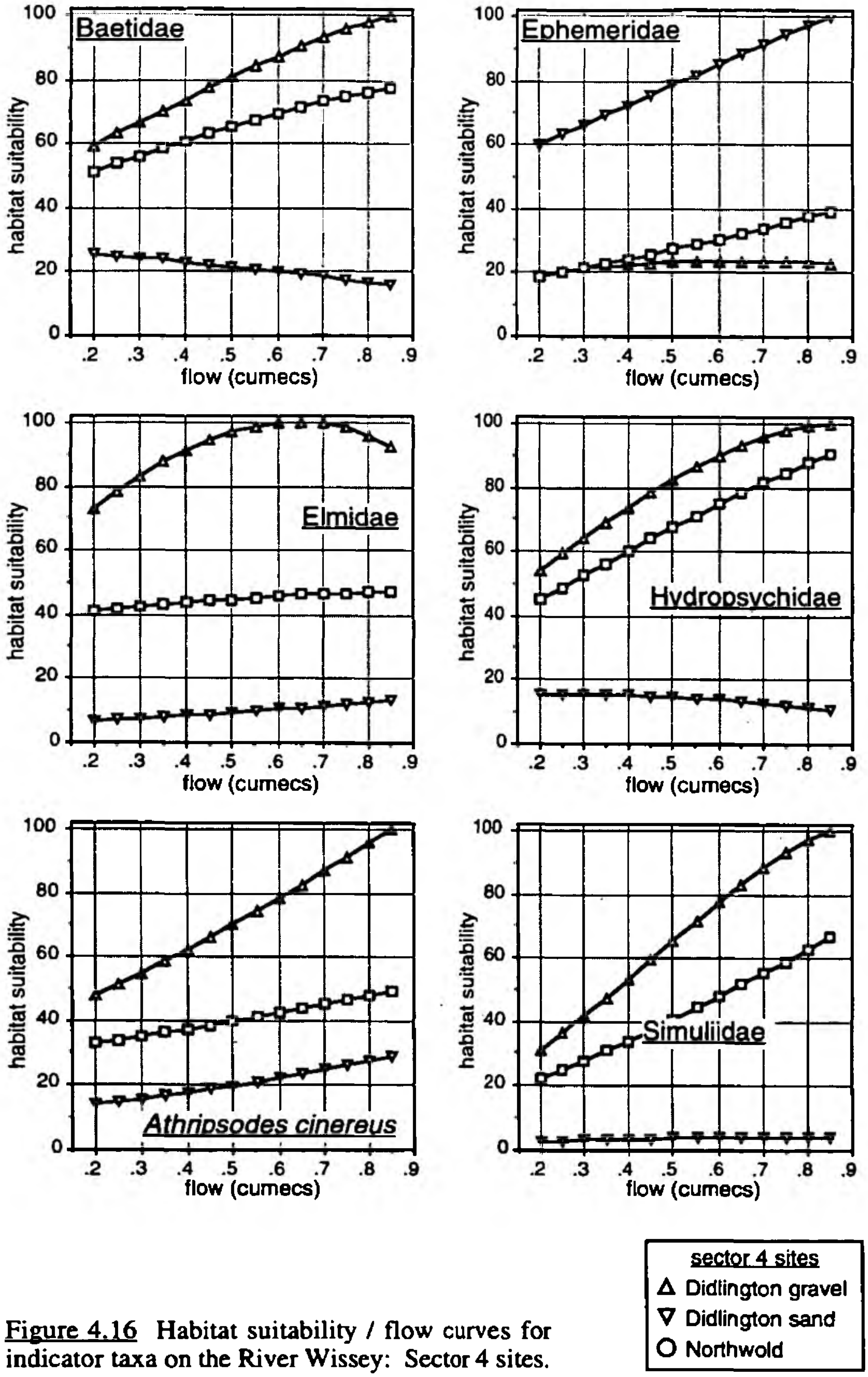


Figure 4.16 Habitat suitability / flow curves for indicator taxa on the River Wissey: Sector 4 sites.

4.9 Long-term change investigations based on EA biological monitoring and flow data.

EA biological monitoring data provide a unique long-term source of information, which can be used, in conjunction with historic flow data, to provide community and family level information on year-on-year changes in response to flow. Records were obtained for all River Wissey sites from 1965-1991 (data were presented in Annex D of Part I of the Report). These data were combined with daily flow data for the same period, in order to investigate long-term responses to flow. Analysis of the macroinvertebrate community information alone from these data is detailed in the previous report. In this Section, information regarding year-on-year differences in numbers of taxa and individual taxon frequencies in relation to long-term flow statistics is considered.

4.9.1 Flow characteristics influencing the fauna.

Flow data (mean daily flows) were obtained for the 1962-'95 period, and used to calculate a number of flow statistics to which the macroinvertebrate fauna could be related. Values of these statistics were extracted for the date of each macroinvertebrate sample. The statistics were:

dayQ	=	flow on day of sampling
7dayQ	=	mean flow over the 7 days prior to sampling
30dayQ	=	mean flow over the 30 days prior to sampling
AprQ	=	mean flow in previous April
sumloQ	=	lowest 7 day mean Q in the summer of the previous year
winmxQ	=	maximum daily flow in previous winter
winhiQ	=	highest 7 day mean Q in previous winter

In order to gain maximum information on the relationship between overall macroinvertebrate community composition and flow characteristics, the multivariate ordination method was used, in which sample communities were first ordinated and secondly ordination axis scores were correlated with the flow statistics. Figure 4.17 illustrates some of the results with an ordination plot of a subset of the data: from upper Wissey sites (Bradenham to Great Cressingham). The results shown were repeated in the other site groups, and indicated that the community composition is most strongly correlated with a) recent flows, best expressed by the 30dayQ, and b) the previous year's flows, best expressed by the previous years winter high flow and summer low flows.

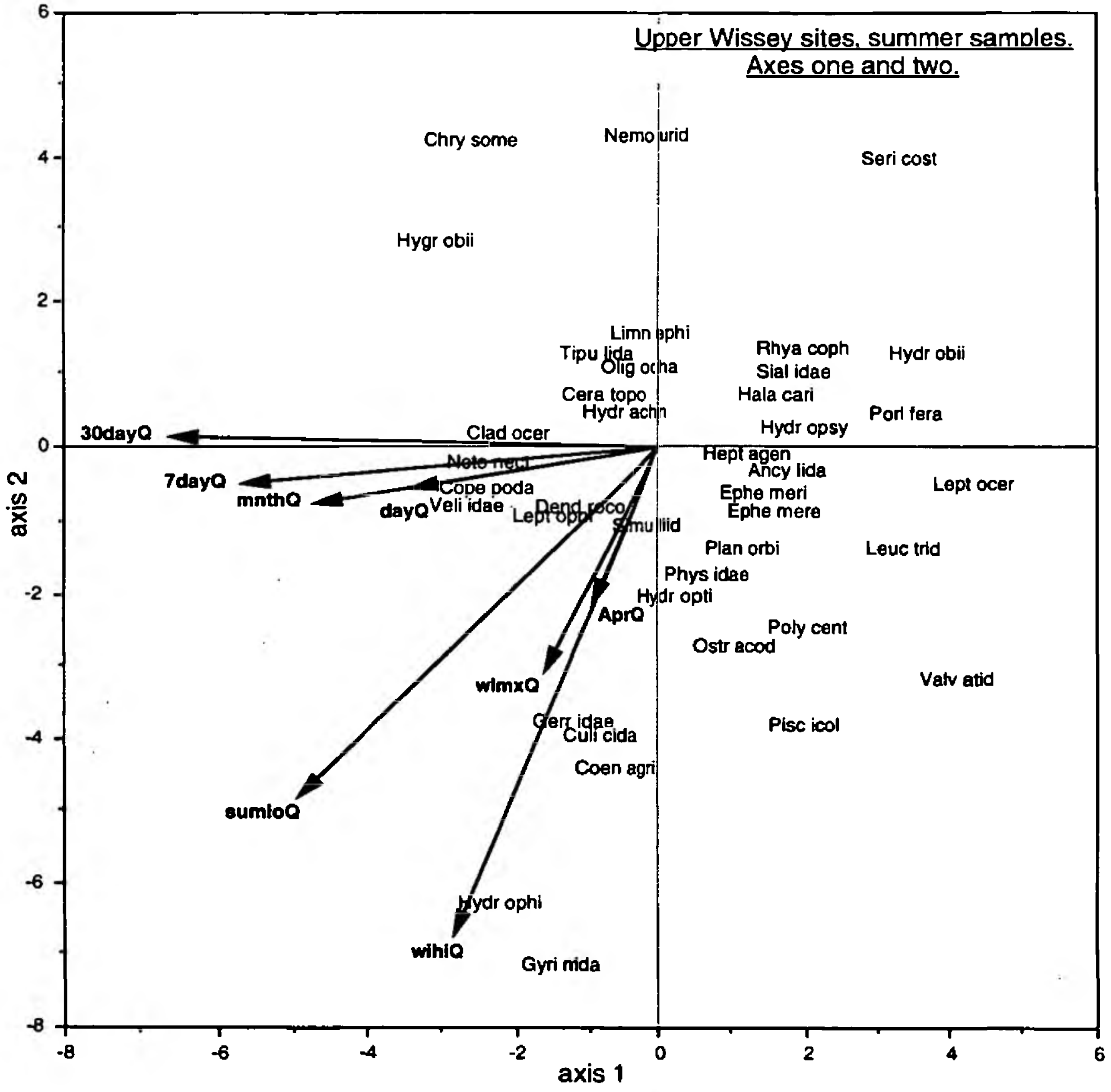


Figure 4.17 Detrended correspondence analyses ordinations of NRA macroinvertebrate sampling records, 1965-1991. Axes 1 and 2. Taxa are shown in relation to flow variables derived from daily flow records.

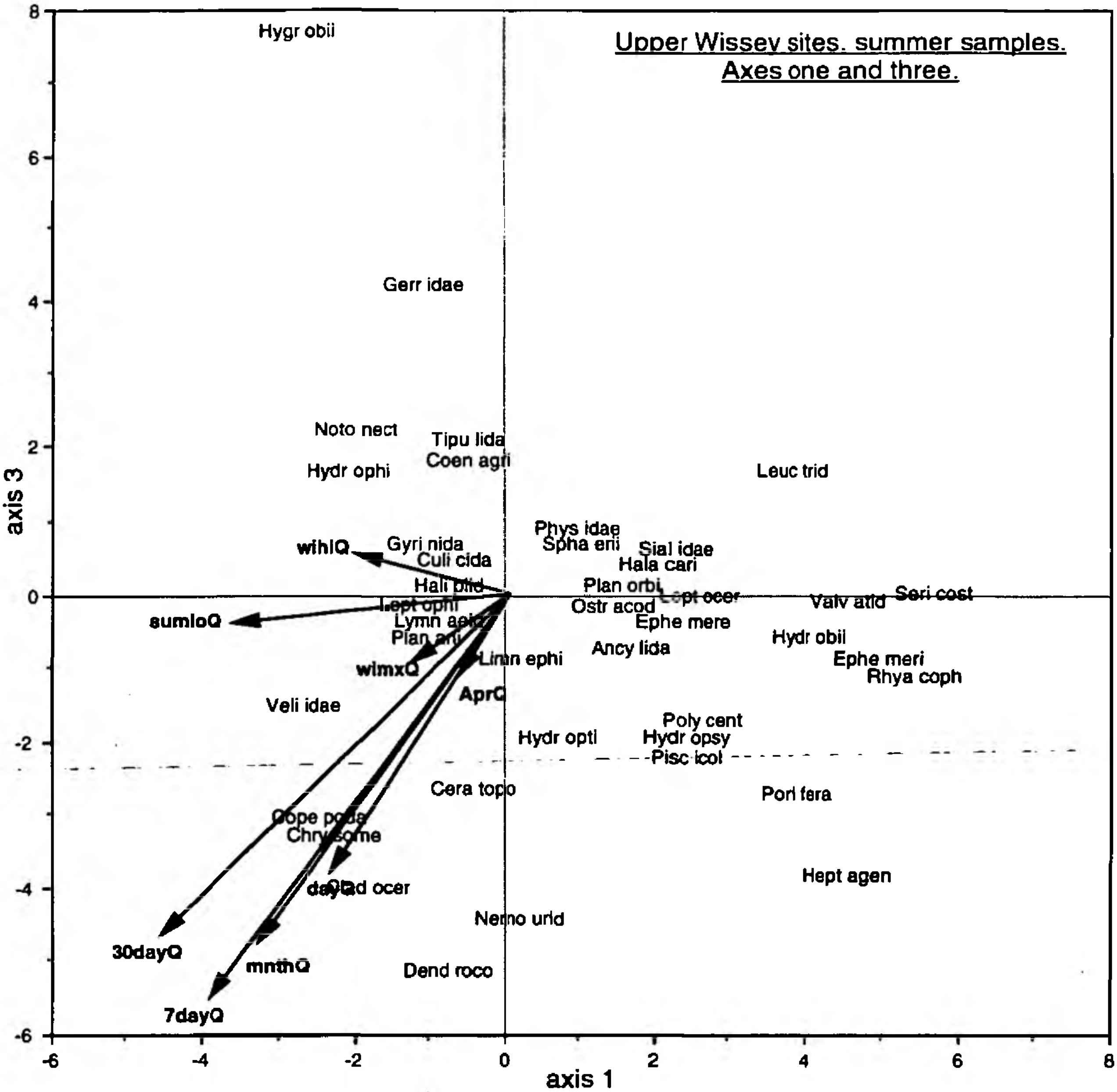


Figure 4.17 Detrended correspondence analyses ordinations of NRA macroinvertebrate sampling records, 1965-1991. Axes 1 and 3. Taxa are shown in relation to flow variables derived from daily flow records.

4.9.2 Changes in numbers of taxa in relation to long-term flow.

Having established that the fauna is responsive to long-term changes in flow, and that recent flows are most important in influencing sample community, a number of additional flow statistics were tested which measured flow at the time of macroinvertebrate sampling. The number of taxa in each sample from the long-term record (summer samples only) were regressed on these statistics in order to determine a) whether numbers of taxa alone - a relatively crude measure of the community - were flow-responsive; b) which flow statistic was the best predictor of number of taxa, and c) whether there were spatial differences in response along the river.

Numbers of taxa were found to be most significantly related to a standardised measure of monthly flow: the standard score of the monthly low flow. This was calculated as the low flow for the month of sampling (lowest average of seven consecutive mean daily flows), minus the mean of the low flows recorded in that month over the long record, divided by the mean of the low flows recorded in that month over the long record. This measure records both the relative magnitude of the monthly low flow in comparison with other years, and is standardised to compensate for the long-term variability in low flows for that month. Sample values of monthly flow, standard score of monthly low flow, and numbers of recorded taxa are given in Appendix 11.

Whilst the ordination analysis (above) showed that communities from all sites (upper, middle and lower river) were correlated with long-term flow statistics, in the analysis of numbers of taxa against flow only the samples taken from sites in the middle reaches of the River Wissey showed the strong relationships between number of taxa and standard score of monthly low flow. The results of this analysis is illustrated in Figure 4.17. The relationship found for the middle river sites has been replicated for other rivers (Babingley and Glen).

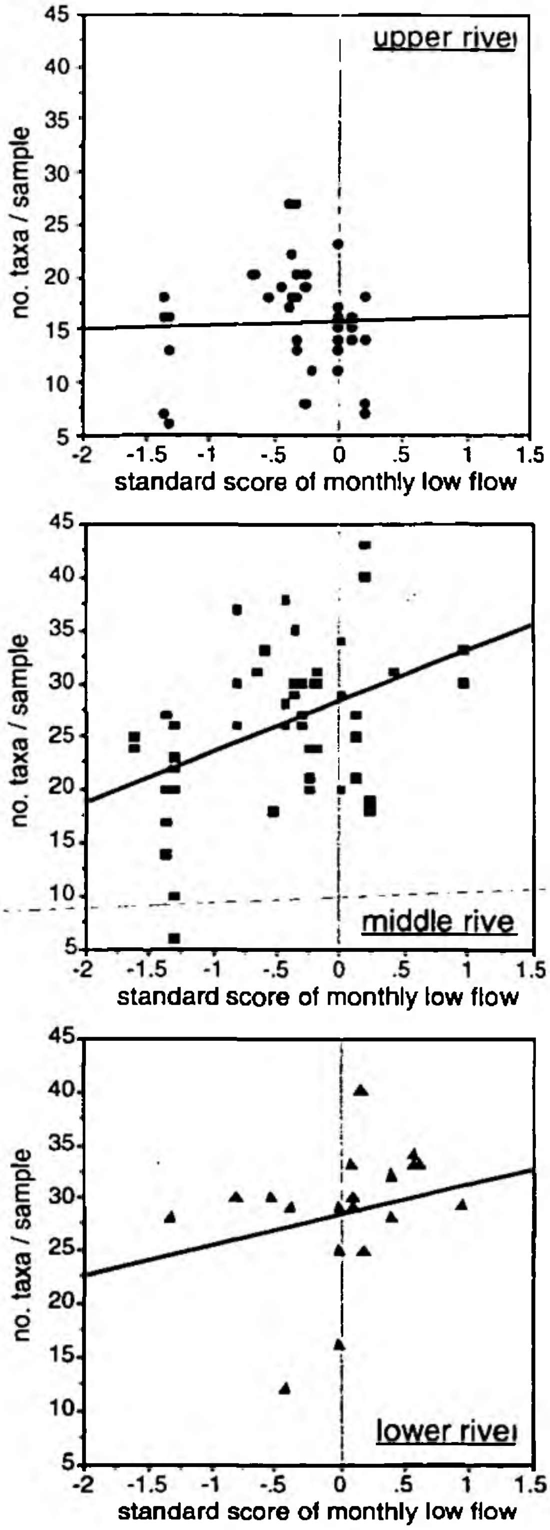


Figure 4.17 Regressions of numbers of BMWP-scoring taxa per sample against standard score of monthly low flow for month of sampling. Upper and lower river samples: regressions not significant; middle river: $R^2 = 0.18$, $p<1\%$.

4.9.3 Distribution of individual taxa between years of high and low flow.

The frequency distribution of samples between years of high and low summer low flows were examined by dividing the samples into those taken when the monthly low flow was lower than the long-term average for the month, and those taken when the monthly low flow was higher than the long-term average for the month. Chi-squared tests were used to compare frequency of taxa in each group of samples. Figure 4.18 illustrates the preferences based on these results for taxa occuring in at least 50% of samples over all flows.

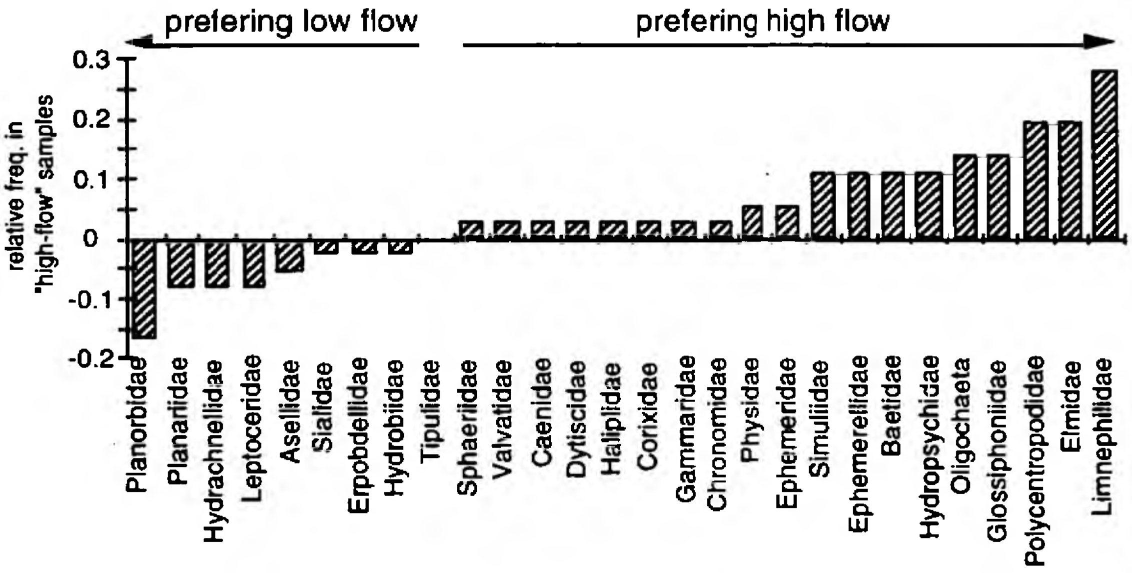


Figure 4.18 Distribution of taxa in summer samples from the middle reaches of the River Wissey in relation to summer low flow. Taxa occuring more frequently in samples where the summer low flow inceeded the long-term average are ranged to the left, those where the long-term average was exceeded are ranged to the right.

Of the taxa included in the analysis, only Elmidae and Limnephilidae showed a statistically significant preference for high flows and no taxa for low flows; this was probably due to the relatively small sample size (27 lower-than-average and 9 higher-than-average flow samples). A majority of taxa showed preference for higher-than-average flow; this might be expected from the results of the previous Section which show total number of taxa to increase with flow. The types of taxa preferring the contrasting flow categories were much as expected, with those having known preferences for silted, slow-flowing conditions more common in low-flow samples (eg. Sialidae, Asellidae), and those known to prefer clean gravels and faster flow more common in the high-flow samples (eg. Elmidae, Hydropsychidae, Ephemerellidae, Baetidae).

The results presented in this Section show that using historical data alone it is possible to infer useful information on the likely gain or loss of numbers of taxa with changing flow, and the types of taxa which are most likely to be gained or lost. As referred to in Section 4.4.5, this latter information can assist in selection of indicator taxa for further, field survey based investigation.

5. RESULTS - OTHER CHALK STREAMS.

The 1992-'93 data set of habitat and macroinvertebrate distributions in other Anglian Region chalk streams allowed a) the River Wissey to be put into a regional context on the basis of physical and faunal characteristics (ie to determine whether the Wissey can be described as a "typical" chalk stream, and b) River Wissey derived macroinvertebrate habitat preference information to be applied across a variety of site types to test the universality of faunal responses and potential use of single-river derived habitat preference information in a broader context.

5.1 Physical habitat and macrophyte cover variability between rivers.

Cell mean values of the three main habitat variables: depth, velocity and macrophyte cover, were examined from the additional Anglian river sites and contrasted with those from the River Wissey. Figure 5.1 shows means and one standard deviations of the variables from the site data. A high degree of variability was seen between rivers, although most values of the variables fell within the range of those found on the River Wissey. Depths and macrophyte cover were generally lower from the other Anglian river sites, whilst velocities recorded at some sites (lower Cam and Thet) exceeded those recorded anywhere on the Wissey. The standard deviations illustrated in Figure 5.1 suggest that the range of values found on the Wissey was relatively small, however, this is mostly a result of the greater number of sample data for the Wissey sites.

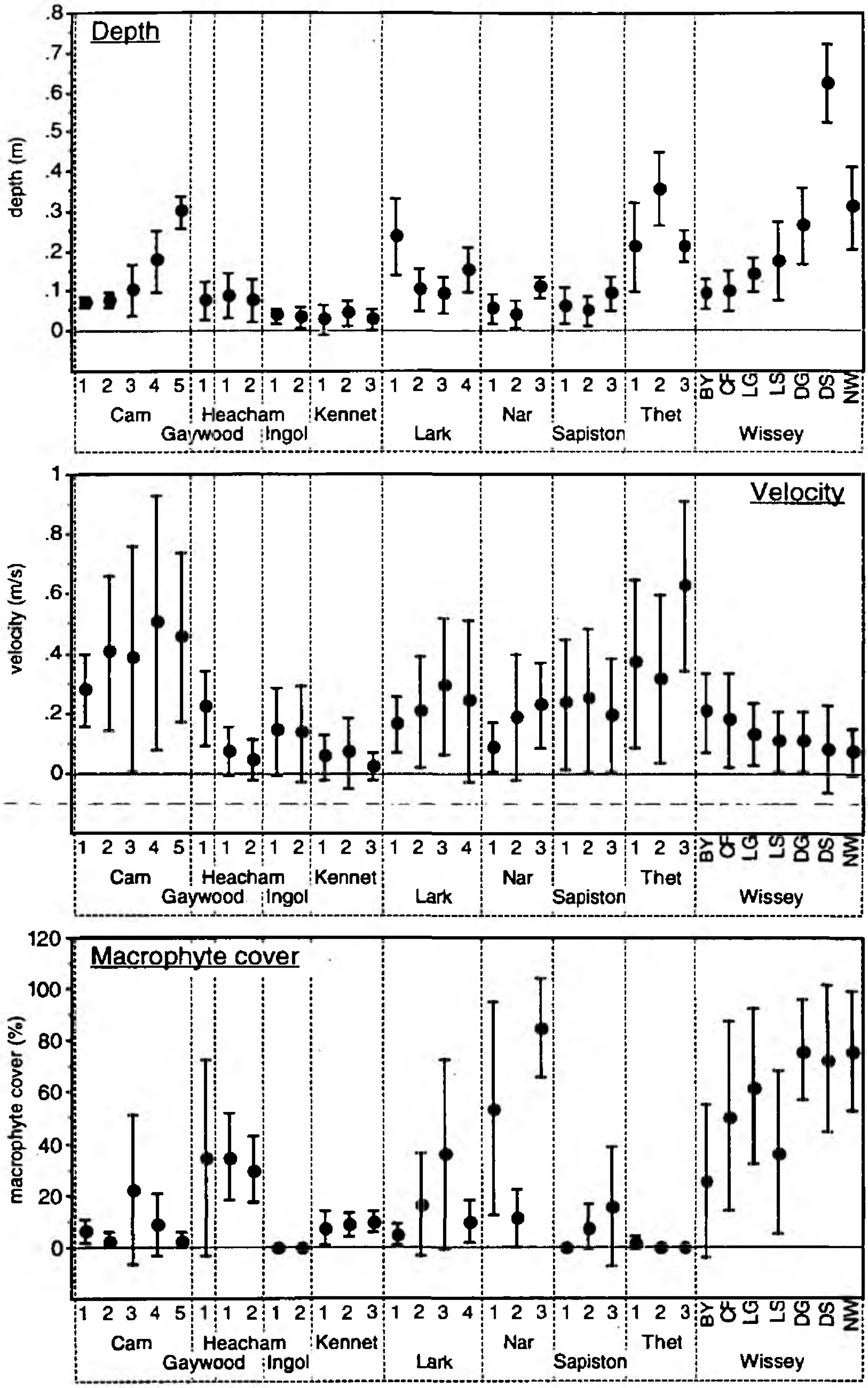


Figure 5.1 Distribution of depths, velocities and macrophyte cover from Anglian river sites. Data were mean cell values; graphs show means and one standard deviation error bars.

5.2 Macroinvertebrate community variability between sites and surveys.

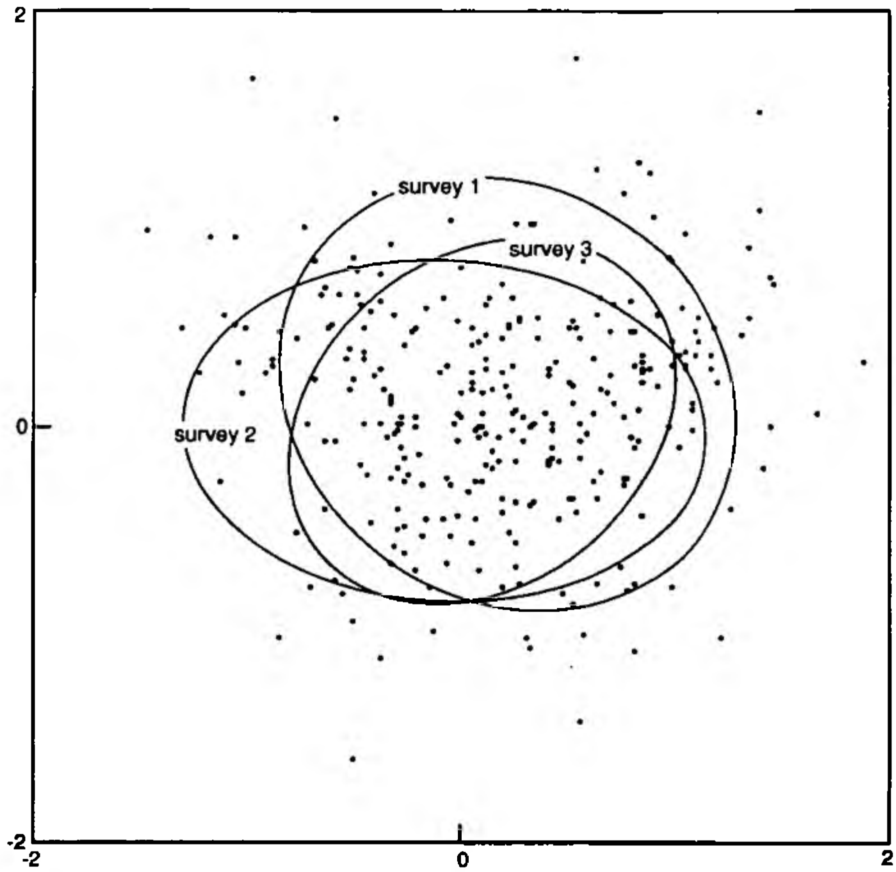
Community analyses were performed on the Anglian rivers data set to investigate the faunal variability between sites and surveys; on the Anglian rivers data alone and, using the October data set, with the Rivers Wissey and Babingley data included.

Figure 5.2 illustrates the results of a correspondence analysis ordination of the faunal data with samples from individual survey dates (top) and rivers (bottom) highlighted by surrounding the sample points with 80% ellipses. It is immediately apparent that a high degree of homogeneity exists between rivers and seasons, (ellipses overlap, ie. many taxa are shared). Whilst the similarity between rivers makes the comparison less "interesting" in terms of describing their faunistic individuality, for the purposes of testing species habitat preferences between rivers (the primary aim of the project) this is probably an advantage.

To examine the relative importance of differences between sites compared to seasons within each river, Figure 5.3 shows a break-down of the original ordination into individual rivers, highlighting sites and seasons. It appears that both site and season play an almost equal rôle in distinguishing between samples, with only the Kennet, Sapiston and Thet showing slightly more difference between site communities than between seasons.

The three surveys were undertaken in August/September, October/November and December/January 1992. For the purposes of comparison with the River Wissey survey results, only the middle survey data were analysed in depth (see below). However, between-season differences in frequency of individual taxa were investigated, with results illustrated in Figure 5.4. The first survey showed greater difference to the subsequent two surveys than either of the latter to each other. Taxa occurring at greater frequency in this first (August/September) survey include a number of beetle species probably related to macrophytes which would be declining in the later surveys; and species such as *Ephemerella ignita* which, because of life-history characteristics, are only collected seasonally.

The relationship between sample communities and measured habitat variables was considered by correlation of the variable values with community ordination scores from correspondence analyses of each survey. Figure 5.5 illustrates the ordination of the sample communities (top) from the October survey and also includes samples from the three main Babingley sites and River Wissey Chalk Hall Farm, Langford Hall gravel and Langford Hall sand sites. Ellipses indicate the river groupings, and the relative strength and direction of correlations of the axis scores with the variables is shown in the second plot (bottom).



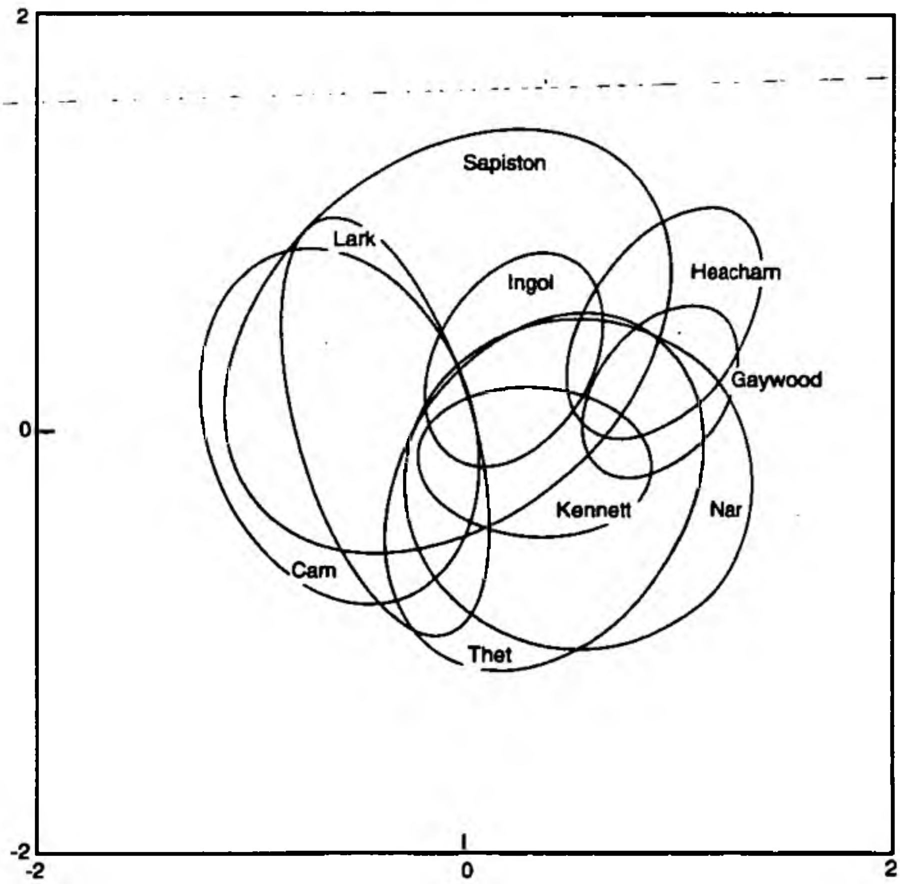


Figure 5.2 Ordination from a correspondence analysis of the Anglian Rivers species data. Top: individual cells indicated by points; and elipses enclosing approximately 80% of the variance of cell scores from each of the three surveys. Bottom: 80% elipses for cells from each river.

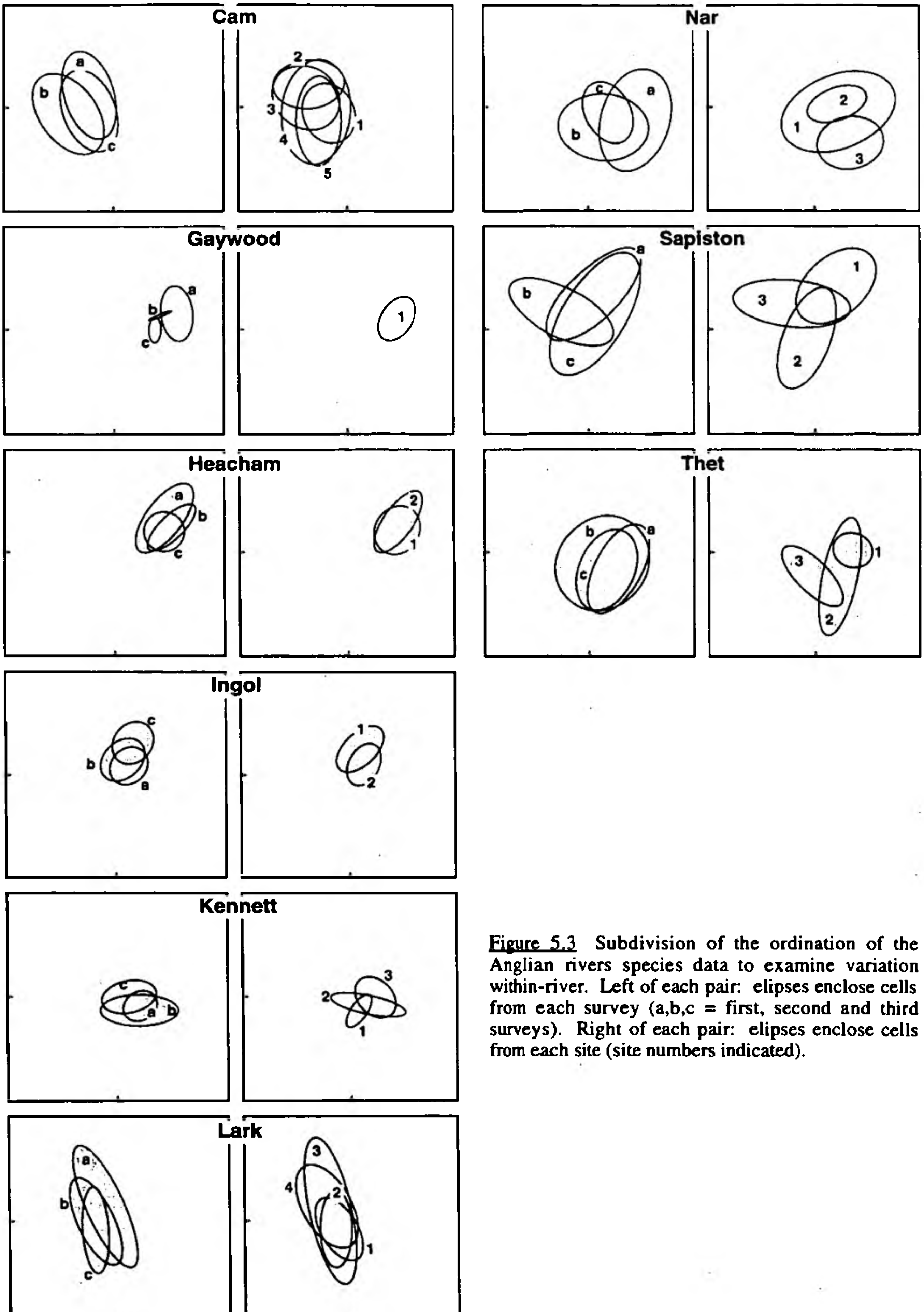
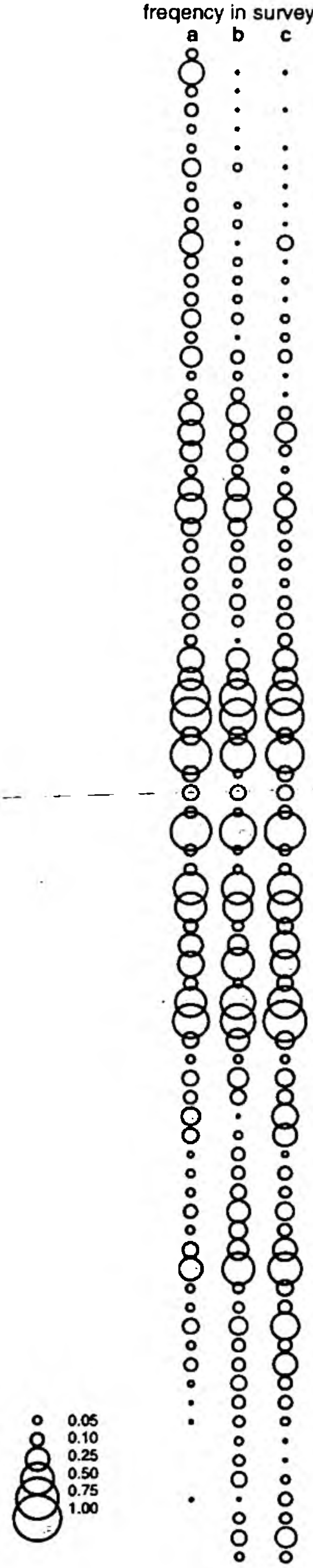
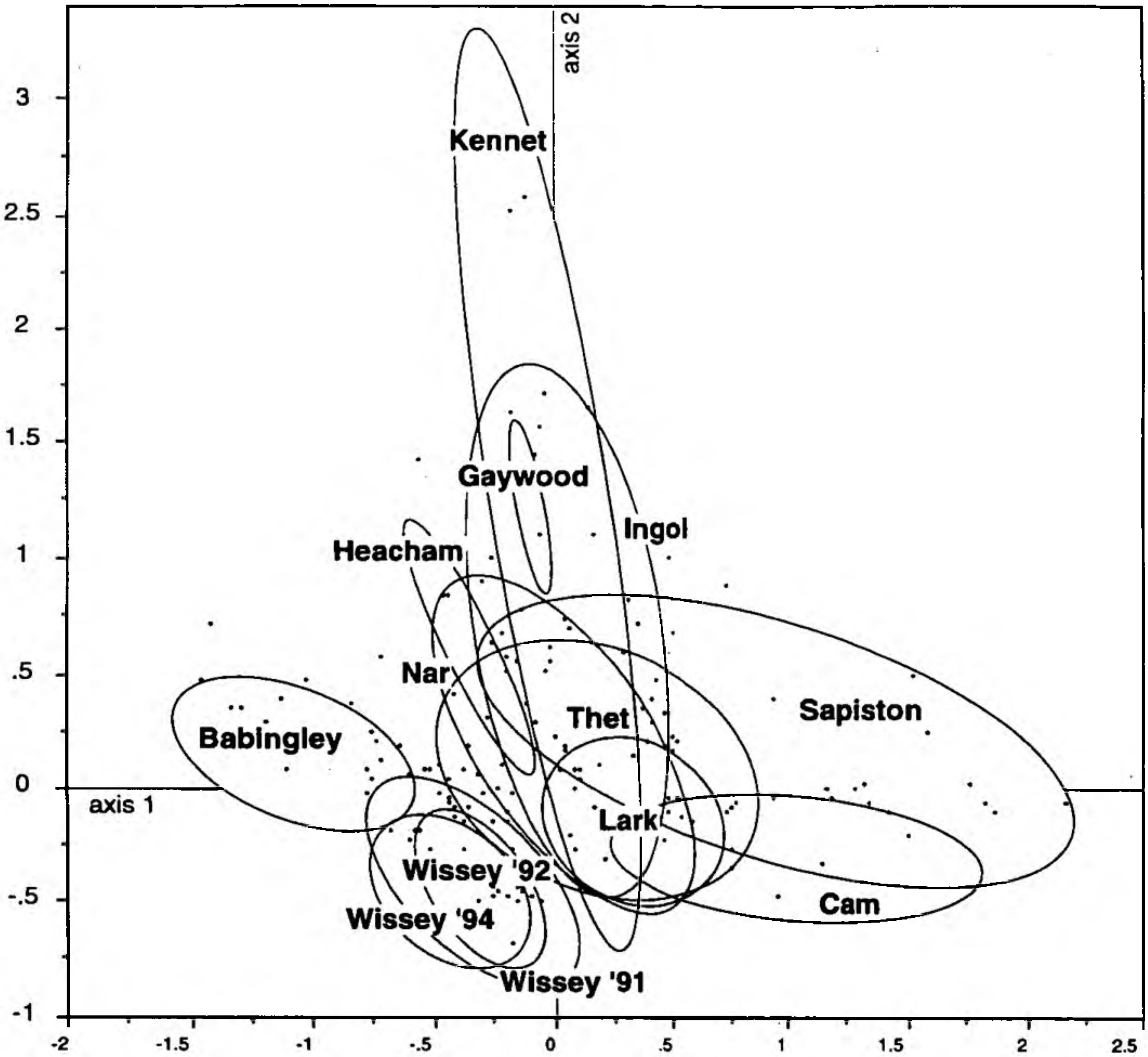


Figure 5.3 Subdivision of the ordination of the Anglian rivers species data to examine variation within-river. Left of each pair: elipses enclose cells from each survey (a,b,c = first, second and third surveys). Right of each pair: elipses enclose cells from each site (site numbers indicated).



taxa	freqency in surveys: a	b	c
Hydrobius fuscipes	0.07	0.00	0.00
Ephemerella ignita	0.31	0.02	0.01
Nepa cinerea	0.08	0.01	0.00
Laccobius striatulus	0.10	0.02	0.01
Planorbis planorbis	0.06	0.02	0.00
Eukiefferiella claripennis	0.06	0.01	0.01
Haliplus lineatocollis	0.15	0.05	0.01
Baetis scambus gp.	0.06	0.00	0.02
Brychius elevatus	0.09	0.03	0.01
Limnophora sp.	0.10	0.05	0.01
Eukiefferiella sp.	0.27	0.01	0.12
Ptychopteridae	0.09	0.05	0.01
Conchapelopia sp.	0.11	0.04	0.03
Agabus sp.	0.09	0.06	0.01
Macropelopia sp.	0.17	0.07	0.05
Hydroptila sp.	0.08	0.02	0.05
Limnius volckmari	0.20	0.09	0.10
Chironomus sp.	0.06	0.05	0.02
Lepidoptera	0.08	0.10	0.01
Tipula sp.	0.27	0.24	0.11
Dicranota sp.	0.31	0.13	0.22
Haliplus sp.	0.21	0.22	0.07
Lymnaea stagnalis	0.08	0.08	0.03
Oulimnius sp.	0.26	0.26	0.10
Planorbis vortex	0.42	0.38	0.22
Planorbis contortus	0.18	0.17	0.10
Bithynia tentaculata	0.11	0.08	0.08
Zonitoides nitidis	0.13	0.14	0.07
Polycentropus flavomaculatus	0.07	0.06	0.05
Theromyzon tessulatum	0.13	0.13	0.09
Baetis rhodani	0.13	0.08	0.12
Brillia modesta	0.08	0.02	0.09
Lymnaea peregra	0.30	0.27	0.25
Sialis lutaria	0.27	0.22	0.24
Glossiphonia complanata	0.64	0.62	0.54
Gammarus pulex	0.70	0.65	0.64
Valvata piscinalis	0.16	0.18	0.13
Potamopyrgus jenkinsi	0.67	0.58	0.65
Limnephilus lunatus	0.12	0.06	0.14
Helobdella stagnalis	0.14	0.14	0.13
Ephemera danica	0.08	0.05	0.09
Erpobdella octoculata	0.70	0.66	0.69
Pericoma sp.	0.07	0.06	0.08
Potamonectes depressus elegans	0.07	0.06	0.08
Asellus aquaticus	0.48	0.52	0.50
Sphaerium sp.	0.43	0.44	0.47
Ancylus fluviatilis	0.10	0.07	0.13
Polycelis nigra	0.28	0.22	0.38
Hydropsyche pellucidula	0.33	0.47	0.38
OSTRACODA	0.09	0.06	0.14
Elmis aenea	0.40	0.57	0.51
OLIGOCHAETES	0.55	0.57	0.80
Physa fontinalis	0.13	0.25	0.15
Sericostoma personatum	0.04	0.05	0.06
Goera pilosa	0.13	0.20	0.18
Helodes sp.	0.09	0.13	0.13
Simulium sp.	0.16	0.01	0.32
Prodiamesa olivacea	0.13	0.05	0.26
Valvata cristata	0.03	0.10	0.03
Hydropsyche angustipennis	0.06	0.10	0.10
Valvata macrostoma	0.05	0.13	0.07
Tinodes waeneri	0.11	0.24	0.17
Coengariidae sp.	0.06	0.16	0.09
Asellus meridianus	0.13	0.21	0.24
Caenis luctuosa	0.28	0.49	0.51
Athripsodes cinereus	0.06	0.08	0.13
Piscicola geometra	0.04	0.07	0.09
HYDRACARINA	0.13	0.17	0.35
Microtendipes sp.	0.04	0.09	0.11
Ceratopogonidae	0.09	0.11	0.28
Dendrocoelum lacteum	0.03	0.13	0.09
Planorbis albus	0.02	0.10	0.09
Dugesia lugubris	0.01	0.07	0.06
Planorbis crista	0.00	0.06	0.01
Planorbarius corneus	0.00	0.08	0.02
Acroloxus Lacustris	0.00	0.13	0.04
Microspectra sp.	0.01	0.01	0.09
Hydropsyche siltalai	0.00	0.07	0.08
Crangonyx pseudogracilis	0.00	0.14	0.19
Athripsodes aterrimus	0.00	0.04	0.07

Figure 5.4 Frequencies of taxa in the three surveys, (right: tabulated; left: illustrated by circles). Taxa are ordered using a correspondence analysis, such that the trend in frequency from first to last survey is displayed upper left to bottom right.



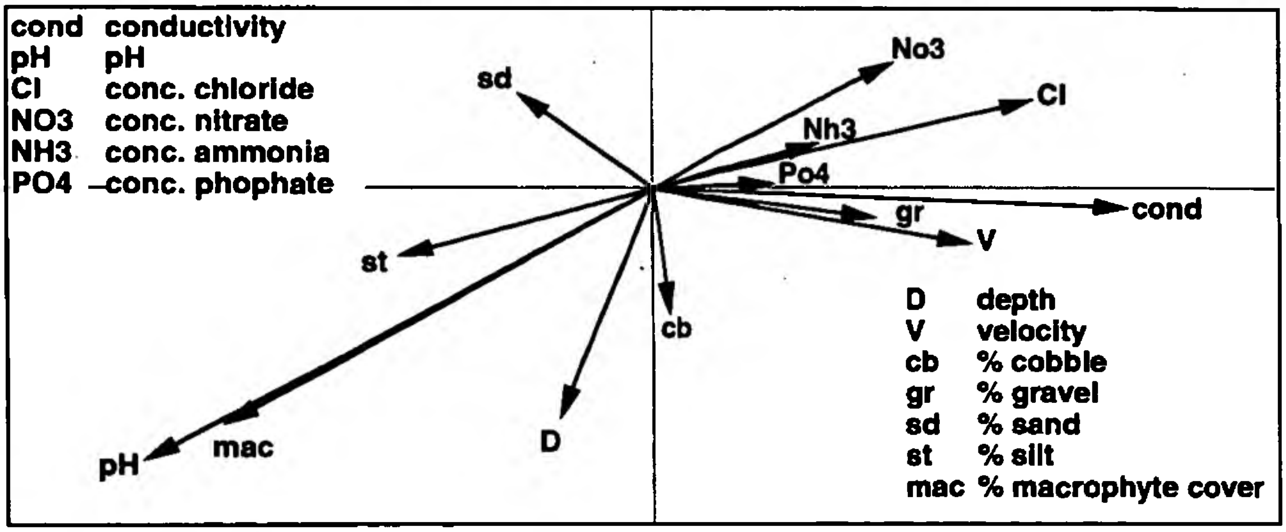


Figure 5.5 Detrended correspondence analysis of Wissey, Babingley and other Anglian rivers species data. Top: ordination of samples - elipses enclose 80% of sample points from each river. Bottom illustration of the correlations between variables and sample scores.

A high degree of community homogeneity is apparent, with overlap between most rivers. The Wissey and Babingley sites plot to the left of the main group of samples, suggesting possible methodological differences between the Loughborough University-based and Anglian NRA-based surveys, despite all attempts to standardise techniques.

Examination of the correlation of the environmental variables with the axis scores suggests that two gradients in site characteristics are operating in determining sample community: High conductivity, phosphate, nitrate and ammonia to low values of these determinands, with the Cam and Sapiston sites at one end of the trend and Nar, Heacham, Babingley and Wissey at the other; and deep, faster flowing, cobble/gravel sites to sand and silt dominated sites (Cam, Lark, Wissey to Gaywood, Kennet, Heacham and Babingley. Thus, both water quality and flow-related characteristics are important, but the former more so especially in distinguishing between rivers.

5.3 Transferability of River Wissey macroinvertebrate habitat suitability predictions.

In Section 4 it was described as to how the observed relationships between taxa and habitat characteristics were quantified using preference functions, predicted abundance and suitability curves. These allowed prediction of taxa habitat suitability and expected abundance in the other chalk streams data from the observed cell depth, velocity and macrophyte values.

5.3.1 Tests of observed and expected distribution of individual taxa.

The indicator taxa selected from the River Wissey analyses were used to predict habitat suitability for the 9 Anglian rivers cell data, using the October data which was collected at approximately the same time as the River Wissey 1992 survey. Observed abundances of the indicator taxa were compared with predicted suitability to test transferability of suitability predictions across chalk streams. Figure 5.6 shows plots of observed abundance against predicted habitat suitability for the six taxa, highlighting cell points from the different Anglian rivers.

A poor fit was encountered between individual taxa suitability and observed abundance. For Elmidae alone a reasonable trend was seen of increasing abundance with suitability, for some rivers only. Most notably significantly high habitat suitability for Simuliidae was predicted in many rivers, but this was rarely recorded at all.

The poor performance of the Wissey-based predictions on a single-taxon level is assumed to be a result of local between-river differences influencing occurrence and productivity of taxa.

5.3.2 Predicted community composition.

Using the method described in Section 4.7, predictions were made of abundance of a range of taxa showing strong habitat preferences on the Wissey. Figure 5.7 shows plots of observed against predicted (ln+1) abundance, using average values for each river. It was not anticipated that the absolute predicted abundance values would be matched by observed abundances (due to local water quality and other factors affecting macroinvertebrate productivity), but the trend in relative abundances of taxa could reasonably be expected to be successfully predicted using this method.

From Figure 5.7 it can be seen that in very few cases (the Nar and to a lesser extent Lark and Thet) were the predictions based on the Wissey habitat preferences matched by the relative magnitude of observed abundances. It was particularly notable that in many cases, high suitability was predicted for many taxa which were not recorded at all in the Anglian river sites. Poorest fits were found with the smallest rivers (eg. the Ingol), whilst best fits were with rivers of similar size to the River Wissey.

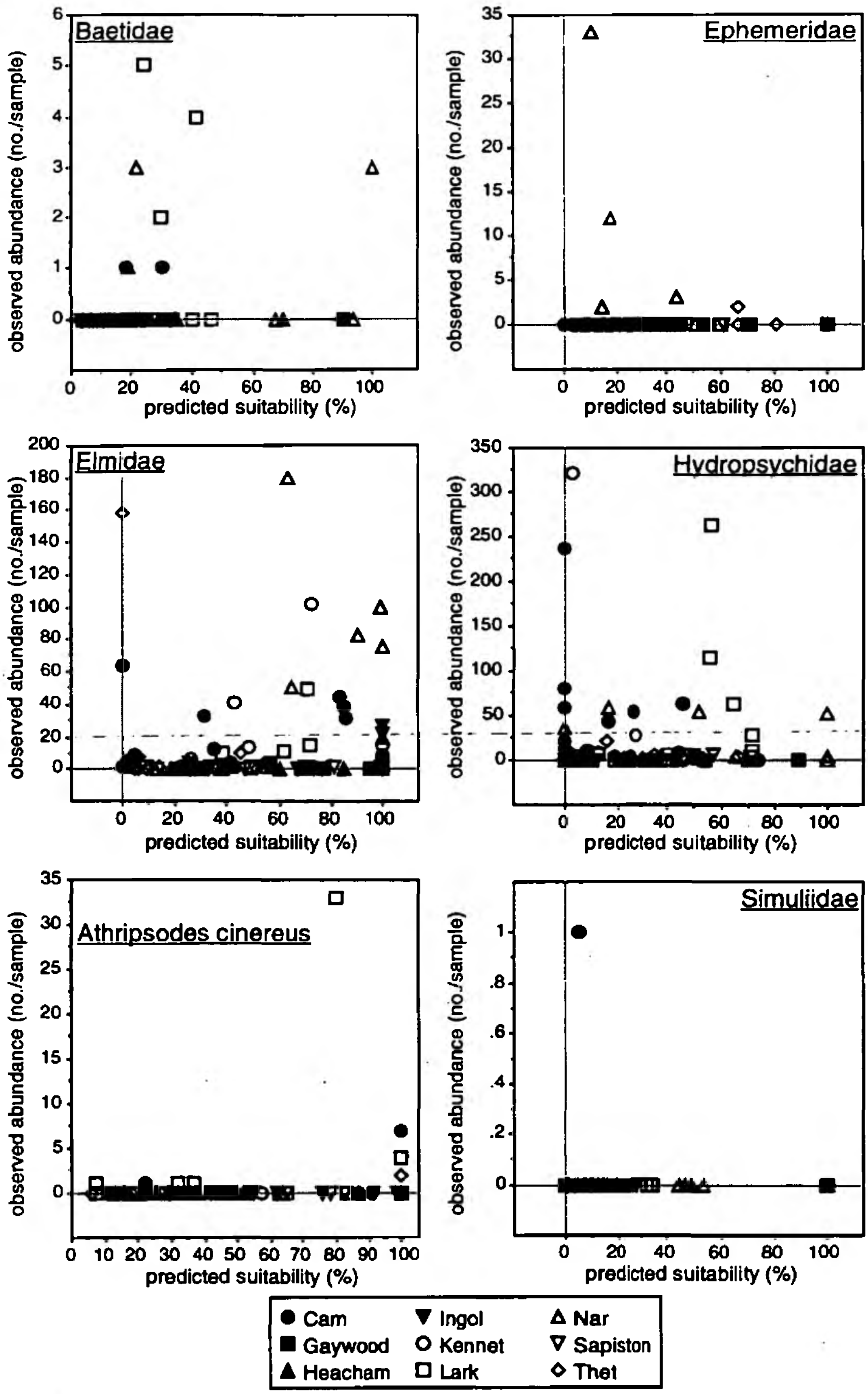


Figure 5.6 Observed abundances of indicator taxa in Anglian river sites plotted against predicted habitat suitability using River Wissey based preference functions. Points are cell values.

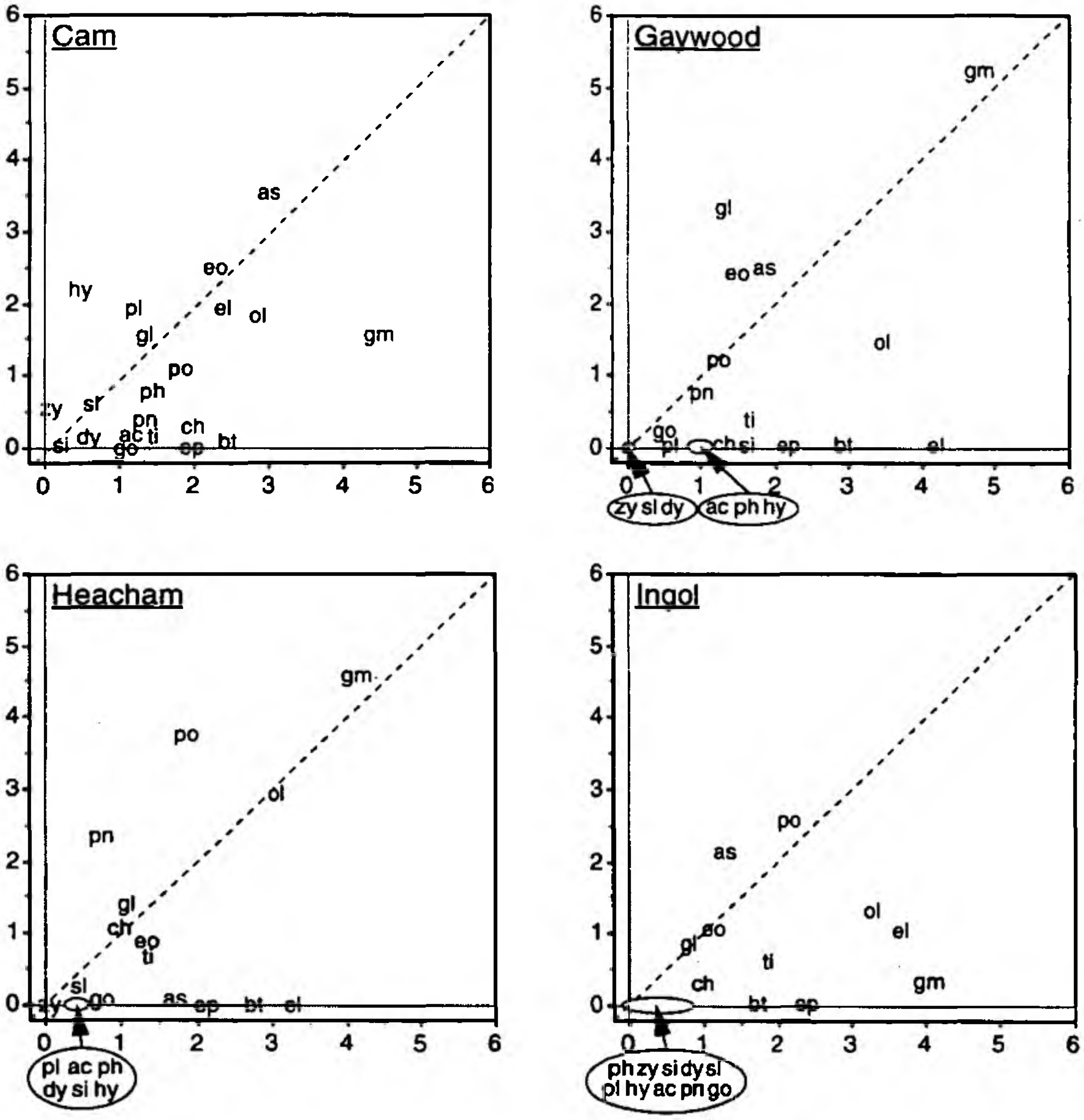
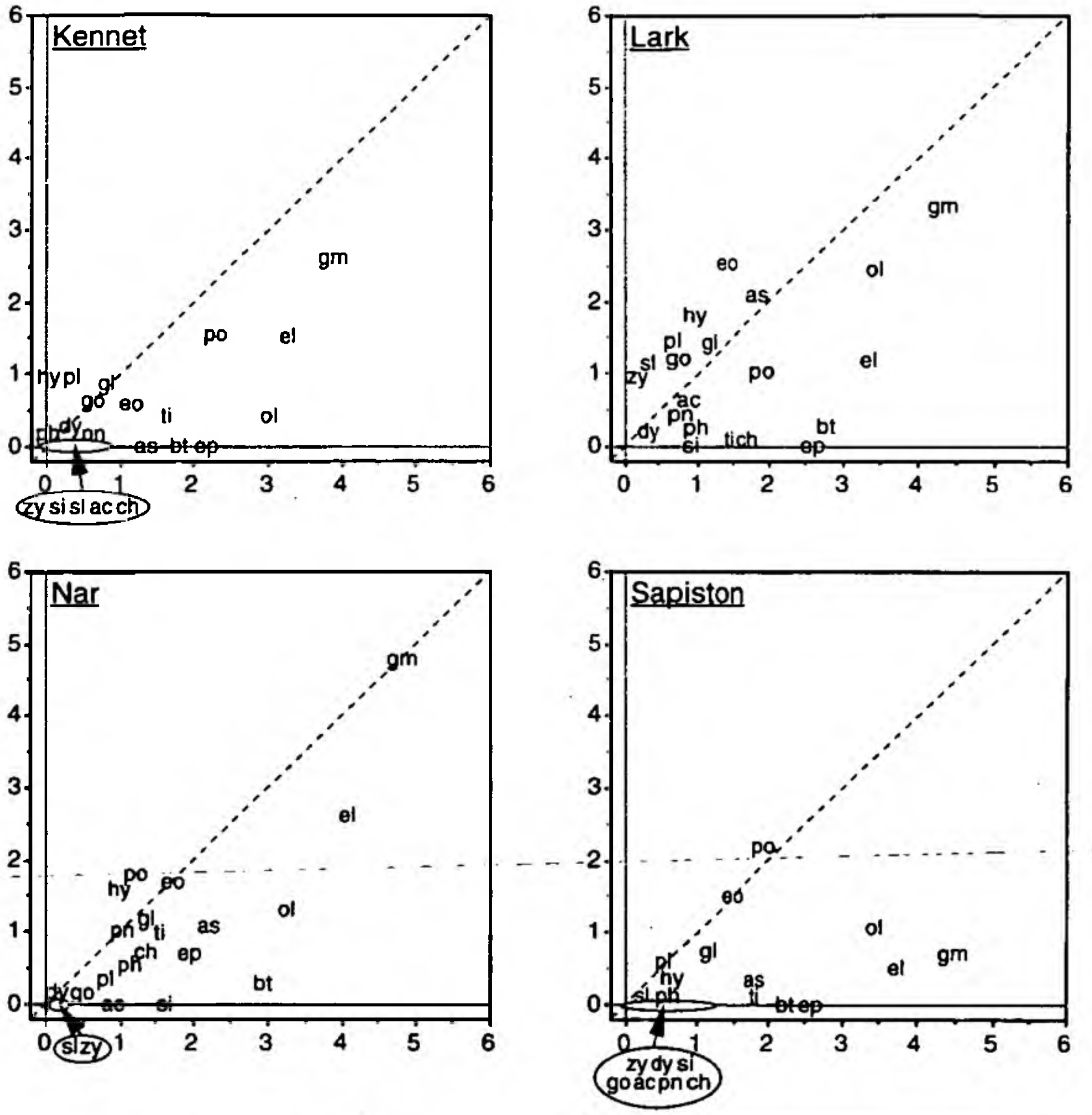


Figure 5.7 Comparison of observed and predicted (ln+1) abundances of selected taxa in all Anglian rivers.

taxa codes

pn	Planariidae	zy	Zygoptera
po	Potamopyrgus jenkinsi	dy	Dytiscidae
ph	Physa fontinalis	el	Elmidae
pl	Planorbiidae	si	Sialis lutaria
ol	Oligochaeta	hy	Hydropsychidae
gi	Glossiphonidae	ac	Athripsodes cinereus
eo	Erpobdella octoculata	go	Goeridae
as	Asellidae	ti	Tipulidae
gm	Gammaridae	ch	Chironomidae
bt	Baetidae	si	Simuliidae
ep	Ephemeridae		



taxa codes

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eo	Erpobdella octoculata	go	Goeridae
as	Asellidae	ti	Tipulidae
gm	Gammaridae	ch	Chironomidae
bt	Baetidae	si	Simuliidae
ep	Ephemeridae		

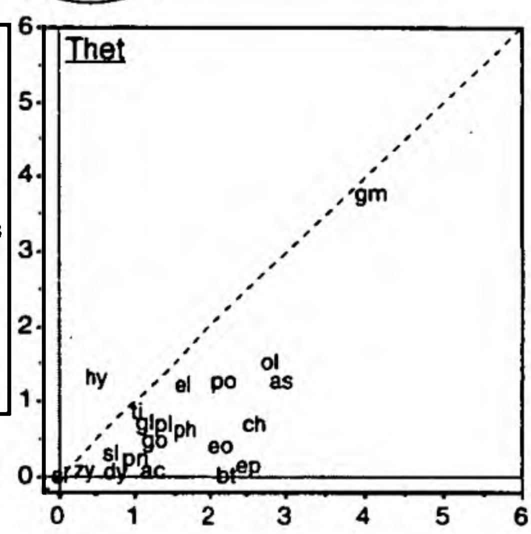

Figure 5.7 (continued).

6. RECOMMENDATIONS.

The previous Sections of this Report have detailed the results of the River Wissey investigations into the relationships between macroinvertebrates, in-stream habitat and flow. In Section 4 it was demonstrated that for a variety of macroinvertebrate taxa it is possible to describe and predict habitat suitability in relation to flow; although it was also discovered that the transferability of macroinvertebrate / habitat information between rivers may be limited (Section 5). On the basis of these results it has been possible to 1) recommend the use of macroinvertebrates as good habitat indicators in setting Ecological Objectives, and 2) recommend a standard methodology, based on that used in this project, for obtaining information on macroinvertebrate habitat / flow relationships for use on other rivers.

6.1 In-river flow needs for the River Wissey.

This Section describes the use of macroinvertebrates in setting Ecological Objectives and recommends EOs for the River Wissey based on macroinvertebrate indicator taxa and also fisheries data (presented in Part I of the Main Report). A specific discussion of the use of macroinvertebrates in setting EOs (as defined in the NRA Report on the Determination of Minimum Flows, 1995) is given in the "Summary of the Recommended Approach to Setting Flows for Ecological Objectives" which accompanies this Report.

6.1.1 Defining Ecological Objectives for the River Wissey.

Current work on the management of flows to protect river ecology recommends the setting of River Flow Objectives (RFOs), defined as Ecologically Acceptable Flow Regimes (EAFRs), and the promotion of sector-based Ecological Objectives (EOs) upon which the RFO is based. Details of this work are available in the NRA Report on Determination of Minimum Flows (1995).

Ecological Objectives for the Wissey were based on both fish and macroinvertebrate data. Information on fish habitat (obtained using PHABSIM, see Part I of the Main Report) provided the basis for defining benchmark flows in winter, spring summer and autumn, whilst macroinvertebrate indicator taxa provided detailed information on benchmark flows required to sustain end-of-summer habitat.

Benchmark flows.

Benchmark flows can be defined as follows:

i) A **Threshold Ecological Flow (TEF)** is the flow that must be sustained at all times, even during the rarest drought, to prevent catastrophic change; the flow that sustains habitat refuges for a target species or a minimum acceptable number of species.

ii) An **Adequate Ecological Flow (AEF)** is the flow below which the target shows major changes, ie the flow that sustains low-flow habitat for target species or a specified number of species. The AEF must be maintained in most years but may be inceeded during rare droughts.

iii) A **Desirable Ecological Flow (DEF)** to sustain connectivity between the different reaches throughout the length of river under investigation, ie sustaining suitable habitat within all reaches of the river under investigation.

iv) An **Optimum Ecological Flow (OEF)** to provide the maximum habitat for the target species or to maximize diversity. Under natural conditions this flow typically occurs infrequently but it is important in sustaining the ecological integrity of a river - many faunal populations may be dependent on an occasional strong year class (i.e. highly successful reproduction, recruitment, growth).

In addition to these ecological benchmarks, a **Channel Maintenance Flow (CMF)** must be defined, usually taken as the bankfull flow, to maintain the overall structure of the channel, and **Habitat Maintenance Flows (HMF)**, usually defined as a proportion of the CMF (often 40%), which flush the channel of accumulated fine sediments and organic detritus.

For macroinvertebrate indicator taxa, which may normally experience large changes in abundance, a reduction in habitat suitability to 67% of the optimum under standard dry-weather flow (q_L for the low flow month) is considered the limit of acceptable loss. Although this figure is subjectively chosen, it is suggested that this is most likely to be the level of habitat loss beyond which there is significant risk of long-term decline in the population. Thus, using the selected indicator macroinvertebrate taxa:

The **TEF** is the flow at which habitat suitability for at least two-thirds of the indicator taxa is maintained at or above 67% of optimum in at least one reach type in one sector;

The **AEF** is the flow at which habitat suitability for at least two-thirds* of the indicator taxa is maintained at or above 67% of optimum in at least one reach type in all sectors;

The **DEF** is the flow at which habitat suitability for all indicator taxa is maintained at or above 67% of optimum in at least one reach type in all sectors;

The **OEF** is the standard dry-weather flow: q_L for the low flow month.

* ie. the 4 less flow-sensitive out of the 6 indicator taxa, using the River Wissey example.

Benchmark flows for macroinvertebrates using habitat suitability / flow curves.

The values of these benchmark flows were ascertained through reference to habitat suitability curves for the indicator taxa (Figure 6.1) The values of the benchmark flows were set at: TEF = 0.20 cumecs; AEF = 0.35 cumecs, DEF = 0.55. Under these flows, habitat is maintained at at least 67% of optimum in the following number of reaches for each indicator:

	TEF (0.20 m^3s^{-1})		AEF (0.35 m^3s^{-1})		DEF (0.55 m^3s^{-1})	
taxon	sector 3	sector 4	sector 3	sector 4	sector 3	sector 4
Baetidae	1	0	1	1	2	2
Ephemeridae	0	0	1	1	1	1
Elmidae	1	1	2	1	2	1
Hydropsychidae	0	0	1	1	2	2
Athripsodes cinereus	0	0	0	0	1	1
Simuliidae	0	0	0	0	1	1

Benchmark flows for macroinvertebrates and fish on the River Wissey.

Table 6.1 lists the ecological targets for the River Wissey based on fish as well as invertebrate taxa, and indicates for which season these apply. Table 6.2 presents the actual benchmark flows determined for both fish and invertebrates.

Table 6.1 Specific Ecological Targets for the River Wissey Sectors 3 and 4.

Fish	Indicator	Season
	Adult brown trout (*Salmo trutta*)	Over-winter
	spawning	Autumn
	Juvenile brown trout	End-of summer
	Adult dace (*Leuciscus leuciscus*)	
	spawning	Spring

Targets for each 'indicator'
To sustain suitable habitat within all reaches of both sectors (Desirable Ecological Flow)
To sustain suitable habitat within one reach type in each sector (Adequate Ecological Flow).
To sustain suitable habitat within one reach type in one sector (Threshold Ecological Flow).

Flow-sensitive macroinvertebrate taxa

Baetidae	Elmidae	*Athripsodes cinereus*
Ephemeridae	Hydropsychidae	Simuliidae

Targets
To sustain suitable habitat for most (4/6) indicator taxa (Adequate Ecological Flow)
To sustain suitable habitat for one indicator taxon (Threshold Ecological Flow)

Channel Form and Riparian Flows
Target
To sustain the natural frequency and duration of the bankfull flow
To sustain 'flushing flows' at critical times of the year

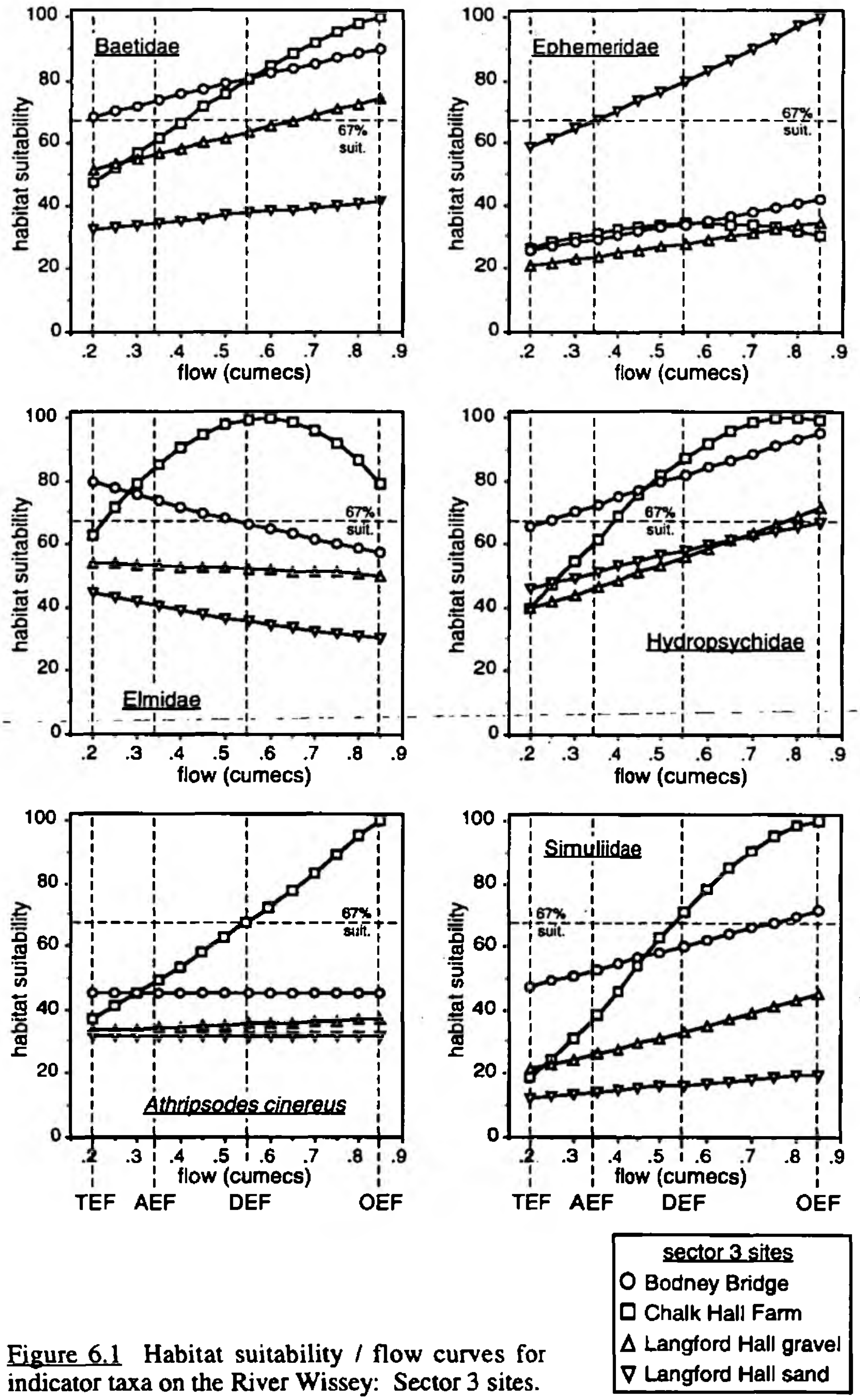

Figure 6.1 Habitat suitability / flow curves for indicator taxa on the River Wissey: Sector 3 sites.

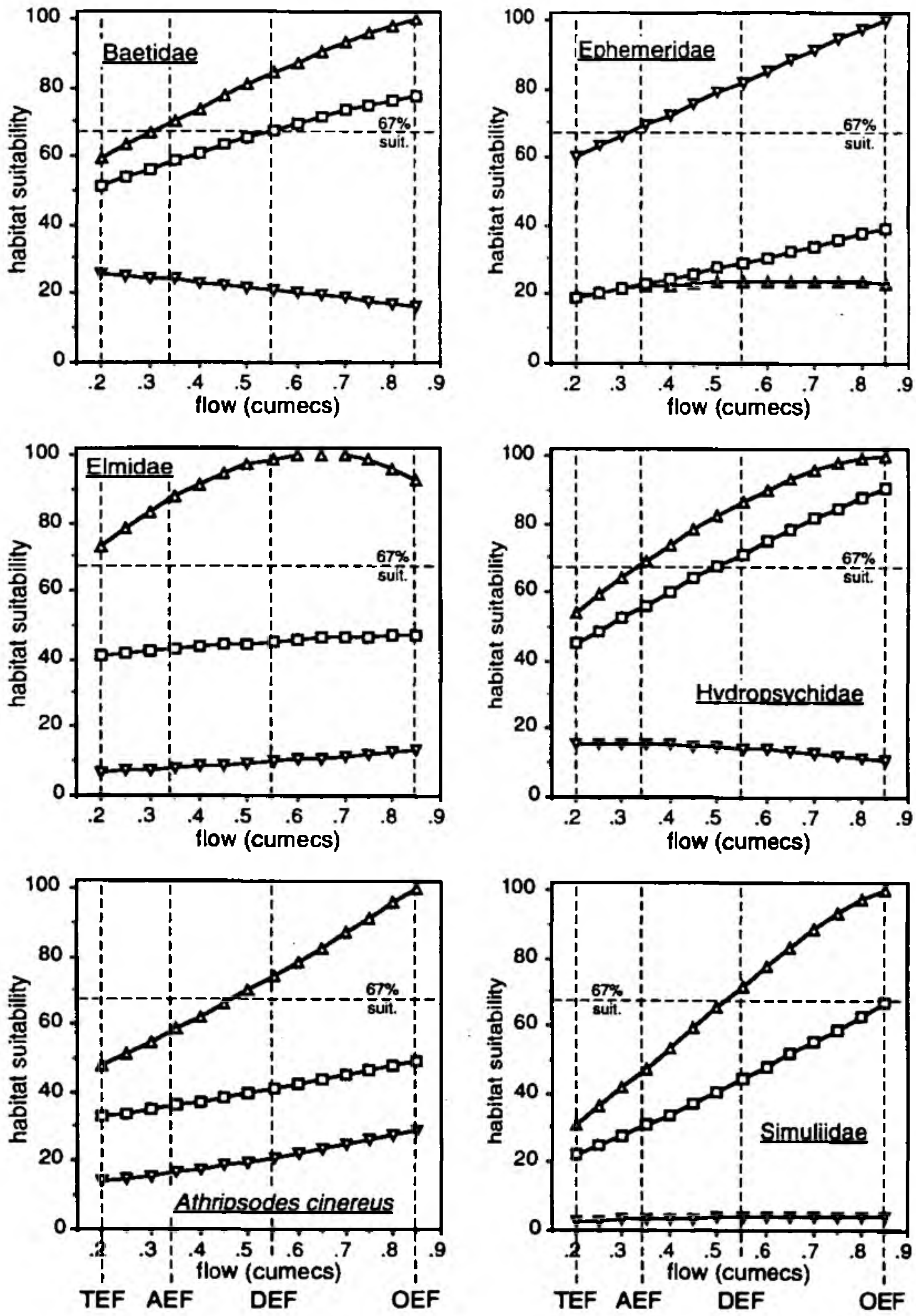

Figure 6.1 (continued) Habitat suitability / flow curves for indicator taxa on the River Wissey: Sector 4 sites.

Table 6.2 Benchmark flows determined for the River Wissey (sectors 3 and 4, having 4 and 3 reach types, respectively).

season	benchmark	macroinvertebrates and dace	macroinvertebrates, dace and juvenile salmonids	macroinvertebrates, dace and adult salmonids
end of summer	OEF	0.85		0.90
	DEF	0.55		0.60
	AEF	0.35	0.30	0.40
	TEF	0.20	0.20	0.30
autumn				
November	OEF	1.40		1.40
"	DEF	0.55[1]		0.90
December	AEF	0.40		0.40
"	TEF	0.35		0.30
winter				
February	OEF	3.50[2]		3.50
"	DEF	2.50		3.50
March	AEF	1.40		2.00
"	TEF	1.00		0.90
April[3]	OEF	2.35		2.50
"	DEF	2.00		2.00
"	AEF	1.30		1.35
"	TEF	1.10		1.20
May	OEF	1.40		
"	DEF	1.00		
"	AEF	0.90		
"	TEF	0.70		

[1] Flow greater than 0.5 cumecs, and must equal or exceed end-of-summer DEF.
[2] With flow exceeding 8.5 cumecs for part of the time.
[3] Flows needed to achieve end-of-summer targets under dry-year flow recession.

6.1.2 Defining Ecologically Acceptable Flow Regimes for the River Wissey.

Construction of annual hydrographs and EAFRs from benchmark flows.

The benchmark flows may be used to define different types of annual hydrograph, by using the natural (dry weather) flow recession curve for the catchment to scale monthly flows through spring and summer to the end-of-summer flow target. For example (see Figure 6.2): wet year hydrograph to provide optimum conditions for each season-specific ecological target, normal low-flow year hydrograph, and a drought year hydrograph. Acceptable frequencies must be given to each of these hydrographs which can then be combined to establish the EAFR and set control rules.

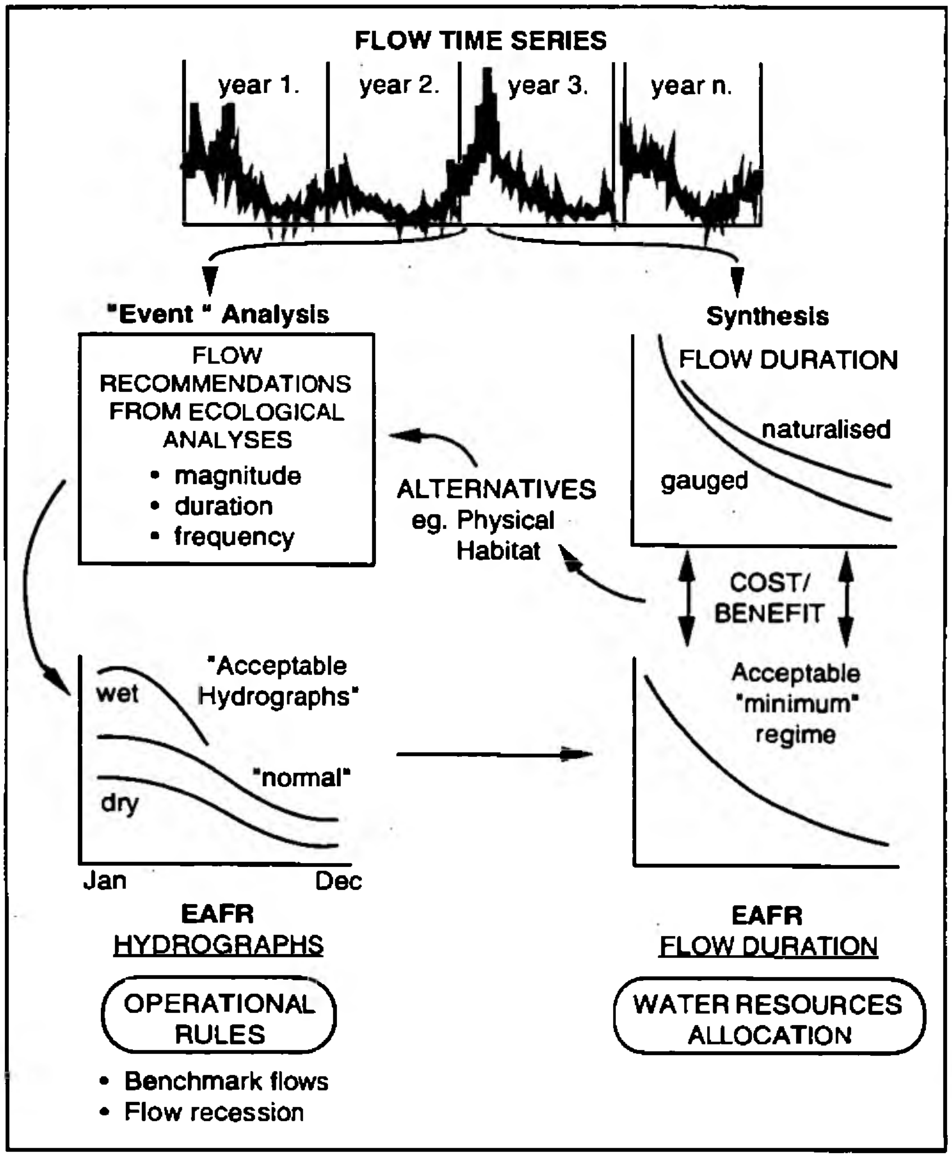

Figure 6.2 Methodology for the determination of Ecologically Acceptable Flow Regimes (EAFRs), based on integrated investigation of hydrology and ecology, following the Babingley recommendations (NRA, 1995).

Wet, normal and dry year hydrographs for the River Wissey.

'Acceptable' minimum flow regimes were determined from the benchmarks given in Table 6.2 for a range of annual flow frequencies: Wet, normal, dry and drought years were defined as having flows with the following frequencies: wet year - flows exceeded 1:3 years, normal year - flows exceeded 1:2 years, dry year - flows inceeded 1:5 years, and drought year -flows inceeded 1:20 years. The recommended minimum flow regimes are tabulated in Table 6.3 and illustrated graphically in in Figure 6.3.

Table 6.3 Recommended minimum-flow regimes for the River Wissey. All flows are in cumecs. R=flow back-estimated from end-of-summer low flow using dry-weather recession. Figures assume no surface-water abstractions. Winter flows are "indicators" of groundwater levels to sustain summer flows.

	Wet year	Normal low	Drought	Severe drought
Frequency flow equalled or inceeded				
a) Invertebrates and dace	1.50	2.00	5.00	20.00
January	2.80	1.50	0.50	0.35
February	3.50	2.50	1.00	0.90
March	2.85	2.30	1.40	1.00
April	2.35R	2.00R	1.30R	1.10R
May	1.70	1.50	0.90	0.75
June	1.30	0.95	0.75	0.50
July	1.00	0.75	0.55	0.35
August	0.90	0.65	0.45	0.25
September	0.85	0.55	0.35	0.20
October	0.85	0.55	0.35	0.20
November	1.40	0.55	0.35	0.20
December	2.00	0.75	0.40	0.35
Mean	1.82	1.30	0.75	0.59
b) Invertebrates, dace and trout				
January	2.80	2.00	0.60	0.40
February	3.50	3.50	0.90	0.90
March	2.85	2.30	2.00	0.90
April	2.50R	2.00R	1.35R	1.20R
May	1.80	1.50	0.90	0.80
June	1.30	0.95	0.75	0.55
July	1.10	0.75	0.55	0.45
August	1.00	0.65	0.45	0.35
September	0.90	0.60	0.40	0.30
October	0.90	0.60	0.40	0.30
November	1.40	0.90	0.40	0.30
December	2.00	1.25	0.50	0.30
Mean	1.88	1.40	0.78	0.58

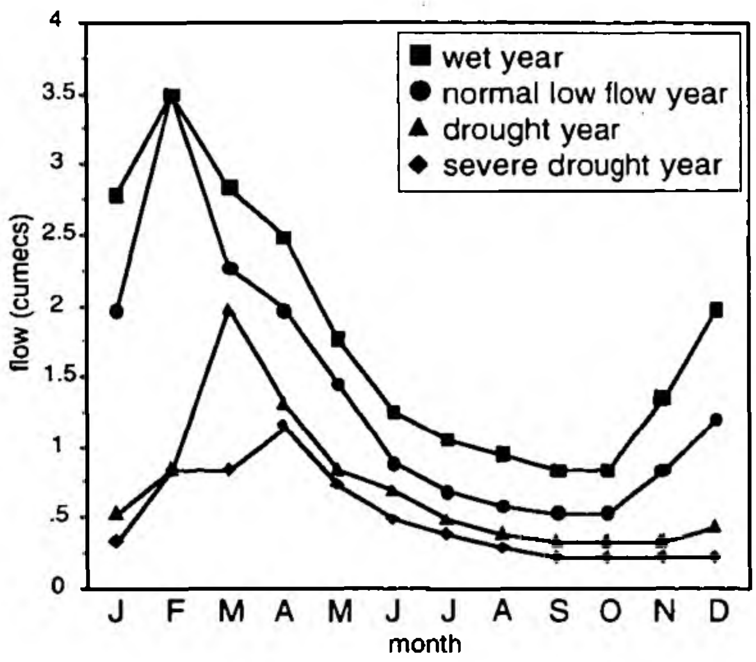

Figure 6.3 Monthly flows to meet the ecological needs of invertebrates, dace and trout on the River Wissey, in wet, normal, drought and severe drought years.

EAFRs for the River Wissey.

Two EAFRs were determined (Table 6.4 and Figure 6.4): i) for invertebrates and dace, and ii) for invertebrates, dace and adult trout. An EAFR for macroinvertebrates alone was not produced because of the similarity with the dace and macroinvertebrate benchmark flows (which also sustain habitat for juvenile trout).

Table 6.4 EAFRs (flow duration percentiles) to meet different Ecological Objectives for the River Wissey. Based on data in Table 6. Percentiles - flows equal to or greater than.

[1] Assumes high flows unaffected by abstractions but the duration of these flows would be reduced if winter surface-water abstractions are allowed; rules for such abstractions are given in the report, and the impact of maximum winter surface-water abstractions on the estimated mean flow is given in the last two rows of the table ([2]).

Flow (cumecs)	Percentiles 1956-'88 (gauged)	Percentiles 1956-'94 (gauged)	Invertebrates and Dace	Invertebrates, Dace and Trout
8.20[1]	0.2	0.15	0.15	0.15
4.33[1]	5	4.3	5	5
3.50[1]	10	9	10	10
1.50			37	32
1.00	70	68.7	48	46
0.90			52	69
0.80	82	79	54	72
0.70	90	85.5	64	78
0.60	94	90	70	91
0.50	98	94	86	94.5
0.40	99.2	96.5	94	98
0.35	99.4	97.5	98	98.8
0.30	99.7	98.3	98.5	100
0.20	99.9	99.8	100	
Estimated mean (cumecs)	1.91	1.81	1.36	1.42
Runoff (mm)	219	208	156	163
[2]Mean (cumecs)			1.07	1.29
[2]Runoff (mm)			123	150

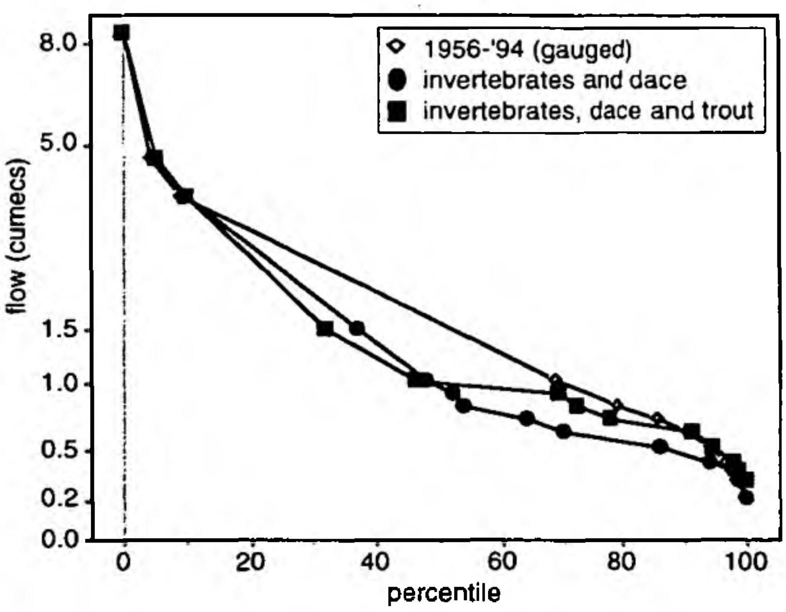

Figure 6.4 EAFRs (flow duration percentiles) to meet the ecological needs of i) invertebrates and dace and ii) invertebrates, dace and trout on the River Wissey, in comparison with the long-term (1956-'94) gauged flow.

6.1.3 Abstractable volumes.

The results given above allow specification of the acceptable maximum volume of abstractions:

Runoff - Environmental needs = Abstractable volume

Thus, for the Wissey (based on the EAFR for trout, dace and invertebrates in Table 6.4), having an average in-river flow requirement of 1.42 cumecs, equivalent to 163 mm of runoff, the **acceptable maximum abstraction (from both groundwater and surface water) is 0.4 cumecs (which equates to 45 mm of runoff or 34.5 Mld) plus average actual abstraction net of actual effluent returns.**

6.1.4 Control rules.

The information gained from in-river flow analyses (see Table 6.4) may be used to recommend flow control rules including 'hands-off' flows (HOF) for surface-water abstraction licenses and maintained flows (MF) to protect in-river needs. The following are examples. Whether or not they are practicable must be evaluated locally. If they are not, a precautionary approach should be adopted.

To sustain the Wissey as a trout stream:

1. Winter HOF (November to June inclusive) = 1.4 cumecs *but a 30-day flow of more than 3.5 cumecs must be spared* ***each*** *year if such flow occurs naturally and a 15 day flow of more than 8 cumecs should be spared at least once every 5 years.* The time-period (November-June), has been chosen to protect the river during the key months (November, May, and June).

2. Summer HOF (July to October inclusive) = 0.90 cumecs (cf the gauged 95th percentile flow for the period 1956-94 of 0.47 cumecs)

In a drought year (with an acceptable frequency of no shorter than 1:5 years) the controls on abstractions may be relaxed:

3. If flow on 1st February has not reached 1.4 cumecs, the HOF for February through June may be reduced to 1.0 cumec and the summer HOF may be lowered to 0.6 cumecs.

End-of-summer maintained flows may also be specified:

4. End-of-the summer flows should normally be maintained, by groundwater support if necessary, at a minimum of 0.4 cumecs (about 20% of the mean daily flow).

5. Exceptionally, under 1:20 year drought conditions, the minimum maintained flow may be reduced to 0.30 cumecs (about half the 1956-94 gauged 95th percentile flow 0.58 cumecs).

6.1.5 The use of Q95.

The tradition of using the 95th percentile flow (Q95), based on historical data, is open to question because the statistic is highly variable depending upon the period of record examined. The full-record (1956-94) statistic for the Wissey (0.47 cumecs[1]) approximates the EAFR Q95 and may be useful for describing the ecologically acceptable flow duration curve. However, the flow under-estimates the volume required to protect the river ecosystem in 'normal' (DEF = 0.60 cumecs) and, especially, wet years (OEF = 0.9 cumecs), but over-estimates the in-river needs during dry years (AEF = 0.4 cumecs) and severe droughts (TEF = 0.3 cumecs).

The research has shown that for both the protection of river ecosystems and the optimization of water resources for abstractions requires more complex rules than a single end-of-summer minimum flow, such as Q95. It is recommended that ecological flows should be defined for all periods of importance for the ecological target(s). For example, for the Wissey the range of targets included trout spawning (November), channel maintenance (February), dace spawning (May) and number of invertebrate taxa (September).

The detatiled application of the flow targets defined in this study to water resources management and licensing policy is outside the scope of this study. However, is is recommended that these targets be applied when developing flow targets for augmentation works; and there is scope for considering seasonally varying hands-off flows or their application to construct a set of tiered hands off flow bands.

[1] This value is calculated from the historical gauged flows. In practise the naturalised Q95 has been used where possible to determine flows to protect the environment (or the groundwater resource allocation to support this flow); this often provides a higher Q95 than the value based on gauged flows.

6.2 Other recommendations for the River Wissey

This second Part of the Report on the River Wissey investigations has specifically presented recommendations for the management of flows based on the extended 1991, '92 and '94 data set. In addition to these, the study provided a catchment perspective of the conservation value and potential of the Wissey, using information from the habitat surveys and special surveys of selected sites and biota. These results and recommendations were provided in Part I of the Report (NRA 1994). A summary of the recommendations is presented in Table 6.5, and the main points outlined below. Specific attention should be given to:

- creating buffer zones along most of the headwater streams to reduce nutrient and fine sediment inputs from agricultural land; control instream macrophyte growth by shading, thus reducing maintenance costs and ecologically damaging dredging activities; and improving the conservation value of the river corridor.

- from Hilborough to Buckenham Tofts weir ensure that no works are undertaken to degrade the channel form and riparian areas.

- from Buckenham Tofts weir downstream, habitat diversity should be improved along the channel margins by creating eddies, backwaters and marginal cover; the careful location of dead trees would be advantageous, and gravel accumulation and limited bank erosion should not be revented.

- during dry summers, management of macrophytes should be limited to the maintenance of a few, fast-flowing runs.

- monitoring of water quality and flows should be undertaken at Hilborough, below the Watton Brook confluence (an important control point in the stream network) in order to monitor long-term trends and short-term incidences.

- monitoring of groundwater levels surveyed into river levels is recommended between North Pickenham and Hilborough, an important reach for groundwater discharge maintaining flows during dry periods.

Table 6.5 Conservation value, potential for enhancement and recommended management for the River Wissey and tributaries.

Sector/reach	Character	Present conservation value	Potential for enhancement	Recommendations
Wissey, Sector 1. Bradenham to Ernford House.	Heavily managed, ditched section through arable surroundings. Good gravel substrate and moderate flow velocities. Upper reach is intermittent.	Low. Some organic pollution and high-nutrient arable runoff problems.	Good. A relatively natural, attractive stream could be achieved with moderate investment in management.	Introduce buffer zones / reduce frequency of dredging to allow emergents / riparian flora to develop. Any additional measures to increase channel diversity.
Wissey, Sector 2. Ernford House to Watton Brook confl.	Moderate to low intensity of management, mainly pasture / wet meadow. Silty runs with few gravel riffles.	Mixed. Some excellent wet meadows of very high value. Instream habitat moderate / poor. Organic pollution problems.	Good. Riparian habitat already quite good, instream habitat could be improved.	Preserve and extend wet meadow areas. Reduce access for stock to riparian margins to limit grazing and poaching. Control organic pollution problem - at source or through root exclusion zones / ponds.
Wissey, Sector 3. Watton Brook confl. to Buckenham Tofts.	Semi-natural, typical Chalk stream. Good pool-riffle structure but some ponding from sluices.	Excellent. Instream habitat good, especially around Chalk Hall Fm., with diverse substrate, flora and invertebrate and fish fauna. Riparian woodland of moderate value.	Moderate. Instream habitat requires preservation rather than enhancement. Riparian alluvial woodland could be significantly improved.	Preserve instream habitat. Replace riparian plantation trees with native species and let understory develop naturally.
Wissey, Sector 4. Buckenham Tofts to College Farm.	Semi-natural , with deep run habitat predominating in-stream. Mainly plantation surrounding.	Moderate. Instream habitat of only moderate quality for invertebrates and flora due to predominance of deep runs. Good adult trout habitat.	Good. Instream habitat fulfils function as adult trout habitat; fry habitat and riparian flora could be greatly improved.	Improve marginal habitat for fry / invertebrates by increasing diversity. Develop backwater areas. Replace riparian plantation trees with native species.
Wissey, Sector 5. College Farm to Whittington.	Heavily managed, fenland section.	Moderate. Habitat typical for this type of section, with good coarse fishery. Riparian zone is poor.	Moderate. Natural character and drainage function will limit potential for instream improvements.	Introduce buffer zones. Create adjacent fish fry habitats - backwater areas. Any measures to increase habitat diversity.
River Gadder. Cockley Cley to Gooderstone.	Intermittent in upper section with artificial lakes; perennial in lower section with wet woodland / meadow.	Good. Natural, if recently more frequent, drying out severely limits instream habitat above spring-head, but seasonally wet meadows at Mill Covert are extremely valuable habitat for rare invertebrates.	Moderate. Intermittency of upper reach limits instream improvements. However, wet meadow areas could be extended.	Preserve and extend wet meadow areas around the springs. Wildfowl lakes are being created above Gooderstone Water Gardens - selective removal of willows and extension of wetlands around these lakes would be an improvement.

Table 6.5 (continued). Conservation value, potential for enhancement and recommended management for the River Wissey and tributaries.

Sector/reach	Character	Present conservation value	Potential for enhancement	Recommendations
River Gadder. Gooderstone to Wissey confl.	Run-type instream habitat through pasture and arable land in the lower part. Dense emergent vegetation in places controlled by cutting.	Moderate / low. Grazing and arable cultivation limit riparian vegetation in most parts. A brown trout population existed prior to 1990.	Moderate. Riparian flora could be improved.	Limit stock access to banks in pasture areas to allow regeneration of riparian zone. Develop buffer zones in lower reach and improve channel management for fish fry habitat.
Stringside Stream. Upstream of Barton Bendish and Beachamwell tributaries	Intermittent headwaters through arable land.	Low. Heavily dredged.	Good. These tributaries are more frequently dry than the upper main river, limiting potential for instream improvements. However, in these intensive arable areas small streams / ditches provide valuable damp refugia for a variety of invertebrates and even birds and small mammals, and provide landscape interest.	Anything to improve riparian zone - both in extent and diversity. Develop buffer zones and aim to reduce dredging / cutting in the medium-term.
Stringside Stream. Beachamwell to confl. with Barton Bendish stream (Lode Dyke).	Intermittent, wooded stream u/s Oxborough Wood; perennial, spring-fed stream through woodland / arable land d/s Eastmoor.	Mixed. In the Beachamwell section there is an interesting aquatic invertebrate fauna associated with the intermittent flows. Lower section of lesser interest.	Moderate. The perennial section could be improved by measures to increase extent and diversity of riparian and instream flora.	Oxborough Woods are already under management to improve the conservation value of the woodland. Instream flora through the Woods may be improved by selective woodland thinning.
Stringside Stream. Confl. with Barton Bendish stream to confl. with Wissey.	Ponded by G.S. in upper section and from main river in lower. Heavily dredged except immediately d/s G.S.	Poor, except for a small section d/s G.S. where the flow is faster and riparian trees prevent access for dredging machinery. Coarse fish proliferate in the lower section, which provides a valuable refuge from the main river during high flows.	Poor. Ponding and necessary drainage work will limit possibilities for enhancement.	Extensions of buffer zone above and below G.S. - increase shading to reduce necessity for frequent dredging.
Watton Brook. Downstream of Watton.	Gravel bed, naturally riffle-pool stream but dredged and cultivated up to banks. Organic pollution problems.	Poor. Very little interest.	Good. Instream habitat could drastically improve if water quality was raised. Potential also for improving riparian habitat.	Buffer zones. Improve / reduce effluent entering stream. Reduce cutting and manage channel to increase instream and riparian macrophytes which will may improve water quality.

6.3 Application of the River Wissey methodology to other rivers.

6.3.1 Conclusions from the River Wissey investigations.

The earlier Sections of this report have investigated the potential for the use of macroinvertebrates as indicators of flow-related habitat, within one river (the Wissey) and across a region (nine other chalk streams). Section 4 developed a method for developing and testing preference information within-river, whilst in Section 5, preference information for macroinvertebrate indicator taxa derived from the River Wissey data set was compared with observed distributions of these taxa in other rivers. It can be concluded from the results of these analyses that:

- Within a river, macroinvertebrates provide useful indicators of flow-related habitat.
- The relationships between taxa at species and family level can be modelled using multivariate regression methods and used to successfully predict relative abundance between sites within-river, at least at the Sector scale.
- Habitat suitability information based on macroinvertebrate taxa can be used in the setting of sector scale Ecological Objectives, through the derivation of end-of-summer benchmark flows to sustain sensitive "indicator" taxa.
- River Flow Objectives can be set using a combination of Ecological Objectives for macroinvertebrates and fish, which provide seasonal benchmarks used in compiling Ecologically Acceptable Flow Regimes.
- Direct transfer of macroinvertebrate habitat preference information between rivers does not provide an adequately sound basis for predicting habitat suitability.
- Macroinvertebrate habitat preference based on survey data from one river may give a guide to the expected dominant taxa in other rivers.
- Historical EA biological and flow data can provide useful information, within any one river, on a) the relationships between taxa-richness and flow between years, and b) the taxa (at BMWP taxa level) most sensitive to year-on-year flow changes.

Thus, whilst the method developed in this report has proved successful in determining habitat suitability / flow relationships within one river, direct transferability of results between rivers is not predicted to be successful.

However, the River Wissey investigations strongly suggest that the application of the field and analytical methods developed for the Wissey to other similar chalk streams will allow equally successful within-river habitat suitability / flow predictions. It is highly recommended that this methodology is employed in the development of Flow Objectives for other rivers. To this purpose, a revised methodology has been prepared for the assessment of macroinvertebrate relationships with instream flows, which is presented in the accompanying Manual.

6.3.2 A standard methodology for assessing macroinvertebrate relationships with flow.

The methodology presented in the Manual is adapted from that employed in this project, and is designed through a series of steps using field-based and historical data to provide increasingly accurate information on the relationships between macroinvertebrate and instream flows - from a) determining whether or not the community is responsive to flow; b) identifying key habitat variables and indicator taxa, to c) production of taxa habitat suitability curves and surfaces and d) the use of these in defining benchmark flows for setting Ecological Objectives for flow management. The steps involved in the method, and the basis of the recommended procedures, are outlined below.

ii) River selection. The assessment of the physical characteristics of the river under investigation is discussed, and the likely applicability of the method appraised based on the experience of the Rivers Wissey and Babingley investigations, analysis of data from other rivers, and basic geomorphological principles.

ii) Catchment surveys and spatial definitions. Catchment survey techniques and the definition of sectors and reaches are recommended, based on the methods used in the 1991-'92 Wissey surveys.

iii) Utilisation of historical data. A recommended set of analyses are presented, using the most successful elements of the Rivers Wissey, Babingley and Glen historical analyses. These comprise a simplified community analysis to aid sector and reach definition; regression analysis to determine the relationship between numbers of taxa and summer low flows, and chi-squared test to identify macroinvertebrate families responding to year-on-year flow differences in flow.

iv) Site survey methods. Field survey methods to collect habitat and macroinvertebrate information are presented, which closely follow those used in the Wissey investigations. Surveys are recommended to be taken in late summer only, and practical survey timetables to provide adequate data for subsequent analyses are suggested.

v) Community relationships with habitat variables. A simplified set of classification and ordination analyses are recommended which allow site classification and sector definition, and identification of key habitat variables for correlation with invertebrate taxa.

vi) Describing taxa-habitat relationships. Based on the comparative tests of various methods to relate macroinvertebrate distributions with habitat data (Wissey Report Part I, Annex D, and Section 4 of Part I above), a multivariate regression method is recommended. A step-by-step guide is provided to organising the species and habitat data, selecting indicator species, performing regression analysis, and producing habitat suitability curves and surfaces. The use of suitability curves and surfaces in site assessment is discussed.

vii) Describing taxa-flow relationships. A method of assessing habitat / flow relationships is described, and linked with taxa / habitat information to produce habitat suitability / flow curves.
viii) Defining flow and habitat management options. Guidelines are given for determining benchmark flows from historical and field-based information on macroinvertebrate / flow relationships.

The methodology is designed to be a self-contained guide for EA use. Details are given in the introduction to the Manual of the expertise required to undertake the various parts of the field and analytical work. It is believed that this methodology provides a successful, practical approach to using macroinvertebrates towards setting Ecological Objectives for flow management.

6.4 Recommendations for further research.

The River Wissey investigations have proved the value of macroinvertebrate data in determining relationships between biota and flows within one river, and predicts that the use of a revised methodology, based on that used in the project and outlined in the Manual, will be successful in determining similar relationships in other, similar, rivers.

The key recommendation of this report is that the standard methodology presented in the Manual be applied to one or more rivers of similar character to the Wissey, and the results compared with those from the River Wissey. This will establish:

1. whether the revised field-survey based methodology is successful in defining macroinvertebrate habitat / flow relationships within other rivers;

2. to what degree the habitat preferences found within another similar river, based on a larger data set than that collected from the other chalk streams examined in Section 5 of this Report, are similar and transferable between rivers; and

3. whether analysis of historical data suggests similar relationships between macroinvertebrate taxa-richness, family occurrence and flow to those recorded from the Wissey, Babingley and Glen data sets.

It is recommended that the further research follow a two-stage process: 1) The application of the methodology to another one or more rivers and 2) the critical comparison of the results from this (these) studies with those from the Wissey. The latter stage will allow the methodology to be appraised and modified towards recommendation for wider application.

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Appendix 1. Depths, current velocities and macropyte cover from habitat surveys, 1991-1994.

NTWD Q = gauged flow at Northwold G.S. on day of survey.
D50%ile and V50%ile = 50th percentile depths and velocities from 60 point measurements.
TM mn = mean macropyte cover from 60 point measurements.

Bradenham

date	NTWD Q	D50%ile	V50%ile	TM mn
May-91	0.528	0.040	0.092	71
Jul-91	0.397	0.160	0.048	26
Aug-91	0.225	0.080	0.000	50
Oct-91	0.202	0.040	0.118	48
Nov-91	0.308	0.040	0.128	26
Dec-91	0.391	0.040	0.113	37
Feb-92	0.763	0.090	0.271	27
Mar-92	0.658	0.050	0.233	18
Apr-92	1.114	0.085	0.372	9
May-92	0.660	0.050	0.194	62
Jun-92	0.378	0.030	0.000	67

Great Cressingham

date	NTWD Q	D50%ile	V50%ile	TM mn
May-91	0.528	0.120	0.235	18
Jul-91	0.397	0.130	0.147	15
Aug-91	0.225	0.073	0.070	14
Oct-91	0.202	0.065	0.063	14
Nov-91	0.308	0.130	0.018	28
Jan-92	0.863	0.200	0.218	17
Feb-92	0.763	0.150	0.233	12
Mar-92	0.658	0.120	0.124	15
Apr-92	1.114	0.160	0.275	48
May-92	0.660	0.120	0.238	16
Jun-92	0.378	0.090	0.080	36
Jul-92	0.410	0.080	0.123	31
Aug-92	0.222	0.060	0.000	28
Sep-92	0.234	0.070	0.000	24
Oct-92	0.309	0.080	0.060	34

Hilborough

date	NTWD Q	D50%ile	V50%ile	TM mn
May-91	0.528	0.110	0.359	8
Jul-91	0.397	0.130	0.288	5
Aug-91	0.225	0.090	0.159	6
Oct-91	0.202	0.070	0.202	12
Nov-91	0.308	0.110	0.283	34
Dec-91	0.391	0.100	0.283	13
Jan-92	0.863	0.225	0.476	17
Feb-92	0.763	0.160	0.485	8
Mar-92	0.658	0.140	0.426	8
Apr-92	1.114	0.180	0.518	17
May-92	0.660	0.130	0.393	13
Jun-92	0.378	0.100	0.227	23
Jul-92	0.410	0.115	0.247	26
Aug-92	0.222	0.100	0.000	54
Sep-92	0.234	0.080	0.201	21
Oct-92	0.309	0.100	0.264	17

Bodney Bridge

date	NTWD Q	D50%ile	V50%ile	TM mn
May-91	0.528	0.140	0.326	0
Jul-91	0.397	0.150	0.245	21
Aug-91	0.225	0.110	0.074	59
Oct-91	0.202	0.140	0.049	61
Nov-91	0.308	0.130	0.229	20
Dec-91	0.391	0.110	0.240	6
Jan-92	0.863	0.200	0.455	7
Feb-92	0.763	0.170	0.439	9
Mar-92	0.658	0.130	0.409	5
Apr-92	1.114	0.180	0.460	34
May-92	0.660	0.140	0.405	43
Jun-92	0.378	0.115	0.202	26
Jul-92	0.410	0.130	0.297	26
Aug-92	0.222	0.100	0.088	46
Sep-92	0.234	0.090	0.195	30
Oct-92	0.309	0.090	0.239	24

Appendix 1. (Continued).

Chalk Hall Farm

date	NTWD Q	D50%ile	V50%ile	TM mn
May-91	0.528	0.100	0.443	1
Jul-91	0.397	0.130	0.419	33
Aug-91	0.225	0.085	0.140	35
Oct-91	0.202	0.080	0.088	67
Nov-91	0.308	0.140	0.029	64
Dec-91	0.391	0.100	0.300	50
Jan-92	0.863	0.200	0.401	23
Feb-92	0.763	0.180	0.457	21
Mar-92	0.658	0.160	0.472	17
Apr-92	1.114	0.180	0.534	50
May-92	0.660	0.200	0.251	61
Jun-92	0.378	0.190	0.099	60
Jul-92	0.410	0.170	0.053	53
Aug-92	0.222	0.140	0.000	60
Sep-92	0.234	0.110	0.156	46
Oct-92	0.309	0.110	0.239	46
Feb-94	3.673	0.580	0.162	75
May-94	2.682	0.500	0.094	60
Oct-94	0.909	0.350	0.037	86

Langford Hall - gravel site

date	NTWD Q	D50%ile	V50%ile	TM mn
May-91	0.528	0.100	0.301	1
Jul-91	0.397	0.095	0.224	20
Aug-91	0.225	0.090	0.258	14
Oct-91	0.202	0.090	0.080	54
Nov-91	0.308	0.160	0.000	68
Dec-91	0.391	0.130	0.078	44
Jan-92	0.863	0.175	0.338	18
Feb-92	0.763	0.120	0.350	17
Mar-92	0.658	0.150	0.376	12
Apr-92	1.114	0.310	0.186	35
May-92	0.660	0.120	0.368	32
Jun-92	0.378	0.100	0.283	28
Jul-92	0.410	0.160	0.000	64
Aug-92	0.222	0.125	0.000	66
Sep-92	0.234	0.130	0.115	64
Oct-92	0.309	0.150	0.142	60
Feb-94	3.673	0.645	0.333	46
May-94	2.682	0.385	0.354	45
Oct-94	0.909	0.240	0.183	66

Langford Hall - sand site

date	NTWD Q	D50%ile	V50%ile	TM mn
May-91	0.528	0.190	0.276	0
Jul-91	0.397	0.130	0.288	7
Aug-91	0.225	0.098	0.175	3
Oct-91	0.202	0.110	0.191	1
Nov-91	0.308	0.200	0.190	26
Dec-91	0.391	0.198	0.198	11
Jan-92	0.863	0.400	0.182	12
Feb-92	0.763	0.260	0.275	6
Mar-92	0.658	0.250	0.233	4
Apr-92	1.114	0.290	0.240	4
May-92	0.660	0.185	0.263	5
Jun-92	0.378	0.155	0.238	1
Jul-92	0.410	0.220	0.220	17
Aug-92	0.222	0.145	0.164	21
Sep-92	0.234	0.170	0.083	18
Oct-92	0.309	0.180	0.068	33
Feb-94	3.673	0.760	0.364	21
May-94	2.682	0.540	0.241	7
Oct-94	0.909	0.420	0.033	41

Diddlington - gravel site

date	NTWD Q	D50%ile	V50%ile	TM mn
May-91	0.528	0.120	0.426	5
Jul-91	0.397	0.190	0.247	35
Aug-91	0.225	0.160	0.187	59
Oct-91	0.202	0.110	0.251	40
Nov-91	0.308	0.150	0.300	52
Dec-91	0.391	0.130	0.236	45
Jan-92	0.863	0.190	0.434	29
Feb-92	0.763	0.155	0.476	24
Mar-92	0.658	0.160	0.468	25
Apr-92	1.114	0.215	0.514	47
May-92	0.660	0.210	0.251	57
Jun-92	0.378	0.300	0.167	59
Jul-92	0.410	0.235	0.000	80
Aug-92	0.222	0.210	0.000	85
Sep-92	0.234	0.210	0.121	74
Oct-92	0.309	0.280	0.127	74

Diddlington - sand site

date	NTWD Q	D50%ile	V50%ile	TM mn
May-91	0.528	0.390	0.217	0
Jul-91	0.397	0.515	0.088	29
Aug-91	0.225	0.400	0.066	40
Oct-91	0.202	0.400	0.076	31
Nov-91	0.308	0.410	0.132	37
Dec-91	0.391	0.425	0.159	8
Jan-92	0.863	0.505	0.234	4
Feb-92	0.763	0.430	0.241	14
Mar-92	0.658	0.410	0.182	3
Apr-92	1.114	0.470	0.216	4
May-92	0.660	0.500	0.167	11
Jun-92	0.378	0.750	0.043	66
Jul-92	0.410	0.730	0.000	76
Aug-92	0.222	0.600	0.000	52
Sep-92	0.234	0.590	0.000	73
Oct-92	0.309	0.630	0.000	73

Northwold

date	NTWD Q	D50%ile	V50%ile	TM mn
May-91	0.528	0.180	0.426	20
Jul-91	0.397	0.380	0.088	84
Aug-91	0.225	0.230	0.097	83
Oct-91	0.202	0.180	0.080	59
Nov-91	0.308	0.130	0.190	53
Dec-91	0.391	0.130	0.342	23
Jan-92	0.863	0.200	0.476	9
Feb-92	0.763	0.160	0.418	5
Mar-92	0.658	0.160	0.418	17
Apr-92	1.114	0.190	0.493	7
May-92	0.660	0.150	0.401	8
Jun-92	0.378	0.160	0.290	23
Jul-92	0.410	0.240	0.077	62
Aug-92	0.222	0.230	0.000	78
Sep-92	0.234	0.270	0.000	84
Oct-92	0.309	0.300	0.000	76

Appendix 2. Regression constants and r-square values for measured depths and velocities at each site, against gauged flow at Northwold and mean macrophyte cover.

Depth = a + b(gauged flow) + c(macrophyte cover)
r2 = r-square for the regression

site	a	b	c	r2
BNHM	0.033	0.053	-0.0003	0.75
GTCR	0.066	0.130	-0.0008	0.75
HLBR	0.050	0.137	0.0003	0.79
BYBR	0.083	0.098	0.0001	0.66
CKHF	0.027	0.134	0.0013	0.93
LHGR	0.023	0.114	0.0012	0.94
LHSD	0.086	0.172	0.0029	0.93
DDGR	0.052	0.083	0.0020	0.52
DDSD	0.240	0.240	0.0048	0.76
NTWD	-0.017	0.206	0.0029	0.73

Velocity = a + b(gauged flow) + c(macrophyte cover)
r2 = r-square for the regression

site	a	b	c	r2
BNHM	0.112	0.259	-0.0021	0.89
GTCR	0.022	0.313	-0.0021	0.81
HLBR	0.165	0.414	-0.0035	0.90
BYBR	0.139	0.401	-0.0023	0.91
CKHF	0.509	0.043	-0.0065	0.59
LHGR	0.336	0.070	-0.0046	0.78
LHSD	0.225	0.048	-0.0045	0.66
DDGR	0.351	0.290	-0.0046	0.90
DDSD	0.138	0.107	-0.0023	0.91
NTWD	0.363	0.155	-0.0046	0.94

Appendix 3.

Predicted depths and velocities at River Wissey sites based on regression relationships with gauged flow and macrophyte cover.

Langford Hall - sand site

Q (cumecs)	macrophytes % cover	Depth (m)	Velocity (m/s)
0.20	17	0.170	0.158
0.25	17	0.179	0.160
0.30	17	0.187	0.163
0.35	17	0.196	0.165
0.40	17	0.204	0.168
0.45	17	0.213	0.170
0.50	17	0.222	0.172
0.55	17	0.230	0.175
0.60	17	0.239	0.177
0.65	17	0.247	0.179
0.70	17	0.256	0.182
0.75	17	0.264	0.184
0.80	17	0.273	0.187
0.85	17	0.282	0.189

Bradenham

Q (cumecs)	macrophytes % cover	Depth (m)	Velocity (m/s)
0.20	48	0.029	0.063
0.25	48	0.032	0.076
0.30	48	0.034	0.089
0.35	48	0.037	0.101
0.40	48	0.040	0.114
0.45	48	0.042	0.127
0.50	48	0.045	0.140
0.55	48	0.048	0.153
0.60	48	0.050	0.166
0.65	48	0.053	0.179
0.70	48	0.056	0.192
0.75	48	0.058	0.205
0.80	48	0.061	0.218
0.85	48	0.063	0.231

Bodney Br.

Q (cumecs)	macrophytes % cover	Depth (m)	Velocity (m/s)
0.20	42.5	0.107	0.122
0.25	42.5	0.112	0.142
0.30	42.5	0.117	0.162
0.35	42.5	0.122	0.182
0.40	42.5	0.127	0.202
0.45	42.5	0.132	0.222
0.50	42.5	0.137	0.242
0.55	42.5	0.142	0.262
0.60	42.5	0.146	0.282
0.65	42.5	0.151	0.302
0.70	42.5	0.156	0.322
0.75	42.5	0.161	0.342
0.80	42.5	0.166	0.363
0.85	42.5	0.171	0.383

Diddlington - gravel site

Q (cumecs)	macrophytes % cover	Depth (m)	Velocity (m/s)
0.20	57	0.183	0.147
0.25	57	0.187	0.161
0.30	57	0.191	0.176
0.35	57	0.195	0.190
0.40	57	0.199	0.205
0.45	57	0.204	0.219
0.50	57	0.208	0.234
0.55	57	0.212	0.248
0.60	57	0.216	0.263
0.65	57	0.220	0.277
0.70	57	0.224	0.292
0.75	57	0.228	0.306
0.80	57	0.232	0.321
0.85	57	0.237	0.335

Great Cressingham

Q (cumecs)	macrophytes % cover	Depth (m)	Velocity (m/s)
0.20	24	0.072	0.035
0.25	24	0.079	0.050
0.30	24	0.085	0.066
0.35	24	0.092	0.081
0.40	24	0.098	0.097
0.45	24	0.105	0.113
0.50	24	0.111	0.128
0.55	24	0.118	0.144
0.60	24	0.124	0.160
0.65	24	0.131	0.175
0.70	24	0.137	0.191
0.75	24	0.144	0.206
0.80	24	0.150	0.222
0.85	24	0.157	0.238

Chalk Hall Farm

Q (cumecs)	macrophytes % cover	Depth (m)	Velocity (m/s)
0.20	56.5	0.128	0.150
0.25	56.5	0.134	0.152
0.30	56.5	0.141	0.154
0.35	56.5	0.148	0.156
0.40	56.5	0.154	0.158
0.45	56.5	0.161	0.161
0.50	56.5	0.168	0.163
0.55	56.5	0.175	0.165
0.60	56.5	0.181	0.167
0.65	56.5	0.188	0.169
0.70	56.5	0.195	0.171
0.75	56.5	0.201	0.173
0.80	56.5	0.208	0.176
0.85	56.5	0.215	0.178

Diddlington - sand site

Q (cumecs)	macrophytes % cover	Depth (m)	Velocity (m/s)
0.20	52	0.538	0.040
0.25	52	0.550	0.045
0.30	52	0.562	0.051
0.35	52	0.574	0.056
0.40	52	0.586	0.061
0.45	52	0.598	0.067
0.50	52	0.610	0.072
0.55	52	0.622	0.077
0.60	52	0.634	0.083
0.65	52	0.646	0.088
0.70	52	0.658	0.093
0.75	52	0.670	0.099
0.80	52	0.682	0.104
0.85	52	0.694	0.109

Hilborough

Q (cumecs)	macrophytes % cover	Depth (m)	Velocity (m/s)
0.20	14.5	0.082	0.197
0.25	14.5	0.089	0.217
0.30	14.5	0.095	0.238
0.35	14.5	0.102	0.259
0.40	14.5	0.109	0.279
0.45	14.5	0.116	0.300
0.50	14.5	0.123	0.321
0.55	14.5	0.130	0.341
0.60	14.5	0.136	0.362
0.65	14.5	0.143	0.383
0.70	14.5	0.150	0.404
0.75	14.5	0.157	0.424
0.80	14.5	0.164	0.445
0.85	14.5	0.171	0.466

Langford Hall - gravel site

Q (cumecs)	macrophytes % cover	Depth (m)	Velocity (m/s)
0.20	57	0.114	0.088
0.25	57	0.120	0.091
0.30	57	0.126	0.095
0.35	57	0.131	0.098
0.40	57	0.137	0.102
0.45	57	0.143	0.105
0.50	57	0.149	0.109
0.55	57	0.154	0.112
0.60	57	0.160	0.116
0.65	57	0.166	0.119
0.70	57	0.171	0.123
0.75	57	0.177	0.126
0.80	57	0.183	0.130
0.85	57	0.189	0.133

Northwold

Q (cumecs)	macrophytes % cover	Depth (m)	Velocity (m/s)
0.20	67.5	0.220	0.084
0.25	67.5	0.230	0.091
0.30	67.5	0.240	0.099
0.35	67.5	0.250	0.107
0.40	67.5	0.261	0.115
0.45	67.5	0.271	0.122
0.50	67.5	0.281	0.130
0.55	67.5	0.292	0.138
0.60	67.5	0.302	0.146
0.65	67.5	0.312	0.153
0.70	67.5	0.323	0.161
0.75	67.5	0.333	0.169
0.80	67.5	0.343	0.177
0.85	67.5	0.354	0.184

Appendix 4. 1994 survey data: February

cell codes: site/transect/cell no.

taxa	CFU1	CFU2	CFU3	CFU4	CFC1	CFC2	CFC3	CFC4	CFL1	CFL2	CFL3	CFL4	LGU1	LGU2	LGU3	LGU4	LGC1	LGC2
Planariidae	1	1	12	3	15	9	9	1	4	2	32	1	5	4	2	8	10	2
Dendrocoelidae	1		12	1			6				8		4		3	6	6	2
Acroloxus lacustris	1		1				1				1						1	
Ancylus fluviatilis					1	17							1					
Potamopyrgus jenkinsi													2	15	3			6
Bithynia leachi					4		6				3							
Bithynia tentaculata											1							
Lymnaea palustris			2		1		9				5	7						
Lymnaea peregra																		
Lymnaea stagnalis												2						
Physa fontinalis	17	7	21		27	17	24		1	2	26		20	9	4	3	31	11
Planorbis albus																		
P. planorbis/carinatus																	1	
Planorbis contortus		1	3		5	5	4				8	7		1				
Planorbis leucostoma													1					
Planorbis vortex			2	1	4	2	12		1	1	5	2			1		1	
Sphaeriidae	1	7	1		20	3	22		17	6	77	8	19	39	10		13	14
Succinea sp.							2					2						
Valvata piscinalis														1				
Zonitoides sp.												6		1				
Oligochaeta	4	5	25	26	115	122	120	24	82	86	89	37	53	344	408	21	75	94
Piscicola geometra					2		3				1						4	
Thermozyon tessulatum			1		1					1								4
Glossiphonia heteroclita						1												
Glossiphonia complanata	1	4			6	3	2	1	3	2	6		1	8	5		3	12
Helobdella stagnalis							2				1					1		1
Erpobdella octoculata		1	14		11	4	24	4	8	4	50	3	3	2	12	10	12	
Asellus aquaticus	42	20	332	13	77	90	152	15	66	24	150	11	116	40	41	104	94	19
Asellus meridianus						1												
Gammaridae	180	68	108	9	162	65	66	10	56	52	78	20	324		51	27	102	46
Austropotamobius pallipes																		
Baetis sp.	29	19	20		12	16	8		12	28	7			18	4	2	10	30
Ecdyonurus sp.																		
Ephemerella ignita																		
Ephemera danica	1	8	1		5		2		8	8	1		7	96	55	1	76	320
Caenis sp.		1			4	1					4							
Nemourella picteti														1		1		
Nemoura avicularis					3								6			1	3	
Leutra sp.																		
Zygoptera	2	1		2	19		1		5	2	5		1		2	1	8	
Nepa cinerea																		
Notonecta glauca																		
Callicorixa praeusta																		
Corixa punctata																		
Hespercorixa sahlbergi																		
Sigara dorsalis							1											
Sigara falleni																		
Sigara venusta																		
Haliplidae l.			1						1									
Haliplus confinis																		
Haliplus lineatocollis																		
Dytiscidae l.				3									5		1		7	
Potamonectes dep.-elegans									1					1				
Hydroporus sp.																		
Agabus paludosus																		

Appendix 4. 1994 survey data: February (contin.)

cell codes: site/transect/cell no.

taxa	CFU1	CFU2	CFU3	CFU4	CFC1	CFC2	CFC3	CFC4	CFL1	CFL2	CFL3	CFL4	LGU1	LGU2	LGU3	LGU4	LGC1	LGC2
Gyrinidae lv.		2	1	1		1			1	1	1		1		1	1	1	1
Ochthebius sp.																		
Hydraena sp.																		
Anacaena limbata																		
Laccobius sp.																		
Heleochares lividus																		
Helodidae lv.			1			1												
Elmis aenea l.	21	10	15	2	9	178	5		6	15	11	1		130	12		5	91
Elmis aenea a.	11	16				44								9				1
Limnius volkmari lv.	2	21	2		4	14	3		1	3	2		4	86	10	1	51	113
Limnius volkmari ad.	1	1				6				2				4				2
Oulimnius sp. lv.	2		9		4	4				1	8		10	38	24	1	4	24
Oulimnius sp. ad.		1				2				1				2				
Sialis lutaria			5	2	18		1	1		1	9	1	26			3	11	
Rhyacophila dorsalis													2					
Polycentropus flavomaculatus																	11	
Tinodes waeneri																		
Lype sp.			1														2	
Hydropsyche pellucidula	72	104	7		37	100	1		5	24	5		1	3			4	1
Hydropsyche angustipennis			1			8			2	2								
Hydropsyche siltalai														2			2	1
Hydroptila sp																		
Phryganea grandis																		
Limnephilidae indet.													1	9				
Limnephilus rhombicus													1				3	1
Limnephilus marmoratus																		
Limnephilus lunatus									1				12	22	9	11	34	14
Limnephilus extricatus																		
Glyphotaelius pellucidus			1					1			2	1	1				2	
Anabolia nervosa													3	17			7	9
Potamophylax latipennis													1				1	1
Halesus radiatus	1		24	8	26		5	3	5	2	2		3	5		1	16	3
Halesus digitatus							1			1								
Chaetopteryx villosa																		
Molanna angustata														4				
Athripsodes sp.																		
Athripsodes atterimus		1							5									
Athripsodes cinereus			1		4	2			1	2				82			7	14
Athripsodes bilineatus																		
Mystacides azurea								1							3		2	
Goera pilosa					2	2			1									
Silo nigricornis																		2
Lepidostoma hirtum																		
Sericostoma personatum	1		2		5				1		1		19	31	8		18	4
Tipulidae	1		5	1			6	5			2	6	1	6	2		6	4
Psychodidae			9	5			5	7			4	4						
Dixidae																		
Ceratopogonidae																		
Chironomidae		1	129	36	48		32	15		3	70	126	54		79	28	53	2
Simuliidae	3508	1660	82	24	664	496	392	3	808	2496	112	3	3		67		100	456
Stratiomyidae					5													
Tabanidae																	9	
Muscidae			3		1		1										2	1
other Diptera lv.			5	1	5		2	1				19	3			4	5	
habitat data (cell means)																		
depth (m)	0.58	0.7	0.29	0.13	0.49	0.59	0.54	0.32	0.71	0.89	0.57	0.25	0.38	0.65	0.72	0.41	0.45	0.68
velocity (m/s)	0.65	0.75	0.06	0.04	0.52	0.7	0.44	0.01	0.3	0.56	0.12	0.02	0.02	0.48	0.61	0.12	0.04	0.47
% cobble	15	40	0	0	10	24.2	0	0	0	32.9	8.33	0	0	0	0	0	0	0
% gravel	26.7	26.7	0	0	30	41.7	11.7	0	30.7	37.1	8.33	0	0	1.43	12.1	5	0	5
% sand	50	26.7	0	0	26.7	34.2	21.7	0	32.1	15	0	0	0	71.4	87.9	8.33	0	80
% silt	8.33	6.67	100	100	33.3	0	66.7	100	37.1	15	83.3	100	100	27.1	0	86.7	100	15
% Ranunculus	55	40	0	0	55	68.3	50	0	22.1	46.4	0	0	0	2.14	2.14	0	0	5.83
% detritus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% total cover	88.3	40	100	100	86.7	68.3	91.7	100	44.3	46.4	66.7	80	100	23.6	2.14	100	80	9.17

Appendix 4. 1994 survey data: February (contin.)

taxa	LGC3	LGC4	LGL1	LGL2	LGL3	LGL4	LSU1	LSU2	LSU3	LSU4	LSC1	LSC2	LSC3	LSC4	LSL1	LSL2	LSL3	LSL4
Planariidae	57	43	26	2	8	8	3	1		1	1				1			5
Dendrocoelidae	7	25	9	2	6	8	1	1										2
Acroloxus lacustris		1																1
Ancylus fluviatilis			2															1
Potamopyrgus jenkinsi	6	4	2	3	1		9			9	103	3	1	22	6		2	24
Bithynia leachi																		
Bithynia tentaculata																		
Lymnaea palustris		3				3												
Lymnaea peregra																		
Lymnaea stagnalis			1															
Physa fontinalis	39	55	49	10	6	15	15		3	1	3		2	1	1	1	2	7
Planorbis albus					1													
P. planorbis/carinatus																		
Planorbis contortus				1					1									
Planorbis leucostoma			1															
Planorbis vortex		1		1		1	1											
Sphaeriidae	23	14	3	32	5		4	1		6	33	1		11	1			28
Succinea sp.			1			1												
Valvata piscinalis																		
Zonitoides sp.																		
Oligochaeta	200	45	25	136	132	18	3	59	2	19	11	19	9	9	3			41
Piscicola geometra	1	3	2	1	1		1											1
Thermozyon tessulatum						1												
Glossiphonia heteroclita																		
Glossiphonia complanata	10	1	1	3	2							1		2				1
Helobdella stagnalis	1							1										
Erpobdella octoculata	17	28	9	4	1	4	2	5			3	1		9	1		1	3
Asellus aquaticus	289	325	184	11	26	44	20	9		14	13	9		27	3			37
Asellus meridianus																		
Gammaridae	129	316	260	37	82	172	68	22	1	13	20	9		5	25			68
Austropotamobius pallipes																		
Baetis sp.	7	2	12	13	10	2	1								2			3
Ecdyonurus sp.																		
Ephemerella ignita					1													
Ephemera danica	165	6	30	142	74	1		15	4	47	2	66	2	5	25	4		27
Caenis sp.	3			1	1					2								
Nemourella picteti	1	1				1	1											2
Nemoura avicularis		3	6		1	1	1										2	6
Leutra sp.																		
Zygoptera		5	7		1	1	2				4			1				
Nepa cinerea																		
Notonecta glauca																		
Callicorixa praeusta						3				2								1
Corixa punctata																		
Hespercorixa sahlbergi		1																
Sigara dorsalis		3				1	1			1								4
Sigara falleni																		3
Sigara venusta																		1
Haliplidae l.	6	2	6															
Haliplus confinis																		
Haliplus lineatocollis																		
Dytiscidae l.	1	3	7				2	1			2	1		1				
Potamonectes dep.-elegans							1											
Hydroporus sp.																		
Agabus paludosus																		

Appendix 4. 1994 survey data: May

taxa	CFU1	CFU2	CFU3	CFU4	CFC2	CFC3	CFC4	CFL1	CFL3	CFL4	LGU2	LGU3	LGU4	LGC1	LGC2	LGC4	LGL1	LGL2
Planariidae	15	12	60	16	12	37	6	21	8	11	23	21	2	21	1	21	51	18
Dendrocoelidae	1		14	7	3	4					1			2	12		19	3
Acroloxus lacustris			1								1							
Ancylus fluviatilis			1	1			6					1						
Potamopyrgus jenkinsi											6	6	2		4	15		7
Bithynia leachi					2			4	1									
Bithynia tentaculata																		
Lymnaea palustris									1									
Lymnaea peregra			1															
Lymnaea stagnalis																	1	
Physa fontinalis	2	6		7	4	7	1	10	3	2	2	5		4	8	2	4	11
Planorbis albus																		
P. planorbis/carinatus								1										
Planorbis contortus			3	1	2		1									1		
Planorbis leucostoma		1	4			3	2	1	1				1					
Planorbis vortex																		
Sphaeriidae	8	16	18	1	27	10	32	20	38	19	42	38	18	19	84	43	11	28
Succinea sp.																		
Valvata piscinalis	2		7															2
Zonitoides sp.	1				1		1			2				1				
Oligochaeta	43	12	44	48	448	138	39	43	72	112	286	218	32	47	74	46	90	65
Piscicola geometra		1													1			
Thermozyon tessulatum			1				1									1	2	
Glossiphonia heteroclita															1			
Glossiphonia complanata		1	5	2	4	2	1	2	1	4	6	3	3	1	5		2	3
Helobdella stagnalis						2	1			1							1	
Erpobdella octoculata			23	13	12	11	10	5	5	5	13	5	1	18	5	3	35	3
Asellus aquaticus	29	19	144	132	28	52	17	25	29	17	17	29	6	86	17	12	110	38
Asellus meridianus																		
Gammaridae	82	70	88	133	104	30	22	60	5	10	116	120	3	13	32	44	58	38
Austropotamobius pallipes																		
Baetis sp.	37	70	98	16	25	65	3	22	6	4	29	68	2	5	29	36	6	42
Ecdyonurus sp.	1																	
Ephemerella ignita											1							
Ephemera danica	9	10	2	5	6	9		8			46	24		5	88	30	17	58
Caenis sp.	32	6	74	59	7	25	8	29	9	7		1		3			1	
Nemourella picteti																		
Nemoura avicularis																		
Leutra sp.	1							2			1	3		1		1		
Zygoptera	7	3	4	1		2		13	1		1					1		
Nepa cinerea																		
Notonecta glauca																		
Callicorixa praeusta																		
Corixa punctata																		
Hespercorixa sahlbergi																		
Sigara dorsalis								1										
Sigara falleni																		
Sigara venusta																		
Haliplidae l.					1													
Haliplus confinis			1					1										
Haliplus lineatocollis																		
Dytiscidae l.				2				1										
Potamonectes depressus-elega	1		1					2										
Hydroporus sp.																		
Agabus paludosus																		

Appendix 4. 1994 survey data: May (contin.)

taxa	CFU1	CFU2	CFU3	CFU4	CFC2	CFC3	CFC4	CFL1	CFL3	CFL4	LGU2	LGU3	LGU4	LGC1	LGC2	LGC4	LGL1	LGL2
Gyrinidae lv.		3	3								1		1					
Ochthebius sp.																		
Hydraena sp.																		
Anacaena limbata																		
Laccobius sp.																		
Heleochares lividus																		
Helodidae lv.																		
Elmis aenea l.	27	17	12	3	26	6		15	2		35	56	1		24	10	4	27
Elmis aenea a.		20									2	20				1		1
Limnius volkmari lv.	6	23	3	1	27	9				1	13	80	4	3	41	39	9	18
Limnius volkmari ad.	1	3				1					2	14			1			2
Oulimnius sp. lv.	1		30	6	3			3		1	7	6		2	3	2	8	3
Oulimnius sp. ad.		1									1	12						
Sialis lutaria	1		3			4	3		1		1		1	5		6	3	
Rhyacophila dorsalis																		
Polycentropus flavomaculatus																		
Tinodes waeneri								1										
Lype sp.			2	1		1												
Hydropsyche pellucidula	9	25	4		20	3						2	1			1		1
Hydropsyche angustipennis	3				1													
Hydropsyche siltalai	5	1	6		5						5	12	1		7	7		5
Hydroptila sp	2	4	5		3	1		2	2	1								
Phryganea grandis																		
Limnephilidae indet.																		
Limnephilus rhombicus											2							
Limnephilus marmoratus																		
Limnephilus lunatus			5	3	2	5	1	3	2		168	16	1	82	21	80	192	72
Limnephilus extricatus																		
Glyphotaelius pellucidus																		
Anabolia nervosa	1							1			2	10					2	
Potamophylax latipennis															1			
Halesus radiatus		6	3	4	1	5	1				2	8				2	6	
Halesus digitatus																		
Chaetopteryx villosa											2				3	2	4	
Molanna angustata														1				
Athripsodes sp.	6	5	12	3	5	4	2	13	1		6	36	1	4	4			4
Athripsodes alterrimus																		
Athripsodes cinereus																		
Athripsodes bilineatus																		
Mystacides azurea			3			1	1							2				
Goera pilosa					6			7			2					2		2
Silo nigricornis																		
Lepidostoma hirtum	6	3	16		5		1	9	2		14	38	2	4	10			8
Sericostoma personatum			2					1			6	50	10	7	7	30	2	8
Tipulidae			2	5			1					2		1	1		1	
Psychodidae			7	4			18		1	5				2			17	
Dixidae																		
Ceratopogonidae	2	1										3						
Chironomidae	39	23	288	266	8	39	78	37	17	396	11	15	1	16	5	3	12	5
Simuliidae	380	130	15	7	84	41	9	19	5		194			32	248	144	8	512
Stratiomyidae				1				1										
Tabanidae											1				1			
Muscidae				1														
other Diptera lv.	6	3	17	1	5	1	1		1	7				3	1		2	1
habitat data (cell means)																		
depth (m)	0.47	0.6	0.21	0.07	0.53	0.5	0.28	0.66	0.43	0.14	0.39	0.49	0.27	0.19	0.4	0.28	0.19	0.45
velocity (m/s)	0.39	0.23	0.1	0.06	0.33	0.14	0.1	0.1	0.08	0.04	0.29	0.42	0.31	0.21	0.47	0.52	0.16	0.51
% cobble	8.33	10	0	0	3.33	1.67	0	0.71	0.83	0	0	0	0	0	0	0	0	0
% gravel	70	71.7	4	0	62.5	21.7	0	33.6	13.3	0	57.9	70.7	27	0	1.67	35	0	50
% sand	10.8	15	0	0	10	15	0.83	31.4	1.67	0	13.6	29.3	15	20	89.2	45	8	38
% silt	10.8	3.33	96	100	10.8	61.7	99.2	34.3	84.2	100	28.6	0	58	80	9.17	20	92	12
% Ranunculus	40	66.7	0	0	65	31.7	0	80	16.7	0	27.1	1	0	0	78.3	20	0	70
% detritus	0	0	14	11.7	0	0	13.3	0	20	0	3.57	0	6	5	0	0	17	0
% total cover	40.8	67.5	82	19.5	65	64	52.3	80.1	51.7	65.7	30.7	1	8	22	81.7	45.2	59	71.4

Appendix 4. 1994 survey data: May (contin.)

taxa	LGL3	LGL4	LSU1	LSU2	LSU3	LSU4	LSC1	LSC3	LSC4	LSL2	LSL3	LSL4
Planariidae	3	13	2	3	3			1	2		1	4
Dendrocoelidae		5			1							
Acroloxus lacustris												
Ancylus fluviatilis	4	1		1								
Potamopyrgus jenkinsi	4	2	15	4		11	9		2			114
Bithynia leachi												
Bithynia tentaculata												
Lymnaea palustris												
Lymnaea peregra												
Lymnaea stagnalis												
Physa fontinalis		3	1		4			1				1
Planorbis albus												
P. planorbis/carinatus												
Planorbis contortus											1	
Planorbis leucostoma												
Planorbis vortex												
Sphaeriidae	4	4	71	9	1	14	23		17			236
Succinea sp.												
Valvata piscinalis												
Zonitoides sp.												
Oligochaeta	13	18	25	89	2	19	21	2	15	21	23	55
Piscicola geometra				1								
Thermozyon tessulatum					1							
Glossiphonia heteroclita												
Glossiphonia complanata	1											
Helobdella stagnalis					1							
Erpobdella octoculata		7	5	6	4	1	2	1	2	1	2	4
Asellus aquaticus	3	21	13	3	6	1	2		3	2	1	24
Asellus meridianus												
Gammaridae	34	19	14	7	1	1	2					18
Austropotamobius pallipes												
Baetis sp.	34	7			1		1					2
Ecdyonurus sp.												
Ephemerella ignita	3											
Ephemera danica	14	24	7	23	1	40	13	2	8	6		19
Caenis sp.			6	5		7	5		3			5
Nemourella picteti												
Nemoura avicularis												
Leutra sp.	1											
Zygoptera												
Nepa cinerea												
Notonecta glauca												
Callicorixa praeusta												
Corixa punctata												
Hespercorixa sahlbergi												
Sigara dorsalis												1
Sigara falleni												
Sigara venusta												
Haliplidae l.												
Haliplus confinis						1						
Haliplus lineatocollis												
Dytiscidae l.		1										
Potamonectes depressus-elegans												
Hydroporus sp.												
Agabus paludosus												

Appendix 4. 1994 survey data: May (contin.)

taxa	LGL3	LGL4	LSU1	LSU2	LSU3	LSU4	LSC1	LSC3	LSC4	LSL2	LSL3	LSL4
Gyrinidae lv.												
Ochthebius sp.												
Hydraena sp.												
Anacaena limbata												
Laccobius sp.												
Heleochares lividus												
Helodidae lv.												
Elmis aenea l.	52	1		2		1	2	1	1		1	
Elmis aenea a.	7											
Limnius volkmari lv.	43	3		1	1	1	1			2		
Limnius volkmari ad.	14											
Oulimnius sp. lv.	1		2									1
Oulimnius sp. ad.	2											
Sialis lutaria		4	6	9		2	2					4
Rhyacophila dorsalis												
Polycentropus flavomaculatus												
Tinodes waeneri	4											
Lype sp.				1								
Hydropsyche pellucidula	4	1										
Hydropsyche angustipennis												
Hydropsyche siltalai	10	5						1				
Hydroptila sp												
Phryganea grandis												
Limnephilidae indet.			10	5								10
Limnephilus rhombicus		1					1					
Limnephilus marmoratus												
Limnephilus lunatus	22	85	35	26	10	1	14	1	1	2	2	62
Limnephilus extricatus												
Glyphotaelius pellucidus												
Anabolia nervosa		2	1	6	1	1			1			2
Potamophylax latipennis	1											
Halesus radiatus	3			3	1		1					
Halesus digitatus												
Chaetopteryx villosa	1	7			2		2		1			
Molanna angustata												
Athripsodes sp.	1	4										
Athripsodes atterimus												
Athripsodes cinereus					1	2			1			
Athripsodes bilineatus												
Mystacides azurea			1	1								6
Goera pilosa												
Silo nigricornis												
Lepidostoma hirtum	5	7										
Sericostoma personatum	3	8	2	8	3		3		2		1	10
Tipulidae	1									1		
Psychodidae		2										
Dixidae												
Ceratopogonidae	1											
Chironomidae	7	3	35	24	2	11	5		4			75
Simuliidae	198	16							1			
Stratiomyidae		1										
Tabanidae	2			2						1		1
Muscidae												
other Diptera lv.	1		2									2
habitat data (cell means)												
depth (m)	0.41	0.2	0.24	0.68	0.76	0.52	0.44	0.53	0.34	0.54	0.46	0.29
velocity (m/s)	0.45	0.32	0.01	0.16	0.37	0.15	0.08	0.39	0.19	0.39	0.36	0.11
% cobble	1.67	0	0	0	0	0	0	0	0	0	0	0
% gravel	43.3	2.5	0	0	2.5	0.83	0	5.33	1.33	6	2.5	0
% sand	38.3	62.5	0	67.5	97.5	65.8	10	94.7	51.7	94	97.5	31.7
% silt	16.7	35	100	32.5	0	33.3	90	0	47	0	0	68.3
% Ranunculus	65.8	0	0	0	0	0	0	0	0	0	0	0
% detritus	0	2.5	0	0	0	18.3	48	0.17	2	0	0.17	0
% total cover	70.8	28	5	3.33	0	18.5	50	0	0	0	0	8.67

Appendix 4. 1994 survey data: October

taxa	CFU1	CFU2	CFU3	CFC1	CFC2	CFC3	CFC4	CFL1	CFL2	CFL3	LGU1	LGU2	LGU3	LGU4	LGC1	LGC2	LGC3	LGC4
Planariidae			1			2	1											
Dendrocoelidae				2	2		2			1								
Acroloxus lacustris			1						1							1		
Ancylus fluviatilis		6		2					4				4					1
Potamopyrgus jenkinsi											17	92	155	16	3	10	204	21
Bithynia leachi	2	3	3	2	8	19	9	2	1	13							1	
Bithynia tentaculata						1												
Lymnaea palustris			3				2							1	5	1		
Lymnaea peregra																		
Lymnaea stagnalis																		
Physa fontinalis	8	18	6	5	43	54	19	52	15	9	38	38	16	2	8	20	18	13
Planorbis albus																		
P. planorbis/carinatus					1					1								
Planorbis contortus		4	1		3	7	5	2		1				1				
Planorbis leucostoma																		
Planorbis vortex	1	8	40	2	5	38	57	5		26	1	2			3		3	
Sphaeriidae	4	14	5	2	64	32	7	56	16	9	52	60	39	24	8	18	42	7
Succinea sp.	1		2	1		1	1											
Valvata piscinalis																		
Zonitoides sp.			10			1	1											
Oligochaeta	4	13	10	73	166	138		340	202	59	148	89	118	57	58	199	217	57
Piscicola geometra		1				2	1	7	6						1		1	
Thermozyon tessulatum				1	1	1	2		2		1	2	1			2	5	
Glossiphonia heteroclita																		
Glossiphonia complanata		3	1	11	3	12	18	12	7	7	2	4	5		2	2	10	4
Helobdella stagnalis						2	5											
Erpobdella octoculata		7	17	10	6	39	76	17	14	34	19	6	1	1	21	7	5	4
Asellus aquaticus	7	12	39	2	15	221	306	13	7	77	43	3	11	4	114	11	3	3
Asellus meridianus																		
Gammaridae	328	272	36	169	64	104	26	65	106	11	144	113	213	20	187	65	60	230
Austropotamobius pallipes															1			1
Baetis sp.	71	73	1	41	61	52		10	37	2	96	177	135	4	52	85	60	69
Ecdyonurus sp.																		
Ephemerella ignita									2				2			2	1	
Ephemera danica	2	3		5	3	1		12	6		8	35	60	13	12	43	41	50
Caenis sp.		2			1	1			1	3		2						
Nemourella picteti																		
Nemoura avicularis												1				1		
Leutra sp.												1	2				1	1
Zygoptera	13	18	3	4	10	13	7	11	10	4	17	33	1		14	1	2	
Nepa cinerea															1			
Notonecta glauca														5				
Callicorixa praeusta														1				
Corixa punctata								1										
Hespercorixa sahlbergi				1														
Sigara dorsalis																		
Sigara falleni																		
Sigara venusta																		
Haliplidae l.											1							1
Haliplus confinis																		
Haliplus lineatocollis						1												
Dytiscidae l.			1								3	1	2		1	1		
Potamonectes depressus-elegans				2				1										
Hydroporus sp.																		
Agabus paludosus			1															

Appendix 4. 1994 survey data: October (contin.)

taxa	CFU1	CFU2	CFU3	CFC1	CFC2	CFC3	CFC4	CFL1	CFL2	CFL3	LGU1	LGU2	LGU3	LGU4	LGC1	LGC2	LGC3	LGC4
Gyrinidae lv.	8	5	2	1		1	1	1	10	14		1				1		3
Ochthebius sp.	1		1															
Hydraena sp.						2				1								
Anacaena limbata			1												3			
Laccobius sp.										1								
Heleochares lividus															1			
Helodidae lv.															1			
Elmis aenea l.	12	51	3	12	24	38	401	16	84	30	16	41	72	3	21	24	42	42
Elmis aenea a.	1	6		1					2			4	1				3	
Limnius volkmari lv.	1	42		7	12	12		5	19	1		19	46	1	6	15	36	7
Limnius volkmari ad.		1											1					
Oulimnius sp. lv.	1	5		1	7	17	14	10	22	5	27	38	36	1	19	26	32	31
Oulimnius sp. ad.																		
Sialis lutaria			2				11	7	1	7	6		1	1	3	1		1
Rhyacophila dorsalis													1		1		1	2
Polycentropus flavomaculatus																		
Tinodes waeneri																		
Lype sp.							1								1			
Hydropsyche pellucidula	29	51	6	44	3	7		9	25	6	10	20	39		17	4	8	105
Hydropsyche angustipennis		2		1					1			1					1	2
Hydropsyche siltalai																		
Hydroptila sp																		
Phryganea grandis								1										1
Limnephilidae indet.																3		
Limnephilus rhombicus													5	2	18			3
Limnephilus marmoratus																		
Limnephilus lunatus						1							2					
Limnephilus extricatus																		
Glyphotaelius pellucidus																		
Anabolia nervosa																		
Potamophylax latipennis																		
Halesus radiatus																		
Halesus digitatus																		
Chaetopteryx villosa																		
Molanna angustata														1				
Athripsodes sp.																		
Athripsodes atterimus						5	3			1								
Athripsodes cinereus					2	2	1	1	3	1	1	6	6	1		2	19	3
Athripsodes bilineatus						2												
Mystacides azurea							1		1									
Goera pilosa		1		1				3	7		2		2		1	2		1
Silo nigricornis											3	1	1		2			
Lepidostoma hirtum																		
Sericostoma personatum		1		1	1	3		2			2	5	18	2	8	6	4	5
Tipulidae			1	1			6			2			1			1		3
Psychodidae			7				4											
Dixidae			1												6			
Ceratopogonidae											1							
Chironomidae	2	9	22	2	2	12	8	65	9	15	20	18	35	4	10	50	11	27
Simuliidae	882	635	3	223	185	505	3	154	426	10	19	255	378	17	16	98	253	223
Stratiomyidae	1						1		1									
Tabanidae							1						2			2	2	
Muscidae		1					1											
other Diptera lv.																		
habitat data (cell means)																		
depth (m)	0.28	0.45	0.1	0.28	0.33	0.32	0.03	0.47	0.46	0.22	0.22	0.26	0.38	0.05	0.08	0.22	0.2	0.3
velocity (m/s)	0.1	0.05	0	0.1	0.1	0.05	0	0.02	0.18	0.03	0.05	0.19	0.21	0	0.02	0.26	0.26	0.29
% cobble	0	1.67	0	3.33	0	0	0	0	0	0	0	0	1.57	0	0	0	0	0
% gravel	46.7	78.3	0	68.3	33.3	11.7	0	41.4	81.4	0	0	22.9	47.9	1.67	0.83	17	0	37.9
% sand	1.67	0	0	0	6.67	1.67	0	14.3	1.43	0	3.33	60	50.6	6.67	15	68	93.4	37.1
% silt	51.7	20	100	28.3	60	86.7	100	44.3	17.1	100	96.7	17.1	0	91.7	84.2	15	6.6	25.6
% Ranunculus	61.7	75	100	51.7	98.3	45	0	70.7	51.4	0	8.33	38.9	7.43	0	0	60	62	42.1
% detritus	0	0	0	6.67	0	0	0	0	0	0	34.2	0	0	0.83	1.67	0.83	0	3.57
% total cover	85	91.7	100	75	98.3	100	100	76.4	61.4	100	100	38.9	8.43	85.8	67.5	61.7	62	62

Appendix 4. 1994 survey data: October (contin.)

taxa	LGL1	LGL2	LGL3	LGL4	LSU1	LSU2	LSU3	LSU4	LSC1	LSC2	LSC3	LSL1	LSL2	LSL3	LSL4
Planariidae	1														
Dendrocoelidae															
Acroloxus lacustris					1	1									
Ancylus fluviatilis				1											
Potamopyrgus jenkinsi	10	20	17	10	2	17	1	12	226	69	66	35	631	363	21
Bithynia leachi	1														
Bithynia tentaculata															
Lymnaea palustris	6														
Lymnaea peregra															
Lymnaea stagnalis			1											1	
Physa fontinalis	14	36	61	26				1	8		5			3	
Planorbis albus															
P. planorbis/carinatus															
Planorbis contortus			1												
Planorbis leucostoma															
Planorbis vortex			2												
Sphaeriidae	41	51	30	10		5		1	6	2	5	4		9	12
Succinea sp.															
Valvata piscinalis															
Zonitoides sp.															
Oligochaeta	142	242	41	29	6	29	7	29	56	44	47	30	29	42	52
Piscicola geometra															1
Thermozyon tessulatum		2	1											2	
Glossiphonia heteroclita															
Glossiphonia complanata	5	15	2			1	1				1			2	
Helobdella stagnalis															
Erpobdella octoculata	16	2		1	2	2	1	1	5		1			7	
Asellus aquaticus	99	7	13	4	1	10		7	11	2	8			50	1
Asellus meridianus															
Gammaridae	241	171	71	107	1	14	7	125	162	42	75	51	8	262	45
Austropotamobius pallipes															
Baetis sp.	111	143	53	97			2		15	18	9	4	5	17	
Ecdyonurus sp.															
Ephemerella ignita	1		1												
Ephemera danica	23	87	66	19		7	24	55	12	168	15	107	37	57	2
Caenis sp.	1	3													
Nemourella picteti															
Nemoura avicularis	1	1												2	
Leutra sp.		3	2											2	
Zygoptera	15	16	10	14		1			6		3			3	1
Nepa cinerea															
Notonecta glauca				1											
Callicorixa praeusta	1														
Corixa punctata															
Hespercorixa sahlbergi								1							
Sigara dorsalis								5			11			2	
Sigara falleni														1	
Sigara venusta								2						1	
Haliplidae l.											1			1	
Haliplus confinis															
Haliplus lineatocollis															
Dytiscidae l.	1		1	1		1		1	4		2	1		4	
Potamonectes depressus-elegans														1	
Hydroporus sp.	1														
Agabus paludosus															

Appendix 4. 1994 survey data: October (contin.)

taxa	LGL1	LGL2	LGL3	LGL4	LSU1	LSU2	LSU3	LSU4	LSC1	LSC2	LSC3	LSL1	LSL2	LSL3	LSL4
Gyrinidae lv.	3	1	1	2						1				1	
Ochthebius sp.															
Hydraena sp.	1														
Anacaena limbata	1														
Laccobius sp.															
Heleochares lividus															
Helodidae lv.															
Elmis aenea l.	43	84	34	26			1	1	3	13	3	2	7	8	1
Elmis aenea a.	2	7	3	1											
Limnius volkmari lv.	20	61	30	11			5	1	3	10		1	1	3	
Limnius volkmari ad.	1	1	1	2											
Oulimnius sp. lv.	27	32	24	14	2	8	2	7	10	68	15	7	7	29	5
Oulimnius sp. ad.	1	1													
Sialis lutaria	1				7	10	2	1	21		1	2		4	4
Rhyacophila dorsalis				1						1					
Polycentropus flavomaculatus				1					1		1			1	
Tinodes waeneri															
Lype sp.															
Hydropsyche pellucidula	29	46	22	67		1	3	1	7	10	3	1	7	16	1
Hydropsyche angustipennis	1	1								1				1	
Hydropsyche siltalai															
Hydroptila sp															
Phryganea grandis				1				1			1				
Limnephilidae indet.															
Limnephilus rhombicus	6		1	4		2		1	2		2	2		3	
Limnephilus marmoratus															
Limnephilus lunatus															
Limnephilus extricatus															
Glyphotaelius pellucidus															
Anabolia nervosa															
Potamophylax latipennis															
Halesus radiatus															
Halesus digitatus															
Chaetopteryx villosa															
Molanna angustata											2				
Athripsodes sp.															
Athripsodes atterimus															
Athripsodes cinereus	1	15	11												
Athripsodes bilineatus															
Mystacides azurea															
Goera pilosa			1	2						2			16	5	
Silo nigricornis	1									1			1	1	
Lepidostoma hirtum															
Sericostoma personatum	4	8	3	4			1	1		2	1	4		3	1
Tipulidae	1	3	1	2			2			3			4	4	
Psychodidae	1													4	
Dixidae	4														
Ceratopogonidae															
Chironomidae	31	21	41	18	1	17	2	5	15	2	14	5	9	22	4
Simuliidae	224	305	399	285	1		3	1	2	1		3	2	8	
Stratiomyidae	1											1			
Tabanidae							1	1		12	5	7	9	4	3
Muscidae									1		1				
other Diptera lv.				1								1			
habitat data (cell means)															
depth (m)	0.12	0.25	0.24	0.22	0.21	0.53	0.65	0.38	0.34	0.47	0.33	0.45	0.47	0.36	0.16
velocity (m/s)	0.02	0.28	0.23	0.18	0	0.05	0.24	0.04	0.01	0.22	0.16	0.13	0.3	0.04	0
% cobble	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% gravel	11.4	0	0.17	20	0	0	28.3	14.2	0	13.7	50	0.71	19.2	1.67	0
% sand	1.43	12	7.5	2	0	40.8	71.7	35.8	0	84.7	46.7	49.3	80.8	28.3	0
% silt	87.1	88	92.3	78	100	59.2	0	50	100	1.67	3.33	50	0	70	100
% Ranunculus	0	86.8	97.2	20	0	0	0	0	0	0	0	0	0	0	0
% detritus	7.14	0	0	6	8.57	15.8	5.83	23.7	7.86	5	6.67	25.3	5	39.2	55
% total cover	88.6	100	97.5	70.2	100	48.3	5.83	30.3	49.6	10	20	28.1	5	55.8	75.8

Appendix 5. Average cell diversities, abundances and numbers of taxa for three River Wissey sites over eight surveys.

site	survey	diversity (H,ln)	abundance	no. taxa
Chalk Hall Farm	May-91	1.95	1035	20.4
	Oct-91	1.77	745	23.9
	Feb-92	1.95	172	18.6
	May-92	1.84	686	20.8
	Oct-92	2.18	605	27.8
	Feb-94	1.66	1276	25.7
	May-94	2.23	588	28.5
	Oct-94	2.06	883	29.0
Langford Hall (gravel)	May-91	1.83	801	18.7
	Oct-91	1.73	206	13.6
	Feb-92	2.03	437	24.1
	May-92	2.19	420	19.7
	Oct-92	2.26	790	24.6
	Feb-94	2.27	912	33.7
	May-94	2.40	623	29.0
	Oct-94	2.38	910	30.6
Langford Hall (sand)	May-91	1.52	485	12.4
	Oct-91	1.96	363	14.0
	Feb-92	1.70	106	12.2
	May-92	1.83	113	11.5
	Oct-92	1.29	243	12.6
	Feb-94	1.96	216	18.1
	May-94	2.05	156	15.6
	Oct-94	1.93	360	20.0

Appendix 6. Taxa abundances and habitat variables (mean cell values) recorded over eight surveys.

LANGFORD HALL - SAND

	survey							
taxon	May-91	Oct-91	Feb-92	May-92	Oct-92	Feb-94	May-94	Oct-94
Planariidae				0.25		1	1.6	
Dendrocoelidae			0.17			0.33	0.1	
Acroloxus lacustris						0.08		0.18
Ancylus fluviatilis				0.25		0.08	0.1	
Potamopyrgus jenkinsi	5	61	1.17	2.83	171	14.9	15.5	131
Bithynia leachi								
Bithynia tentaculata								
Lymnaea palustris								
Lymnaea peregra			0.08		0.08			
Lymnaea stagnalis								0.09
Physa fontinalis		0.18	0.25		1.17	3	0.7	1.55
Planorbis albus								
P. planorbis/carinatus								
Planorbis contortus						0.08	0.1	
Planorbis leucostoma								
Planorbis vortex					0.75	0.08		
Sphaeriidae	6	0.91	1.67	5.83	2.17	7.08	37.1	4
Succinea sp.				0.08				
Valvata piscinalis								
Zonitoides sp.				0.08				
Oligochaeta	34.5	35.5	16	20	21.8	14.6	27.2	33.7
Piscicola geometra						0.17	0.1	0.09
Thermozyon tessulatum					0.08		0.1	0.18
Glossiphonia heteroclita								
Glossiphonia complanata	0.13		0.25	0.17	0.08	0.33		0.45
Helobdella stagnalis			0.08	0.08		0.08	0.1	
Erpobdella octoculata	0.13	0.36	0.92	0.83	0.83	2.08	2.8	1.73
Asellus aquaticus			0.58		5.17	11	5.5	8.16
Asellus meridianus								
Gammaridae	1.88	54.3	24.7	2.92	6.42	19.3	4.3	72
Austropotamobius pallipes								
Baetis sp.	0.38	5.36	1.33	6.08	4.08	0.5	0.4	6.36
Centroptilum pennulatum			0.42					
Procloeon bifidum					0.08			
Ecdyonurus sp.								
Leptophlebia marginata			0.08					
Ephemerella ignita		1		2.83				
Ephemera danica	16.6	64.5	26.7	23.8	10.8	16.4	11.9	44
Brachycercus harrisella		0.18						
Caenis sp.	0.75	57.9	1.58	33.9	2.08	0.17	3.1	
Nemourella picteti						0.25		
Nemoura avicularis			0.17		0.08	0.75		0.18
Leutra sp.								0.18
Zygoptera		0.09	0.25	0.08	0.83	0.58		1.27
Nepa cinerea								
Notonecta glauca					0.17			
Callicorixa praeusta						0.25		
Corixa punctata								
Hesperconxa sahlbergi				0.08				0.09
Sigara dorsalis			0.33			0.5	0.1	1.64
Sigara falleni						0.25		0.09
Sigara concinna								
Sigara venusta						0.08		0.27
Haliplidae l.			0.08		0.08			0.18
Brychius elevatus								
Haliplus confinis							0.1	
Haliplus lineatocollis								
Dytiscidae l.		0.27	0.25		0.5	0.58		1.18
Potamonectes depr.-elegans		0.09			0.08	0.08		0.09
Hydroporus sp.								
Agabus paludosus								
Gyrinidae lv.		0.55	0.08			0.25		0.18
Ochthebius sp								
Hydraena sp.								

	survey							
taxon	May-91	Oct-91	Feb-92	May-92	Oct-92	Feb-94	May-94	Oct-94
Anacaena limbata								
Laccobius sp								
Heleochares lividus								
Helodidae lv.						0.08		
Elmis aenea l.		4.91	0.08	0.17	0.58	0.83	0.8	3.55
Elmis aenea a.		2.45				0.08		
Limnius volkmari lv.	0.25	2.36	0.25	0.83	0.33	0.33	0.6	2.18
Limnius volkmari ad.		0.09						
Oulimnius sp. lv.		37	0.08	0.17	3.92	0.58	0.3	14.5
Oulimnius sp. ad.		2.45	0.17			0.17		
Sialis lutaria			0.17		0.83	3.08	2.3	4.73
Rhyacophila dorsalis						0.08		0.09
Plectrocnemia conspersa								
Polycentropus flavomaculatus			1.25	0.17	0.75	0.58		0.27
Tinodes waeneri								
Lype sp.			0.08			0.08	0.1	
Hydropsyche pellucidula		1.45			0.17			4.55
Hydropsyche angustipennis		0.27						0.18
Hydropsyche siltalai		0.73	0.08				0.1	
Hydroptila sp								
Phryganea grandis								0.18
Limnephilidae indet.						6.92	2.5	
Limnephilus rhombicus						0.17	0.1	1.09
Limnephilus marmoratus								
Limnephilus lunatus		0.09	0.92	0.33	0.33	11.4	15.4	
Limnephilus extricatus								
Glyphotaelius pellucidus								
Anabolia nervosa			0.08			1.75	1.2	
Potamophylax latipennis						0.08		
Halesus radiatus			0.17			3.63	0.5	
Halesus digitatus								
Chaetopteryx villosa				0.08			0.5	
Molanna angustata								0.18
Athripsodes sp.								
Athripsodes atterimus								
Athripsodes cinereus		0.64	0.42	0.83	0.17	0.08	0.4	
Athripsodes bilineatus								
Mystacides azurea			0.08		0.92		0.8	
Mystacides longicornis			0.08					
Goera pilosa		1.73	0.25		0.08	0.17		2.09
Silo nigricornis						0.08		0.27
Lepidostoma hirtum	0.13			0.08				
Sericostoma personatum			0.42	0.5		1.33	2.9	1.18
Tipulidae	0.75	13.3	6.08	1.25	1.67	0.75	0.1	1.18
Psychodidae			0.08		0.17	0.25		0.36
Dixidae					0.33			
Ceratopogonidae			0.42					
Chironomidae	3.13	12.7	16.9	8.33	2.17	43.3	15.6	8.73
Simuliidae		0.09	0.25	0.33		44.9	0.1	1.91
Stratiomyidae								0.09
Tabanidae		0.64	0.58	0.17	1.67	0.58	0.4	3.82
Muscidae			0.08			0.08		0.18
other Diptera lv.					1.17	1.33	0.4	0.09

variable								
water depth (m)	0.19	0.11	0.27	0.21	0.17	0.74	0.48	0.4
current velocity (m/s)	0.25	0.15	0.21	0.19	0.11	0.31	0.22	0.11
% cobble	0		0	0	0	0	0	0
% gravel	0		0.01	0	0.15	0	1.65	11.6
% sand	83.5		67.9	69.8	61.2	67.4	61	39.8
% silt	16.5		32.1	30.2	38.6	32.6	37.1	48.6
% Ranunculus	0	0	0	0	0	0	0	0
% detritus	0	0.23	0.26	2.35	5.95	0	6.87	18
% total cover	0	0.53	5.76	6.21	36.7	19.8	8.55	39

Appendix 6. Taxa abundances and habitat variables (mean cell values) recorded over eight surveys.

LANGFORD HALL - GRAVEL

	survey							
taxon	May-91	Oct-91	Feb-92	May-92	Oct-92	Feb-94	May-94	Oct-94
Planariidae	2.18		2.42	0.09	0.17	14.6	17.4	0.08
Dendrocoelidae	0.09		0.17		0.25	6.5	4.2	
Acroloxus lacustris						0.17	0.1	0.08
Ancylus fluviatilis	3.36	2.91	1.92	1.36		0.25	0.6	0.5
Potamopyrgus jenkinsi	0.36	21.7	0.67	22.1	72.7	3.5	4.6	47.9
Bithynia leachi								0.17
Bithynia tentaculata								
Lymnaea palustris						0.5		1.08
Lymnaea peregra								
Lymnaea stagnalis					0.08	0.08	0.1	0.08
Physa fontinalis		0.82	2.42		12.6	21	3.9	24.2
Planorbis albus						0.08		
P. planorbis/carinatus						0.08		
Planorbis contortus	0.18		0.08		0.08	0.17	0.1	0.17
Planorbis leucostoma						0.17	0.1	
Planorbis vortex			0.33		0.33	0.42		0.92
Sphaeriidae	5.55	3.18	3.25	41.4	31.1	14.3	29.1	31.8
Succinea sp.					0.67	0.17		
Valvata piscinalis						0.08	0.2	
Zonitoides sp.						0.08	0.1	
Oligochaeta	88.4	9.45	51.3	94.9	89.8	129	88.9	116
Piscicola geometra			0.08		0.08	1	0.1	0.17
Thermozyon tessulatum			0.08	0.09	0.25	0.42	0.3	1.17
Glossiphonia heteroclita							0.1	
Glossiphonia complanata	0.18	2.91	0.75	0.55	3.42	3.83	2.4	4.25
Helobdella stagnalis			0.08		0.25	0.25	0.1	
Erpobdella octoculata	9.55	2.27	6.67	3.62	6.92	8.5	9	6.92
Asellus aquaticus	1.18	0.09	3.33	0.27	34.4	108	33.9	26.3
Asellus meridianus								
Gammaridae	330	90.5	129	33.7	113	129	47.7	135
Austropotamobius pallipes								0.17
Baetis sp.	109	15	126	31.9	72.8	9.17	25.8	90.2
Centroptilum pennulatum								
Procloeon bifidum								
Ecdyonurus sp.								
Leptophlebia marginata								
Ephemerella ignita	11.8			25.6		0.08	0.4	0.58
Ephemera danica	22.4	10.7	11.3	28.2	47.3	81.1	30.6	38.1
Brachycercus harrisella								
Caenis sp.	16	1.18	4.5	35.7	15	0.42	0.5	0.5
Nemourella picteti			0.25			0.42		
Nemoura avicularis		0.18	0.08		0.08	1.75		0.33
Leuctra sp.							0.7	0.83
Zygoptera		0.18	0.08	0.09	2.5	2.17	0.2	10.3
Nepa cinerea								0.08
Notonecta glauca								0.5
Callicorixa praeusta					0.17	0.25		0.17
Corixa punctata								
Hesperocorixa sahlbergi						0.08		
Sigara dorsalis			0.17		0.83	0.33		
Sigara falleni								
Sigara concinna					0.08			
Sigara venusta								
Haliplidae l.					0.33	1.17		0.17
Brychius elevatus								
Haliplus confinis								
Haliplus lineatocollis								
Dytiscidae l.			0.08		0.75	2	0.1	0.92
Potamonectes depr.-elegans			0.25		0.33	0.08		
Hydroporus sp.								0.08
Agabus paludosus								
Gyrinidae lv.	0.73		0.33		0.08	0.75	0.2	1
Ochthebius sp.								
Hydraena sp.								0.08

	survey							
taxon	May-91	Oct-91	Feb-92	May-92	Oct-92	Feb-94	May-94	Oct-94
Anacaena limbata								0.33
Laccobius sp								
Helochares lividus								0.08
Helodidae lv.					0.25			0.08
Elmis aenea l.	8.45	1.82	2.5	34.7	45.2	29	21	37.3
Elmis aenea a.	2		4.83	5.64	21	1.08	3.1	1.75
Limnius volkmari lv.	82.9	35.2	25.5	15.7	26.3	46.4	25.3	21
Limnius volkmari ad.	0.18		1.33	0.36	6	0.83	3.3	0.5
Oulimnius sp. lv.	0.27	0.82	0.75	0.55	73.6	14.9	3.2	25.6
Oulimnius sp. ad.	0.64		0.42	0.18	1	0.25	1.5	0.17
Sialis lutaria		0.55	0.25		0.25	5.42	2	1.17
Rhyacophila dorsalis	0.27	0.27	0.08	0.18	0.42	0.25		0.5
Plectrocnemia conspersa								
Polycentropus flavomaculatus	2.55		0.92		0.83	1.08		0.08
Tinodes waeneri	0.91			0.09			0.4	
Lype sp.			0.17		0.08	0.17		0.08
Hydropsyche pellucidula	0.36	0.36	1.67	0.18	4.92	1.42	1	30.6
Hydropsyche angustipennis			0.08			0.08		0.5
Hydropsyche siltalai	17.3	0.18	2.33	3.45	0.17	0.58	5.2	
Hydroptila sp	0.09							
Phryganea grandis								0.17
Limnephilidae indet.						6.58		0.25
Limnephilus rhombicus						0.92	0.3	3.25
Limnephilus marmoratus						0.25		
Limnephilus lunatus			2.92	1.45	0.08	21.2	73.9	0.17
Limnephilus extricatus						0.08		
Glyphotaelius pellucidus					0.17	0.33		
Anabolia nervosa	0.09					4.67	1.6	
Potamophylax latipennis						0.33	0.2	
Halesus radiatus			1.83			5.58	2.1	
Halesus digitatus								
Chaetopteryx villosa	0.18			0.55			1.9	
Molanna angustata		0.09				0.33	0.1	0.08
Athripsodes sp.							6	
Athripsodes atterimus								
Athripsodes cinereus	5.45	0.36	7.17	0.36	0.75	10.5		5.42
Athripsodes bilineatus	4		0.33	7.73				
Mystacides azurea			0.08	0.36	0.58	0.67	0.2	
Mystacides longicornis								
Goera pilosa	0.18	0.36	2.42	0.45			0.6	0.92
Silo nigricornis		0.09	0.42			0.25		0.67
Lepidostoma hirtum	5.82			2.09			8.8	
Sericostoma personatum	3.09	0.45	2.17	3.91	0.25	9.5	13.1	5.75
Tipulidae	6.64	3.27	3	0.64	2.58	4	0.6	1
Psychodidae			0.08		0.75	2.58	2.1	0.08
Dixidae					4.17			0.83
Ceratopogonidae	1.64			3.64	0.08		0.4	0.08
Chironomidae	36	0.82	17.3	16.1	8.25	65.8	7.8	23.8
Simuliidae	21.1		12.3	1.36	84.8	133	135	206
Stratiomyidae			0.08		0.75	0.17	0.1	0.08
Tabanidae		0.09			0.25	0.92	0.4	0.5
Muscidae		0.27	0.83			1.58		
other Diptera lv.				0.18		2.92	0.8	0.08

variable								
water depth (m)	0.1	0.1	0.12	0.11	0.14	0.57	0.33	0.21
current velocity (m/s)	0.26	0.09	0.27	0.3	0.13	0.34	0.37	0.17
% cobble	5.75		15.7	2.61	3.19	0	0.17	0.13
% gravel	45.3		31.6	43	20.7	3.34	28.6	13.3
% sand	24.4		16.2	20.9	29.6	50.1	35.9	29.8
% silt	24.6		36.5	33.5	46.4	46.6	35.1	56.9
% Ranunculus	0	1.31	0.12	3.33	22.1	1.5	26.2	35.2
% detritus	6.79	10.8	0	2.58	0.69	0.92	3.41	4.52
% total cover	0.76	53.6	19.2	31.7	62.3	45.9	41.8	70.2

Appendix 6. Taxa abundances and habitat variables (mean cell values) recorded over eight surveys.

CHALK HALL FARM

	survey							
taxon	May-91	Oct-91	Feb-92	May-92	Oct-92	Feb-94	May-94	Oct-94
Planariidae	4.5	15.5	0.75	2.5	8.25	7.5	19.8	0.4
Dendrocoelidae		0.5	0.17		0.92	2.33	2.9	0.7
Acroloxus lacustris						0.33	0.1	0.2
Ancylus fluviatilis	0.08	0.67	0.83	0.75	2.33	1.5	0.8	1.2
Potamopyrgus jenkinsi	0.58				0.08			
Bithynia leachi		0.83	0.33	0.08	0.5	1.08	0.7	6.2
Bithynia tentaculata	0.08	0.08	0.08		0.08	0.08		0.1
Lymnaea palustris	0.17					2	0.1	0.5
Lymnaea peregra		0.08	0.08				0.1	
Lymnaea stagnalis	0.17	0.17				0.17		
Physa fontinalis	0.25	10.3	2.25		13.3	11.8	4.2	22.9
Planorbis albus					0.08			
P. planorbis/carinatus		0.33	0.08				0.1	0.2
Planorbis contortus	0.92	1.08	0.67	0.17	0.92	2.75	0.7	2.3
Planorbis leucostoma							1.2	
Planorbis vortex	0.42	2.08	0.67	0.33	4.08	2.5		18.2
Sphaeriidae	11.1	4.83	2.92	3.92	18	13.5	18.9	20.9
Succinea sp			0.08			0.33		0.6
Valvata piscinalis	0.33	0.17		0.08	0.17		0.9	
Zonitoides sp.						0.5	0.5	1.2
Oligochaeta	33.7	4.5	15.2	29.3	42.4	61.3	99.9	101
Piscicola geometra	0.08		0.08		0.5	0.5	0.1	1.7
Thermozyon tessulatum	0.17	0.58		0.17	0.83	0.25	0.2	0.7
Glossiphonia heteroclita					0.08	0.08		
Glossiphonia complanata	0.58	1.5	0.58	0.67	2.08	2.33	2.2	7.4
Helobdella stagnalis	0.33	0.83	0.33	0.33	1.75	0.25	0.4	0.7
Erpobdella octoculata	14.7	9.58	8.83	5.58	8.17	10.3	8.4	22
Asellus aquaticus	8.92	28.9	8.5	4.17	43.9	82.7	49.2	69.9
Asellus meridianus						0.08		
Gammaridae ·	137	361	32	41.3	203	72.8	60.4	118
Austropotamobius pallipes								
Baetis sp.	167	68.8	9.58	122	51.5	12.6	34.6	34.8
Centroptilum pennulatum								
Procloeon bifidum								
Ecdyonurus sp.				0.08			0.1	
Leptophlebia marginata					0.08			
Ephemerella ignita	4.08	0.17		37				0.2
Ephemera danica	4.92	1.42	1.5	6.67	4.83	2.83	4.9	3.2
Brachycercus harrisella								
Caenis sp.	107	65.2	1	156	44.5	0.83	25.6	0.8
Nemourella picteti								
Nemoura avicularis			0.08		0.25	0.25		
Leutra sp.				0.08			0.3	
Zygoptera			0.08		1.58	3.08	3.1	9.3
Nepa cinerea								
Notonecta glauca								
Callicorixa praeusta		0.08						
Corixa punctata								0.1
Hesperocorixa sahlbergi								0.1
Sigara dorsalis		0.75				0.08	0.1	
Sigara falleni		0.33			0.17			
Sigara concinna								
Sigara venusta								
Haliplidae l.		1.17			1.92	0.17	0.1	
Brychius elevatus					0.08			
Haliplus confinis							0.2	
Haliplus lineatocollis		0.08						0.1
Dytiscidae l.	0.42			0.08	0.08	0.25	0.3	0.1
Potamonectes depr.-elegans	0.08	0.75	0.08	0.17	0.25	0.08	0.4	0.3
Hydroporus sp.								
Agabus paludosus								0.1
Gyrinidae lv.				0.08	1.75	0.67	0.6	4.3
Ochthebius sp.								0.2
Hydraena sp.								0.3

	survey							
taxon	May-91	Oct-91	Feb-92	May-92	Oct-92	Feb-94	May-94	Oct-94
Anacaena limbata								0.1
Laccobius sp								0.1
Helochares lividus								
Helodidae lv.						0.17		
Elmis aenea l.	9.17	82.2	0.75	11.3	30.5	22.8	10.8	67.1
Elmis aenea a.	1.42	0.58		9.17	10.6	5.92	2	1
Limnius volkmari lv.	15.3	7.17	2.25	4.08	9.33	4.33	7	9.9
Limnius volkmari ad.	0.17	0.25		0.67	0.83	0.83	0.5	0.1
Oulimnius sp. lv.	0.17	13.6			22.8	2.33	4.4	8.2
Oulimnius sp. ad.		0.08		0.5	0.83	0.33	0.1	
Sialis lutaria		0.25	0.33	0.08	0.67	3.17	1.2	2.8
Rhyacophila dorsalis								
Plectrocnemia conspersa			0.17					
Polycentropus flavomaculatus		0.58	0.25	0.08	1.25			
Tinodes waeneri							0.1	
Lype sp.						0.08	0.4	0.1
Hydropsyche pellucidula	0.17	2.17	1.5		10.1	29.6	6.1	18
Hydropsyche angustipennis	0.08	0.17	0.17	0.17	0.33	1.08	0.4	0.4
Hydropsyche siltalai	11.7	2.08	1	7.08	1.25		1.7	
Hydroptila sp				0.08			2	
Phryganea grandis								0.1
Limnephilidae indet.								
Limnephilus rhombicus								
Limnephilus marmoratus								
Limnephilus lunatus			0.17	0.33		0.08	2.1	0.1
Limnephilus extricatus								
Glyphotaelius pellucidus						0.42		
Anabolia nervosa							0.2	
Potamophylax latipennis								
Halesus radiatus	0.17		0.25			6.33	2	
Halesus digitatus						0.17		
Chaetopteryx villosa								
Molanna angustata								
Athripsodes sp.							5.1	
Athripsodes atterimus				0.08		0.5		0.9
Athripsodes cinereus	11.6	14.7	1	5.08	2	0.83		1
Athripsodes bilineatus	2.08			2.5				0.2
Mystacides azurea		0.25		0.08	0.42	0.08	0.5	0.2
Mystacides longicornis								
Goera pilosa	0.08	1.75	1.17	0.17	0.42	0.42	1.3	1.2
Silo nigricornis			0.08					
Lepidostoma hirtum	2.75			1.33			4.2	
Sericostoma personatum	2.67	0.08	0.5	1.08		0.83	0.3	0.8
Tipulidae	1	4.08	4	0.5	4.83	2.17	0.8	1
Psychodidae			0.08			2.83	3.5	1.1
Dixidae		0.25						0.1
Ceratopogonidae	1.5						0.3	
Chironomidae	182	3.08	7.17	32.1	4.67	38.3	119	14.6
Simuliidae	295	29.4	63.5	199	45.6	854	69	303
Stratiomyidae						0.42	0.2	0.3
Tabanidae								0.1
Muscidae		0.75	0.42		0.42	0.42	0.1	0.2
other Diptera lv.						2.75	4.2	

variable								
water depth (m)	0.12	0.09	0.17	0.19	0.1	0.5	0.39	0.29
current velocity (m/s)	0.42	0.13	0.37	0.29	0.18	0.35	0.16	0.08
% cobble	18.9		14.3	3.31	19.9	10.9	2.49	0.5
% gravel	64.9		42.8	52.6	31.3	17.7	27.7	36.1
% sand	12.1		20.3	6	7.76	17.2	8.48	2.57
% silt	4.17		22.6	38.1	41	54.2	60	60.8
% Ranunculus	0.56	6.92	6.78	21.7	9.69	28.1	30	55.4
% detritus	0	4.17	0	0.83	6.31	0	5.9	0.67
% total cover	0.56	69.9	24.3	59.9	50.7	76	58.9	88.8

Appendix 7. Regression relationships between "indicator" taxa and depth, current velocity and macrophyte cover.

D = depth (m)

V = current velocity (ms^{-1})

M = % macrophyte cover

Baetidae:

$$(\ln+1) \text{ abundance} = 1.06 + 4.63D - 7.66D^2 + 5.46V - 6.47V^2 + 0.046M - 0.00033M^2$$

($R2 = 0.17$)

Ephemeridae:

$$(\ln+1) \text{ abundance} = 1.91 + 5.73D - 3.06D^2 + 4.20V - 9.75V^2 - 0.020M + 0.00009M^2$$

($R2 = 0.34$)

Elmidae:

$$(\ln+1) \text{ abundance} = 2.96 - 7.33D + 5.56D^2 + 12.07V - 19.41V^2 + 0.0071M + 0.00003M^2$$

($R2 = 0.34$)

Hydropsychidae:

$$(\ln+1) \text{ abundance} = -0.51 + 4.27D - 6.48D^2 + 7.88V - 11.66V^2 + 0.0060M + 0.00005M^2$$

($R2 = 0.19$)

Athripsodes cinereus:

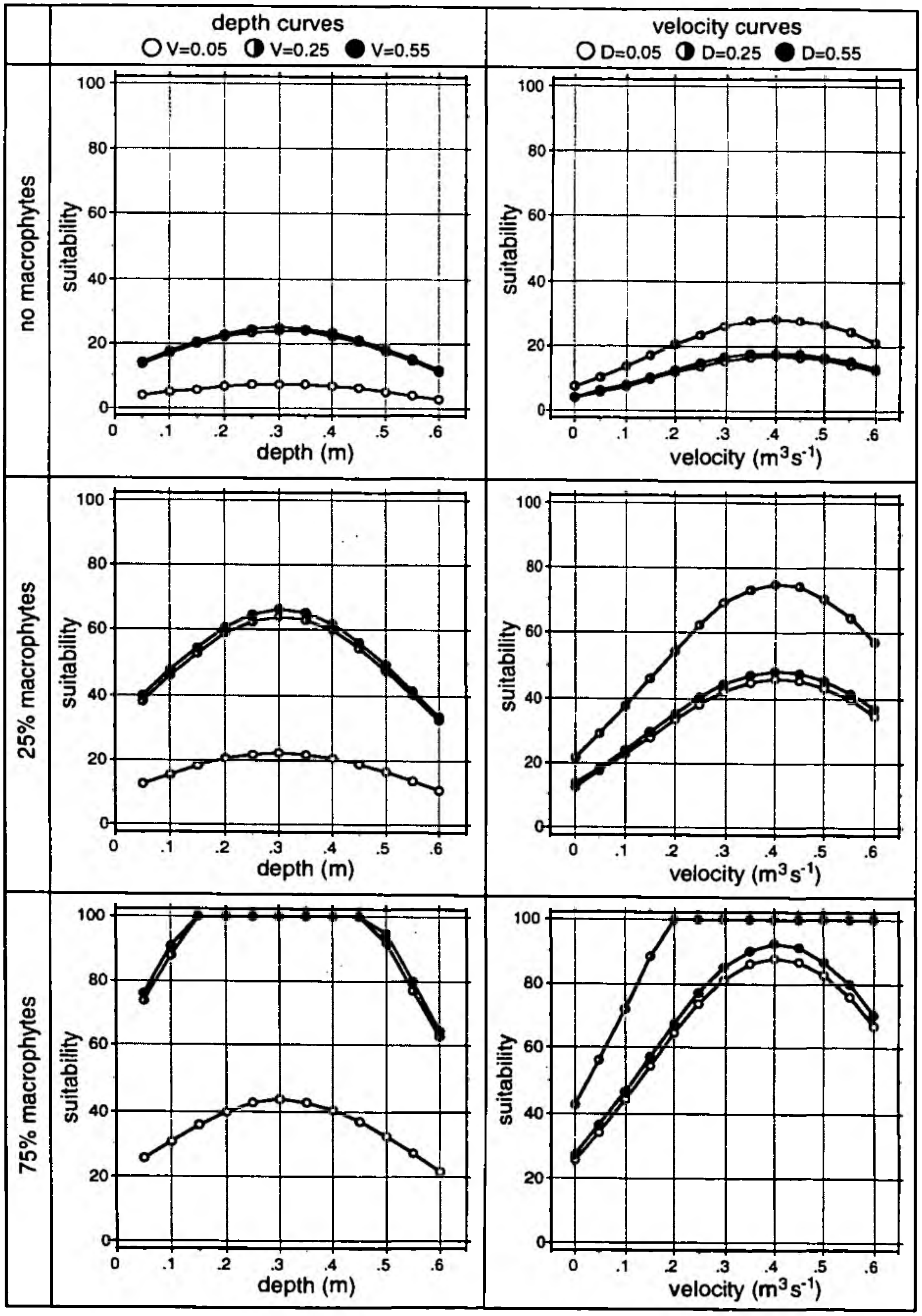
$$(\ln+1) \text{ abundance} = 0.28 - 1.37D + 1.32D^2 + 2.92V - 0.54V^2 + 0.0057M - 0.00002M^2$$

($R2 = 0.10$)

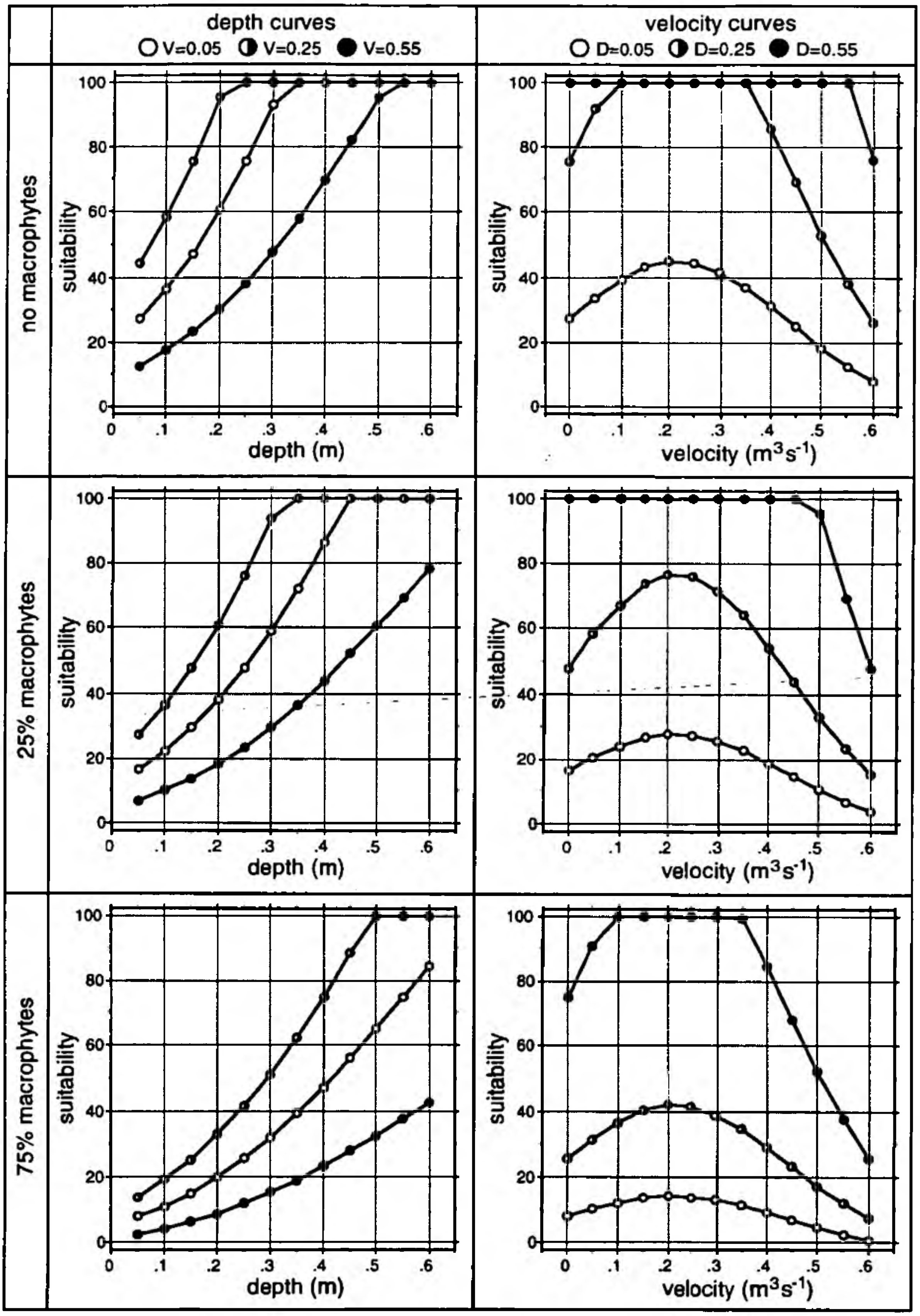
Simuliidae:

$$(\ln+1) \text{ abundance} = -1.76 + 3.80D - 6.52D^2 + 15.13V - 19.86V^2 + 0.031M + 0.000004M^2$$

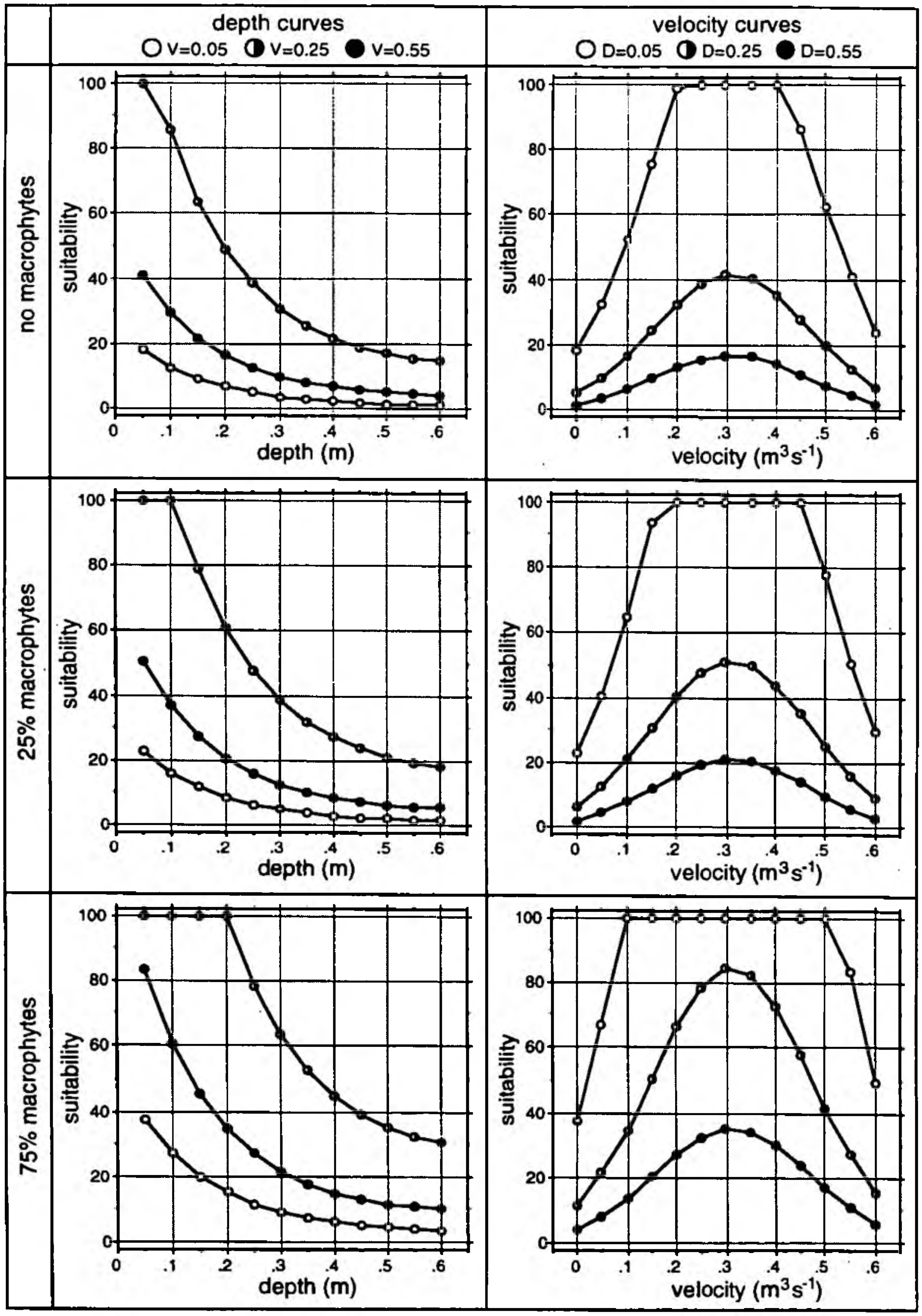
($R2 = 0.29$)



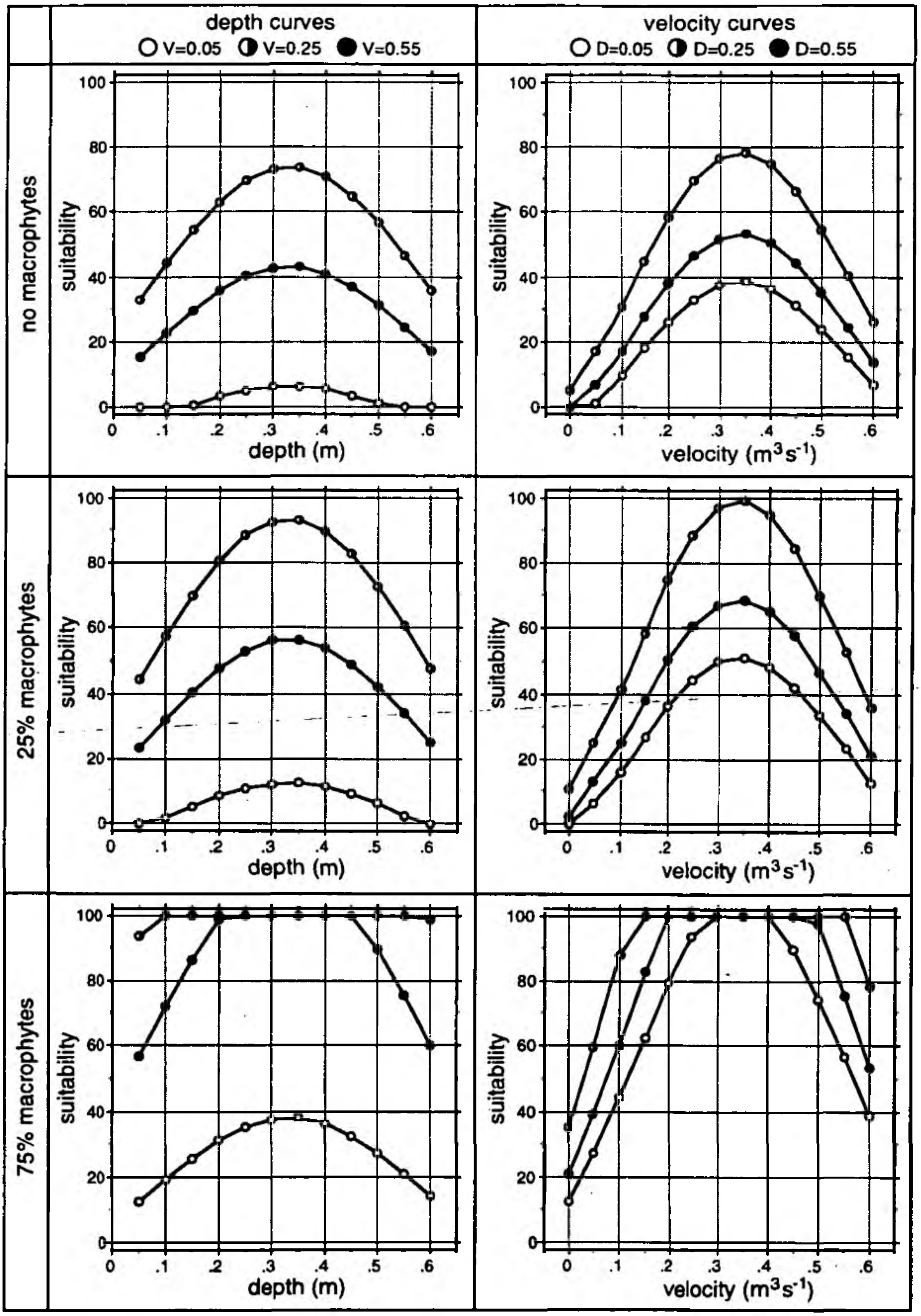
Appendix 8 Suitability curves for indicator taxa: Suitability curves for Baetidae in Sector 3.



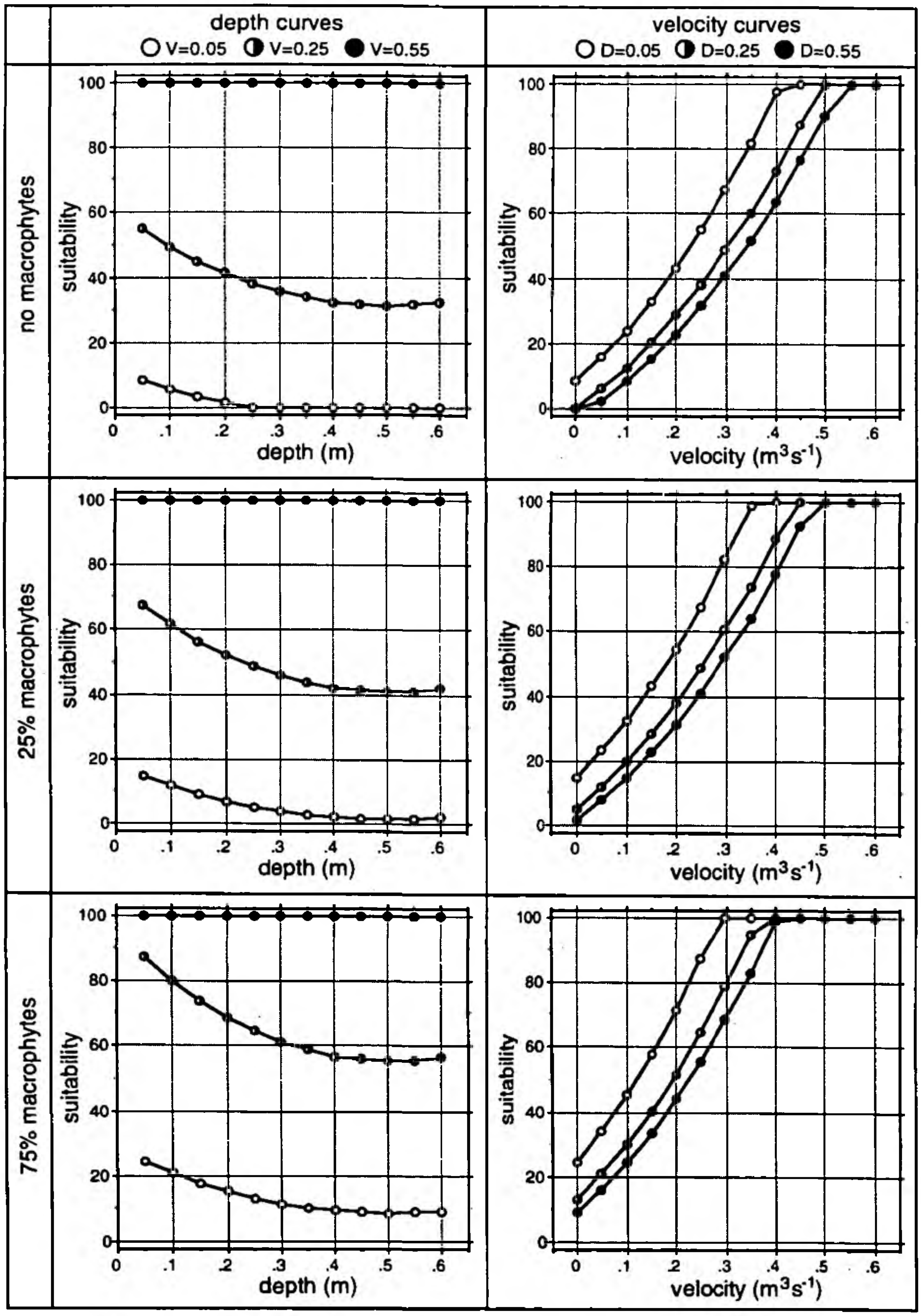
Appendix 8 Suitability curves for indicator taxa: Suitability curves for Ephemeridae in Sector 3.



Appendix 8 Suitability curves for indicator taxa: Suitability curves for Elmidae in Sector 3.

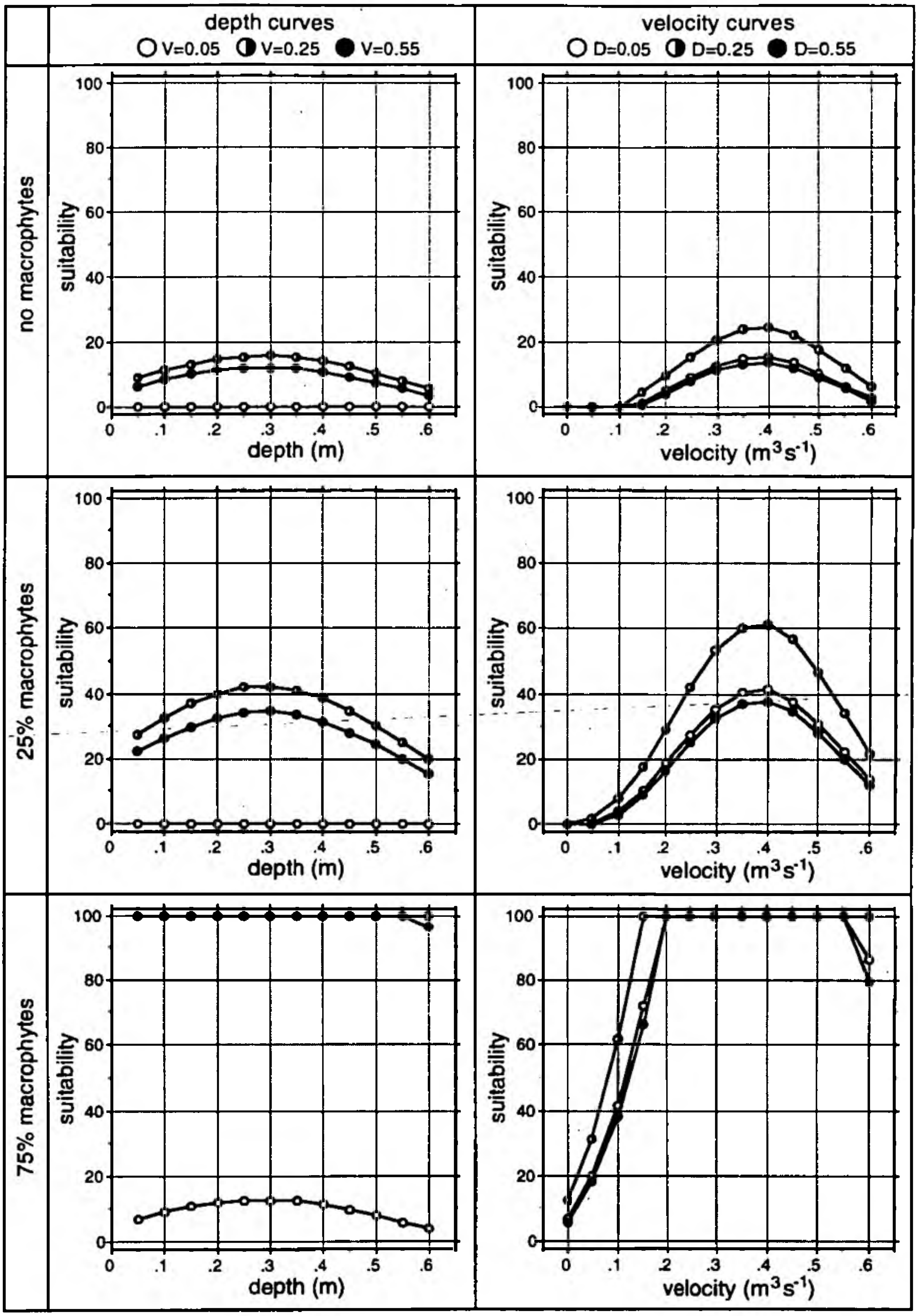


Appendix 8 Suitability curves for indicator taxa: Suitability curves for Hydropsychidae in Sector 3.

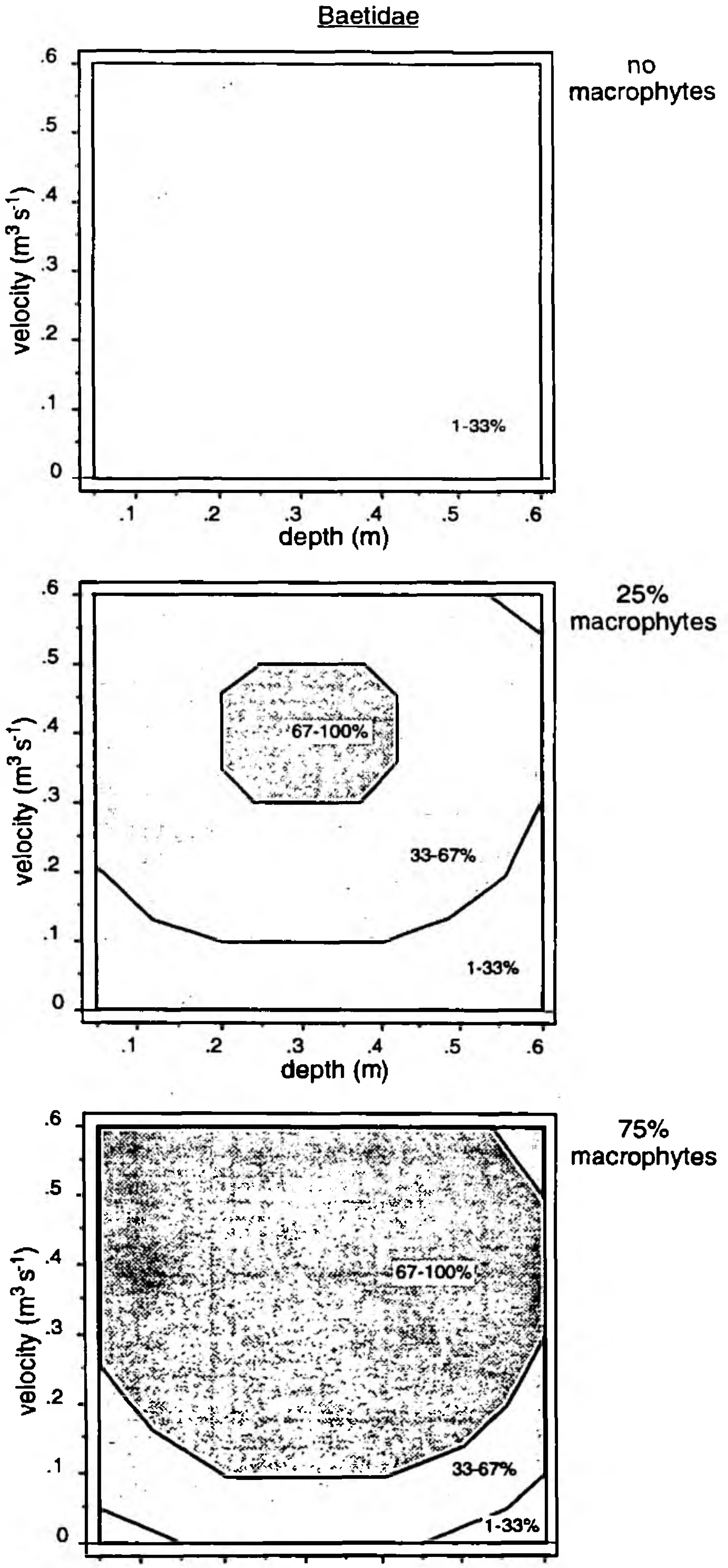


Appendix 8 Suitability curves for indicator taxa:

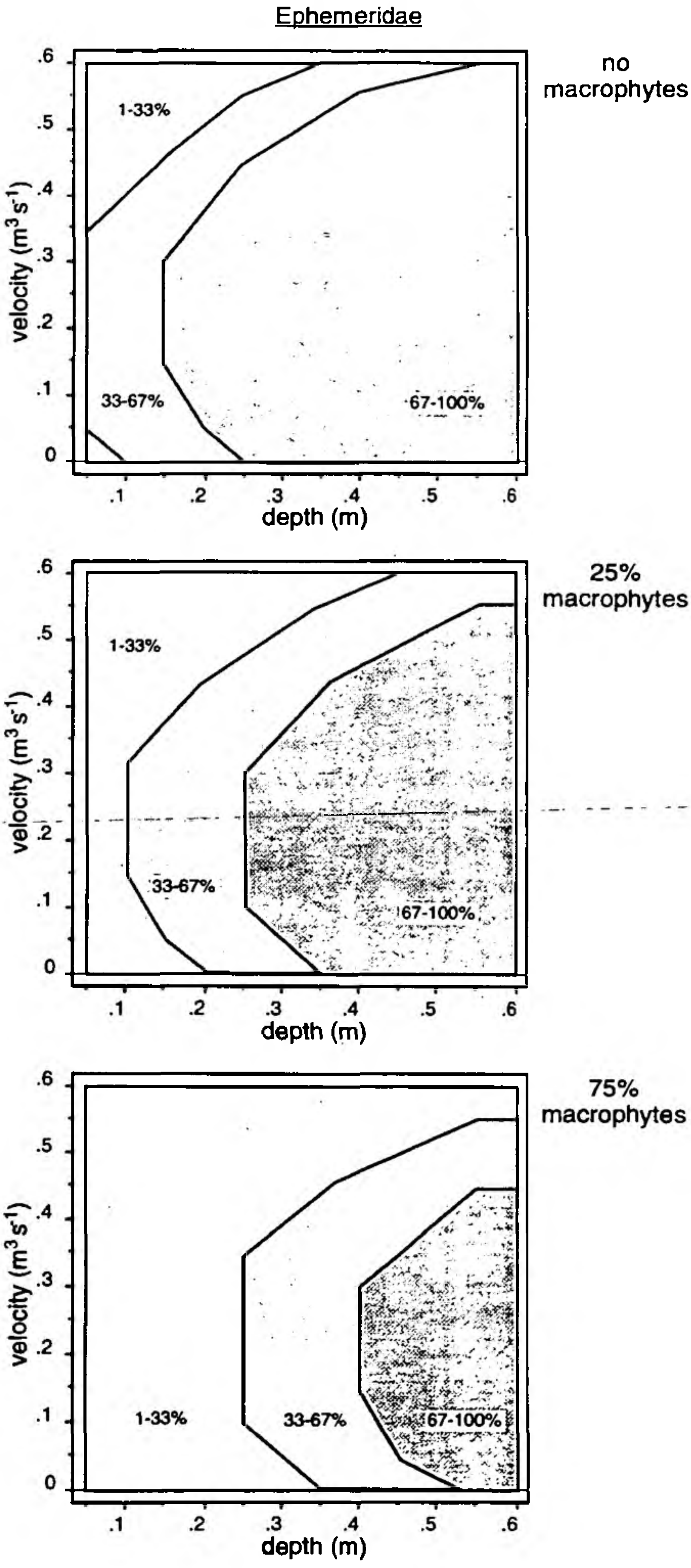
Suitability curves for *Athripsodes cinereus* in Sector 3.



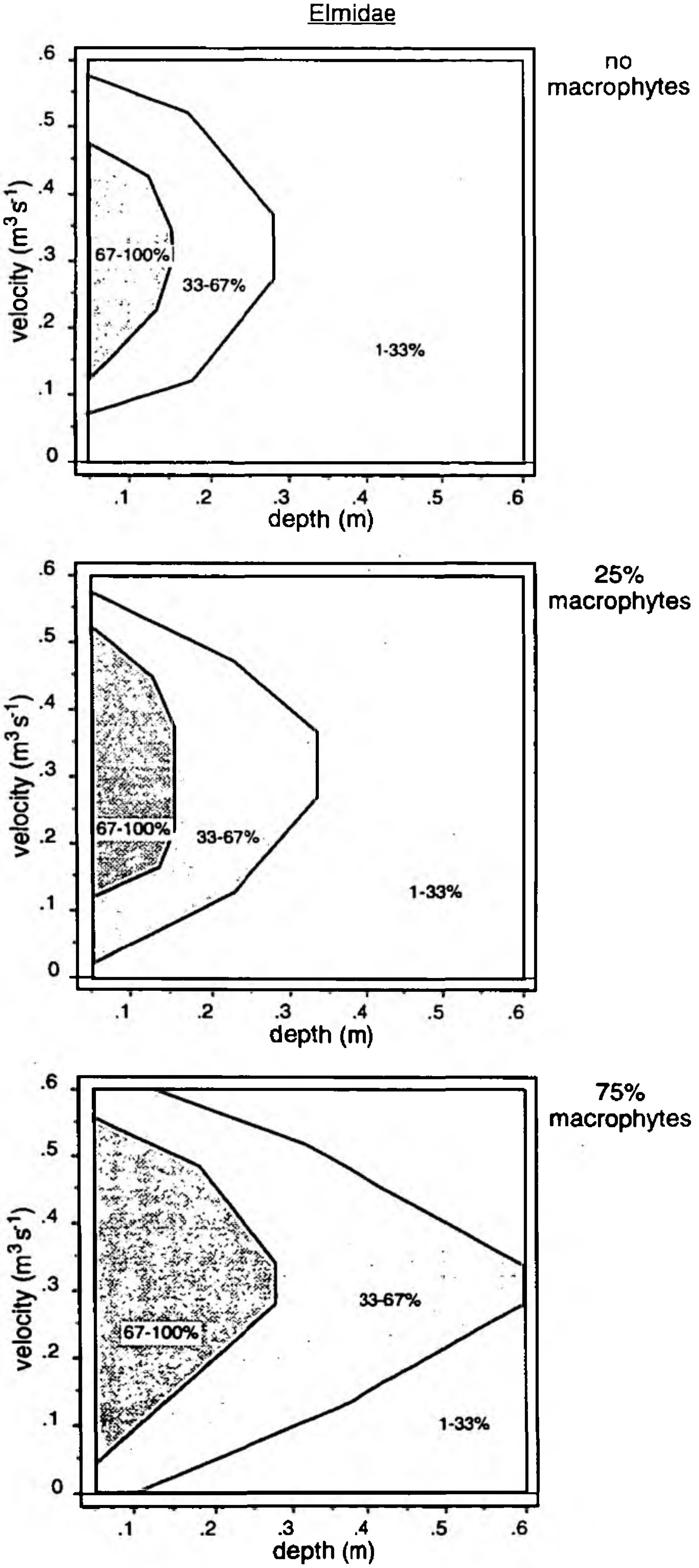
<u>Appendix 8</u> Suitability curves for indicator taxa: Suitability curves for Simuliidae in Sector 3.



Appendix 9 Suitability surfaces for River Wissey indicator taxa: Suitability surfaces for Baetidae in Sector 3 under three macrophyte cover scenarios.

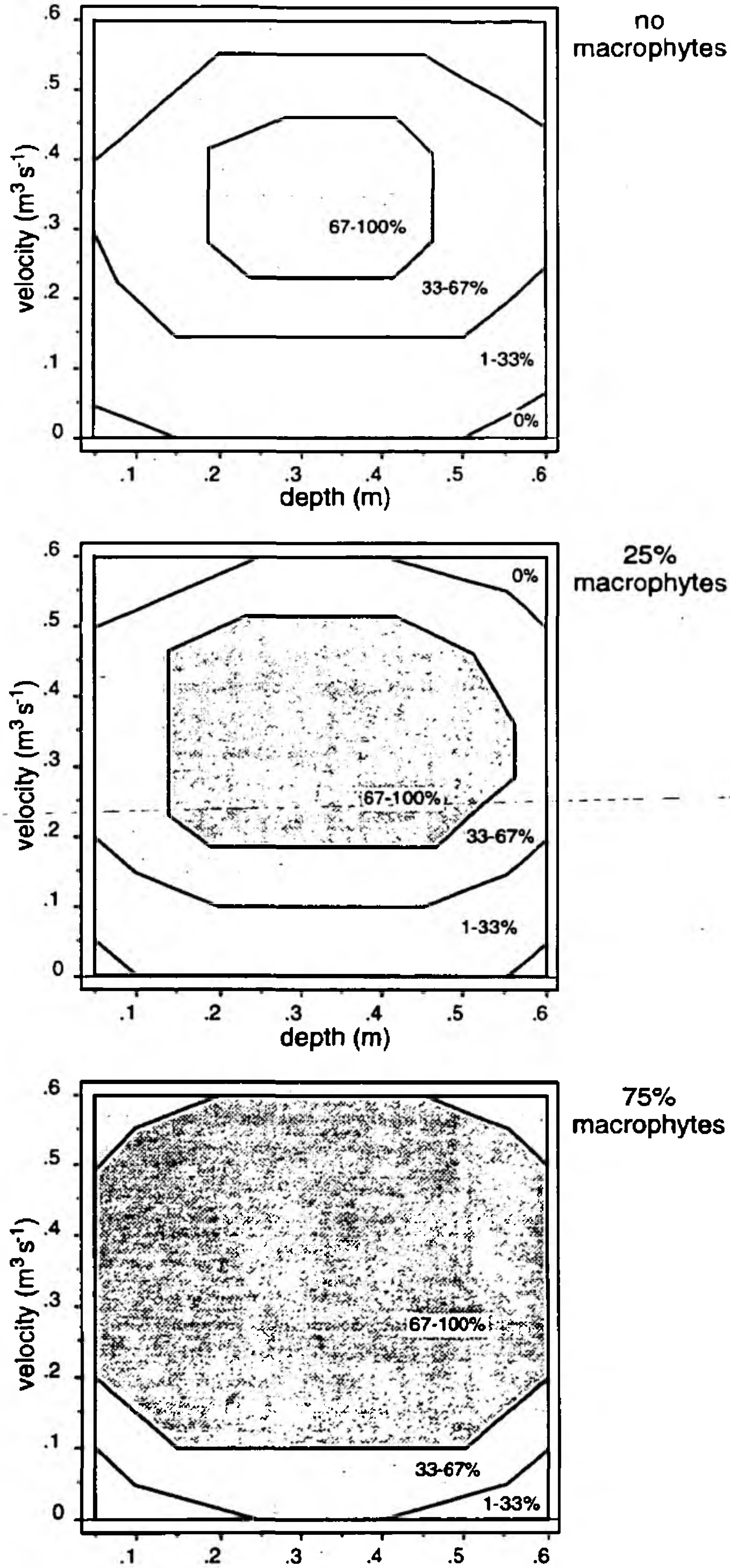


Appendix 9 Suitability surfaces for River Wissey indicator taxa: Suitability surfaces for Ephemeridae in Sector 3 under three macrophyte cover scenarios.



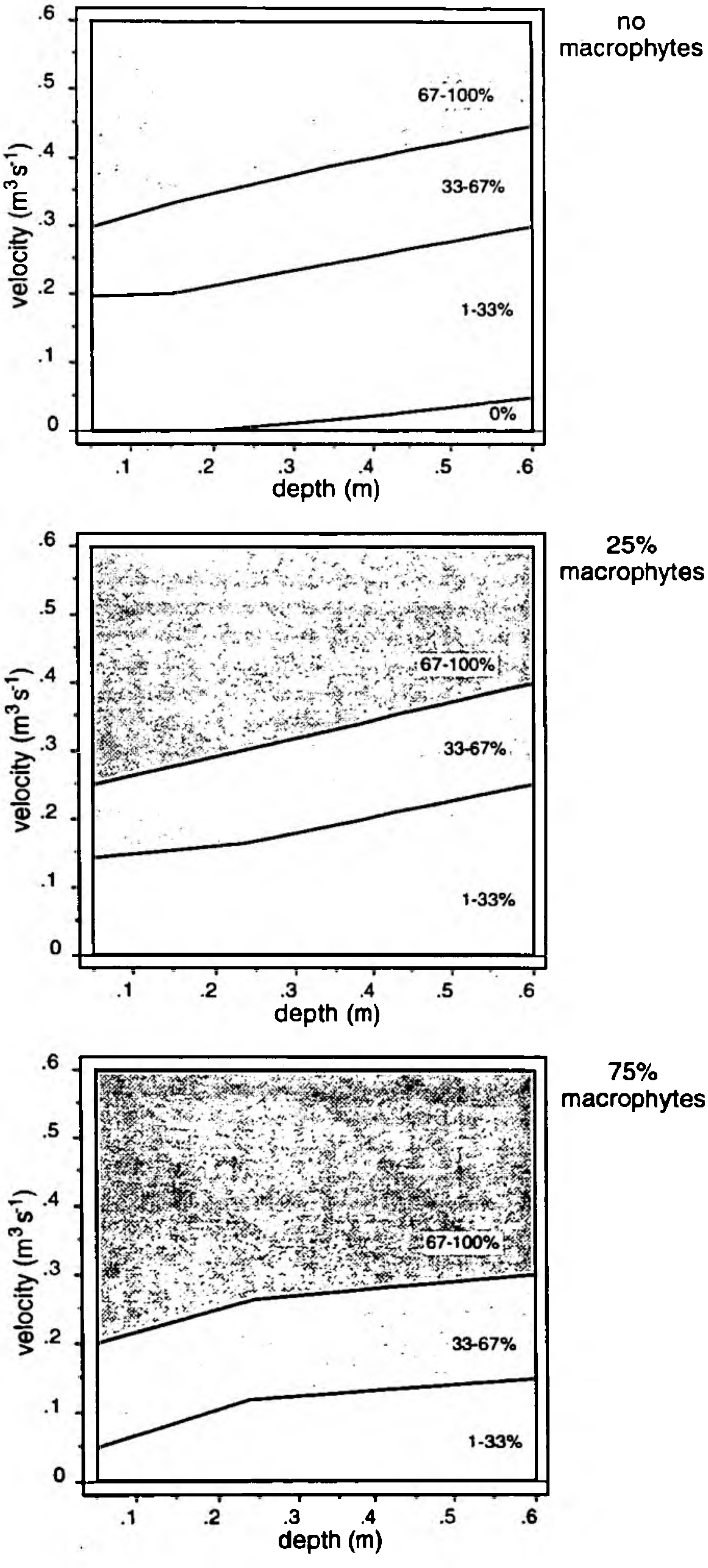
Appendix 9 Suitability surfaces for River Wissey indicator taxa: Suitability surfaces for Elmidae in Sector 3 under three macrophyte cover scenarios.

Hydropsychidae

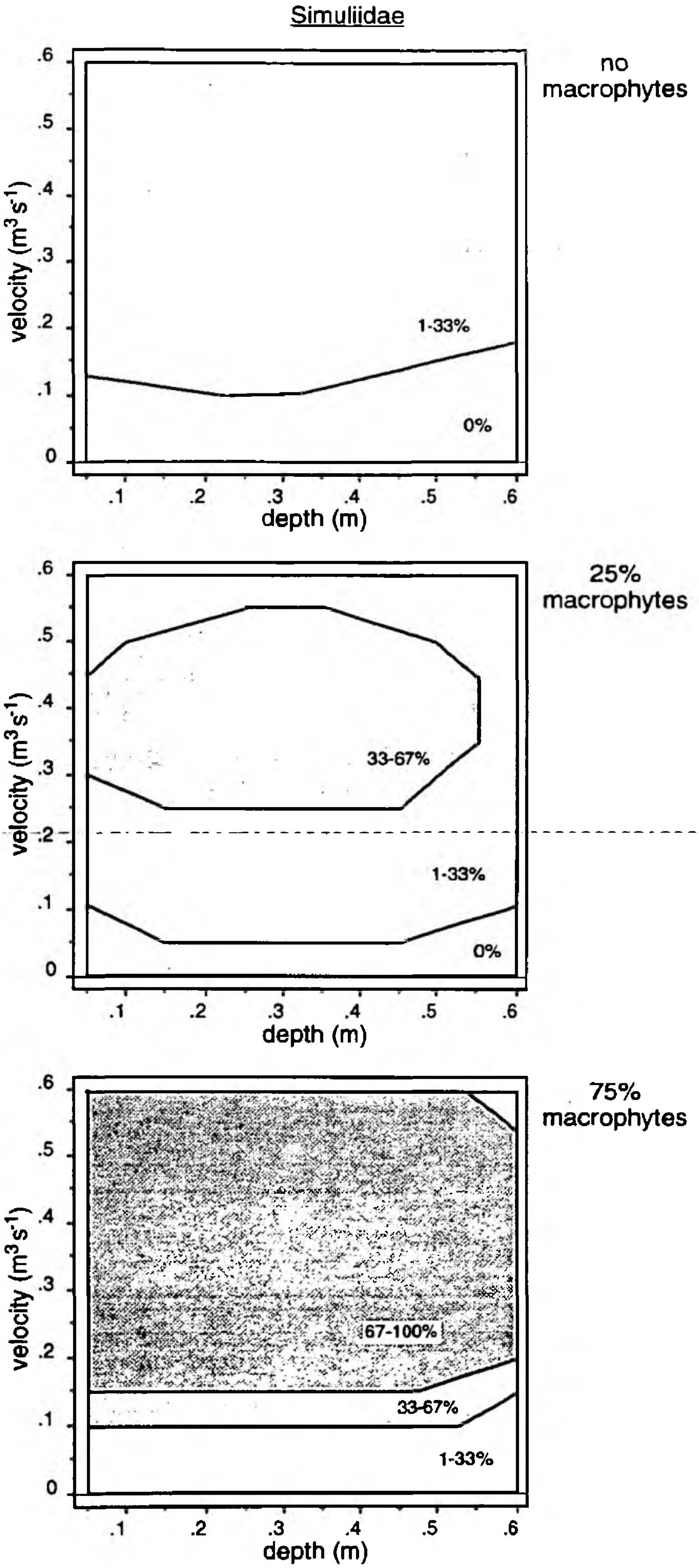


Appendix 9 Suitability surfaces for River Wissey indicator taxa: Suitability surfaces for Hydropsychidae in Sector 3 under three macrophyte cover scenarios.

Athripsodes cinereus

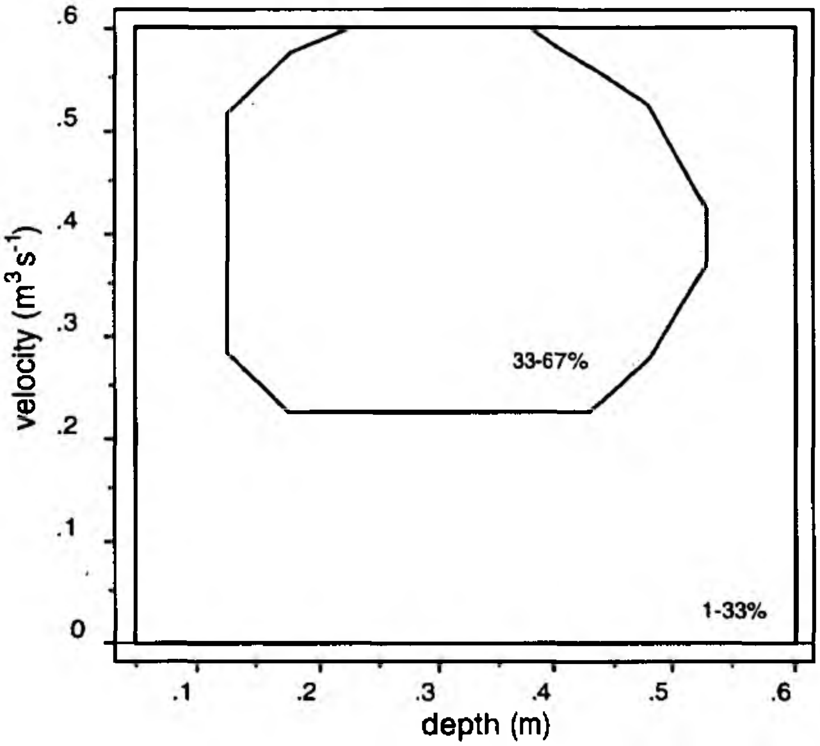


Appendix 9 Suitability surfaces for River Wissey indicator taxa: Suitability surfaces for *Athripsodes cinereus* in Sector 3 under three macrophyte cover scenarios.

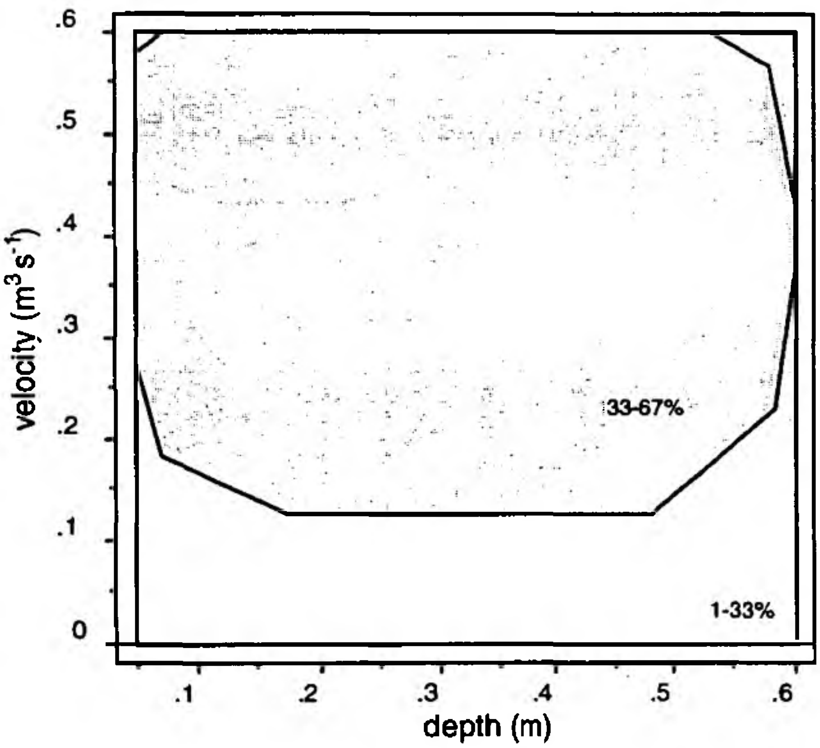


Appendix 9 Suitability surfaces for River Wissey indicator taxa: Suitability surfaces for Simuliidae in Sector 3 under three macrophyte cover scenarios.

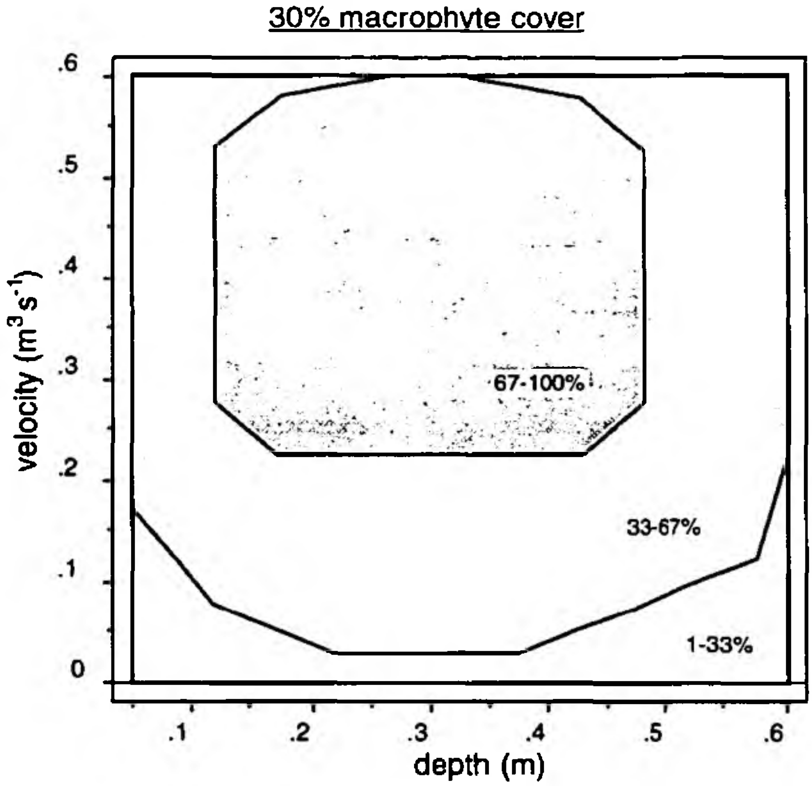
10% macrophyte cover

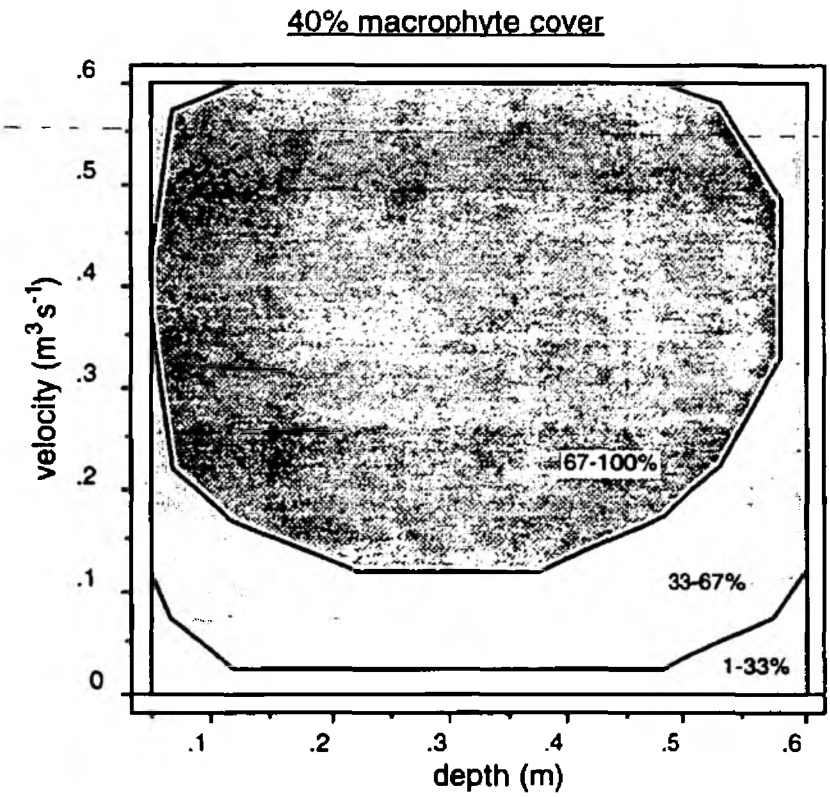


20% macrophyte cover

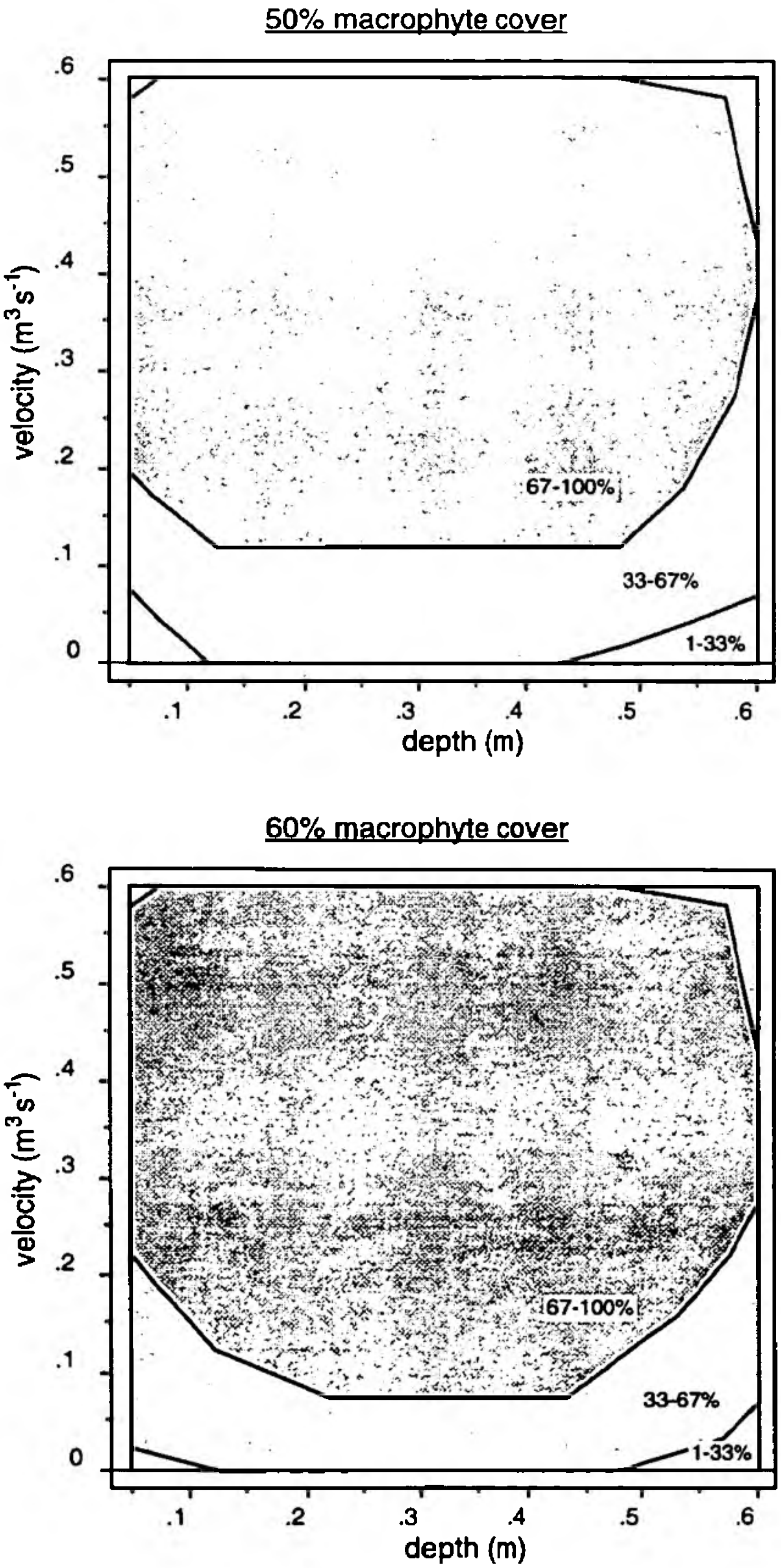


Appendix 10 Suitability surfaces for Baetidae, Sector 3 of the River Wissey: Depth/velocity surfaces for 10% and 20% macrophtye cover.
(all depth/velocity combinations provide suitabilities in class 1-33% at zero percent macrophyte cover.)

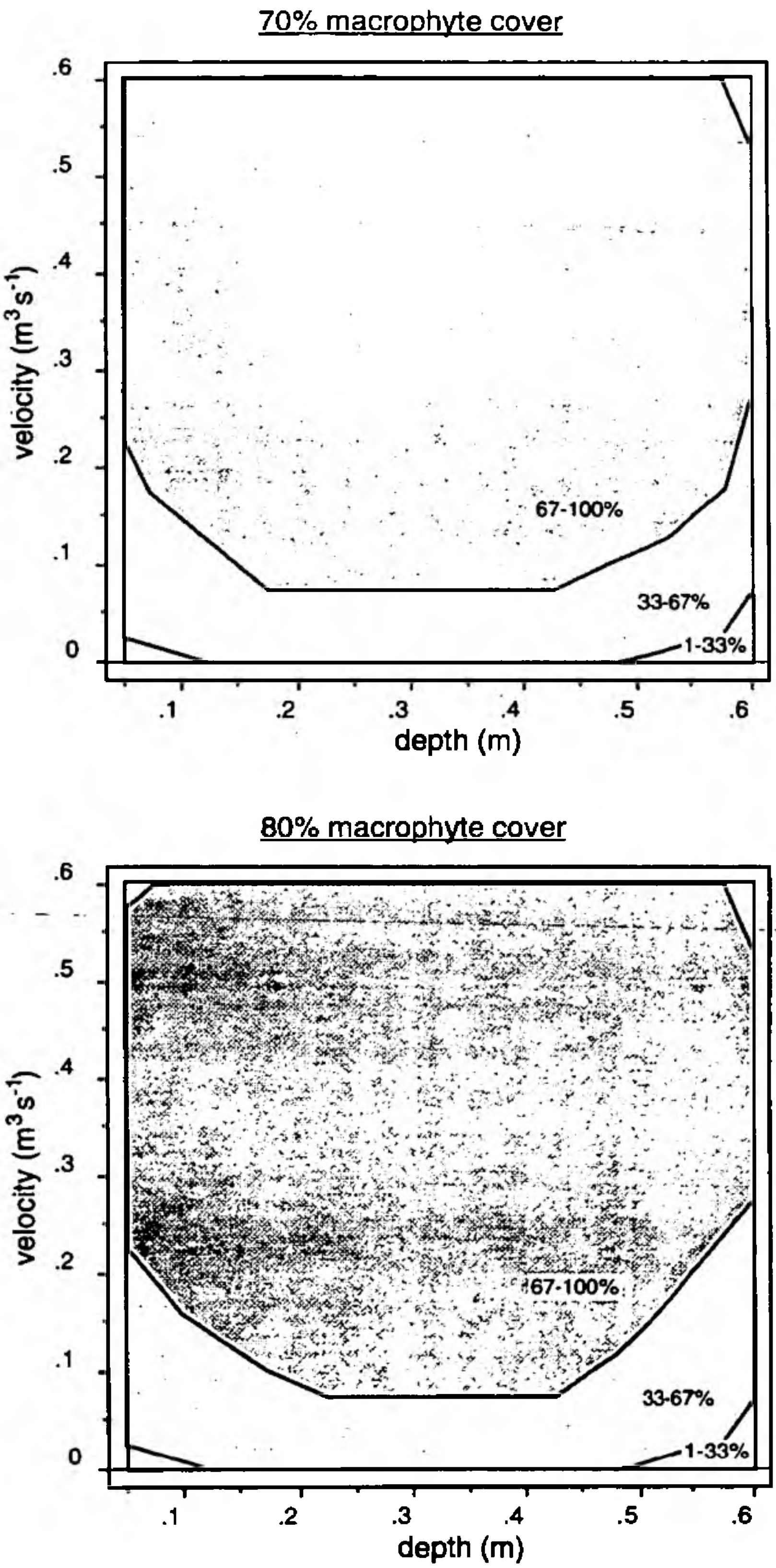




Appendix 10 Suitability surfaces for Baetidae, Sector 3 of the River Wissey: Depth/velocity surfaces for 30% and 40% macrophtye cover.

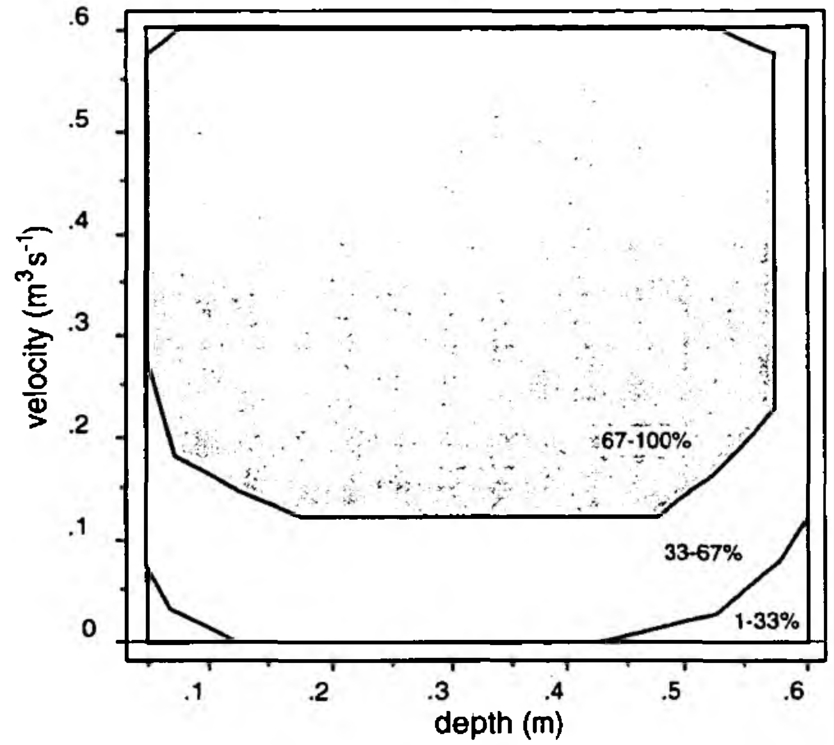


Appendix 10 Suitability surfaces for Baetidae, Sector 3 of the River Wissey: Depth/velocity surfaces for 50% and 60% macrophtye cover.

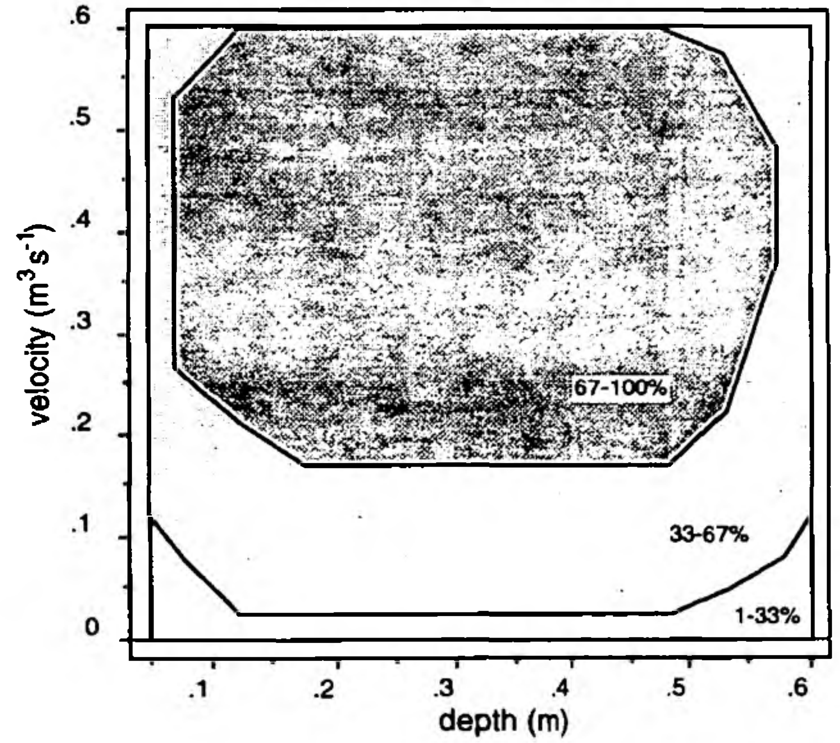


Appendix 10 Suitability surfaces for Baetidae, Sector 3 of the River Wissey: Depth/velocity surfaces for 70% and 80% macrophtye cover.

90% macrophyte cover



100% macrophyte cover



Appendix 10 Suitability surfaces for Baetidae, Sector 3 of the River Wissey: Depth/velocity surfaces for 90% and 100% macrophtye cover.

Appendix 11. Numbers of taxa and flow statistics for NRA invertebrate samples.

A = long-term (over period of record) average low flow for the month
B = long-term standard deviation of low flows for the month
C = seven-day low flow for the month at time of sampling
D = difference between low flow for the month at time of sampling (C),
and long-term average low flow for that month (A).
E = standard score of low flow for the month at time of sampling

site	year (19--)	month (no.)	A	B	C	D	E	no. taxa
WGCR	72	10	0.770	0.359	0.771	0.001	0.002	29
WGCR	73	9	0.667	0.301	0.610	-0.057	-0.191	24
WGCR	84	8	0.708	0.295	0.580	-0.127	-0.432	26
WHLB	90	11	0.987	0.508	0.320	-0.667	-1.313	20
WBYB	73	9	0.667	0.301	0.610	-0.057	-0.191	31
WBYB	84	8	0.708	0.295	0.580	-0.127	-0.432	38
WBYB	90	11	0.987	0.508	0.320	-0.667	-1.313	26
WLGF	72	11	0.987	0.508	0.796	-0.192	-0.376	29
WLGF	75	8	0.708	0.295	0.617	-0.090	-0.307	26
WLGF	85	11	0.987	0.508	0.584	-0.404	-0.793	37
WIKB	72	11	0.987	0.508	0.796	-0.192	-0.376	30
WIKB	73	9	0.667	0.301	0.610	-0.057	-0.191	30
WIKB	75	8	0.708	0.295	0.617	-0.090	-0.307	27
WIKB	84	9	0.667	0.301	0.561	-0.106	-0.353	35
WIKB	85	9	0.667	0.301	0.724	0.056	0.188	40
WIKB	90	8	0.708	0.295	0.231	-0.477	-1.613	24
WIKB	90	11	0.987	0.508	0.320	-0.667	-1.313	23
WNTW	72	10	0.770	0.359	0.771	0.001	0.002	34
WNTW	75	8	0.708	0.295	0.617	-0.090	-0.307	30
WNTW	77	8	0.708	0.295	0.744	0.036	0.123	25
WNTW	81	8	0.708	0.295	0.988	0.280	0.949	33
WNTW	84	9	0.667	0.301	0.561	-0.106	-0.353	35
WNTW	85	9	0.667	0.301	0.724	0.056	0.188	43
WNTW	86	11	0.987	0.508	0.691	-0.296	-0.583	33
WNTW	90	8	0.708	0.295	0.231	-0.477	-1.613	25
WNTW	90	11	0.987	0.508	0.320	-0.667	-1.313	22
BHLB	72	10	0.770	0.359	0.771	0.001	0.002	20
BHLB	84	8	0.708	0.295	0.580	-0.127	-0.432	28
BHLB	90	11	0.987	0.508	0.320	-0.667	-1.313	6
GCKY	84	10	0.770	0.359	0.810	0.039	0.110	21
GOXB	81	8	0.708	0.295	0.988	0.280	0.949	30
GOXB	83	11	0.987	0.508	0.885	-0.103	-0.201	30
GOXB	84	9	0.667	0.301	0.561	-0.106	-0.353	29
GOXB	85	11	0.987	0.508	0.584	-0.404	-0.793	30
GOXB	86	10	0.770	0.359	0.482	-0.289	-0.802	26
GOXB	90	11	0.987	0.508	0.320	-0.667	-1.313	10