National Rivers Authority
Project B2.1 Ecologically Acceptable Flows

INTERIM REPORT

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Executive Summary

The current high profile of low flow conditions existing in UK rivers after two years of severe drought conditions, coupled with the requirement under 1989 Water Act for the NRA to set Minimum Acceptable Flows when requested by the Secretary of State has prompted the need to develop operational tools for managing aquatic communities in British Rivers on a national scale. The Instream Flow Incremental Methodology (IFIM) developed by the Aquatic Systems Branch of the U.S. Fish & Wildlife Service has been used widely for this purpose. IFIM is the subject of previous studies and ongoing research in several countries world wide including Canada (Shirvell,C.S.,Morantz,D.L., 1983), New Zealand (Scott, D., Shirvell, C.S.,1987), Norway (Heggenes, J.,1990) and France (Souchon, Y., Trocherie, F., Fragnoud, E., Lacombe, C.,1989). Initial assessment of application of the IFIM to UK rivers was conducted by a collaborative team including staff from the Institute of Hydrology, Institute of Freshwater Ecology, Institute of Terrestrial Ecology and the Department of Geography, Loughborough University of Technology. The method was applied at five sites on the rivers Gwash and Blithe. Details are given in (Bullock, A., Gustard, A. and Grainger, E. S., 1991). Since October 1990 work has continued in the assessment of the applicability of the IFIM for British rivers under R&D Project B2.1 Ecologically Acceptable Flows. For this commission the method is being assessed by application on selected study reaches on ten different rivers in England and Wales. Study rivers were selected from ten different ecological groups identified by analysis of data from the RIVPACS database.

In this report we shall describe the application of IFIM using PHABSIM, in terms of theory, practical data collection and model calibration procedures. Recommendations are made concerning the minimum data requirements for hydraulic and habitat models, and the preferred choice of hydraulic model given the availability of different types of data. An outline of the process of model calibration for the different hydraulic models is given. These recommendations are made are made largely on the basis of previous UK application and those recommendations made by Dr Robert Milhous and Dr Thomas Hardy of the U.S. Fish & Wildlife Service.

The criteria used for river/reach selection for the study is described. Major improvements to the model data entry procedure have been made. These are discussed both in terms of technical details and practical application procedures. The collection of data has not yet progressed to a stage where a full calibration data set is available for any single study site hence experience of model calibration has been limited to test data sets. For this reason we are unable to present the results of any completed hydraulic simulations. Technical details of the calibration procedure, based on recommendations from U.S. Fish & Wildlife Service recommendations is included here.

Although the current study is intended to assess the methodology, and intentionally avoids sites with specific current operational problems, it has been suggested that individual NRA regions may wish to begin collection of data in a format compatible

with the data requirements of PHABSIM, before results of the current assessment are available. Chapters 4 and 5 deal specifically with this matter, giving advice, on the basis of current experience of applying the model to UK rivers, to assist in the data collection exercise.

Once sufficient calibration data has been collected output from hydraulic simulations will be combined with habitat suitability data to give habitat-discharge relationships for all target species at each study site. These will be combined with time series of historical flows to give habitat time series which will be used in the analysis of the seasonal variation of available physical habitat. For one of the sites this analysis will be used as part of the methodology in setting an ecologically acceptable flow regime. Fish sampling data will be compared with outputs of PHABSIM simulations.

The methodology used for the construction of habitat suitability information for fish, macroinvertebrate and microphyte species is discussed and completed preference curves are given. This exercise is almost complete and most of the remaining effort in terms of ecological studies will be directed towards interpretation and validation of PHABSIM model outputs.

Hydrological studies have been delayed due to problems gaining access to study sites. It is hoped that sufficient data will be collected in the coming months to bring the data entry program back on target. Accordingly efforts will be made to bring model calibration back in line with the target completion date.

Key Words

Cover
Current Metering
Depth
Discharge
Ecology
Ecologically Acceptable Flows
Electrofishing
Fish
Habitat
Habitat Suitability Indices (Preference Curves)
Hydraulics
Hydrology
IFIM
Kick Sampling
Macroinvertebrate
Microphyte
PHABSIM
RIVPACS
Substrate
Velocity
Weighted Usable Area

Preface

This report describes the application of the Instream Flow Incremental Methodology using the PHABSIM system to rivers in the UK. The contents of this report are based on documented material from application in the USA and from experience gained from application of the method in the UK by staff from the Institute of Hydrology, Institute of Freshwater Ecology, Institute of Terrestrial Ecology and Loughborough University. Previous PHABSIM studies conducted by the above organisations have been commissioned as follows:

Department of the Environment: Initial model transfer and assessment of application on the rivers Gwash and Blithe.

Acknowledgements

The authors would like to acknowledge the Aquatic Systems Branch of the US Fish & Wildlife Service who developed the Instream Flow Incremental Methodology, in particular Dr Robert Milhous for his contribution to UK application of the methodology.

Abstract

The Instream Flow Incremental Methodology (IFIM) allows the quantification of a weighted measure of physical habitat available to aquatic species for the range of discharges experienced in a river. This information, when combined with hydrological data describing the flow regime may be used as a tool in the setting of flow regimes optimal for ecological management.

Work under R&D Commission B2.1 Ecologically Acceptable Flows commenced in October 1990. For this commission the IFIM is being assessed through application on ten different rivers in England and Wales, chosen to lie in ten different ecological groups identified by analysis of data from the RIVPACS database.

1 Introduction

1.1 HISTORICAL BACKGROUND

One recent development of water resources management in the United Kingdom is the use of computer models which relate the requirements of freshwater ecology to low river flows. A multidisciplinary team funded by the Department of the Environment and headed by the Institute of Hydrology, involving the Institute of Freshwater Ecology, Institute of Terrestrial Ecology and Loughborough University (Petts, 1990) has gained experience in the use of one such technique, the Instream Flow Incremental Methodology (IFIM).

The IFIM is a concept developed by the United States Fish and Wildlife Service to fill a particular need for decision makers in the water resources arena. The methodology provides a quantitative method to assess species habitat trade-offs against other uses of water, particularly surface water abstractions for irrigation, domestic and industrial water use which can threaten the integrity of running water ecosystems. The goal of the method is to relate ecological values to stream discharge in a manner generally consistent with methods for quantifying other beneficial uses of water.

Water management in the United Kingdom has historically adhered to discharge-based methods in the setting of prescribed flows, being set according to the Dry Weather Flow. The Dry Weather Flow is itself an undefined discharge, but which is indexed by a low flow discharge, typically either the 95 percentile flow duration statistic, or the mean annual minimum seven day flow frequency statistic. It is only a recent phenomenon in the United Kingdom that cognisance is given by resource planners to the ecological value of low river flows; for example, the Yorkshire National Rivers Authority region now employ an environmental weighting scheme, which sets prescribed flows as a proportion of the Dry Weather Flow (DWF) weighted according to a range of environmental characteristics and uses (Drake and Sherriff, 1987). Thus the Environmental Prescribed Flow is set at 1.0 x DWF for the most sensitive rivers and at 0.5 x DWF for the least sensitive, which will determine the amount of water available for offstream uses, pollution dilution and environmental protection.

Recommendations from a review of compensation flows below impounding reservoirs in the United Kingdom (Gustard et al. 1987) suggest that a reevaluation of awards is warranted but that any negotiation of new awards should move away from simply setting prescribed flows as a fixed percentage of the mean flow. The review establishes that many reservoirs provide compensation flows which were determined by industrial and political constraints and which no longer apply. Furthermore, the majority of compensation flows were awarded when there were little or no hydrometric data to describe differences in catchment hydrology and little knowledge of the impact of impoundments on downstream aquatic ecology. It is the inheritance of this historical legacy that prompts a reassessment of current compensation flows. Equally, the recognition that aquatic ecosystems have specific flow requirements which perhaps bear little relation to existing compensation awards is a strong argument towards the reassessment of prescribed flows, moving away from discharge-based methods alone towards habitat methods.

However, while quantitative models and design techniques are available for estimating discharge statistics in rivers, for example Low Flow Studies (Institute of Hydrology 1980), there is a paucity of operational tools for managing aquatic communities in British rivers at a national scale. A notable exception is the development of the RIVPACS (River Invertebrate Prediction And Classification System) technique, appropriate for modelling invertebrates. Fish management models tend to be more scheme-specific in nature, for example the fisheries study downstream of Roadford Reservoir which commenced in 1984 aimed at developing operating rules to minimise detrimental impacts upon salmonids in the Tamar and Torridge rivers. The recent development of the HABSCORE technique by the Environmental Appraisal Unit of the National Rivers Authority - Wales establishes an operational tool for the management of salmonid populations in Welsh rivers. Essentially, both RIVPACS and HABSCORE adopt the same rationale - that the carrying capacities of streams are to a large extent dependent on channel structure and the environmental regime (hydrological, chemical, temperature) experienced within the stream. These characteristics can be measured by a combination of site features (width, depth, substrate, cover etc.) and catchment features (altitude, gradient, conductivity etc.). By measuring these features and species populations at a number of pristine sites which have variable habitat, multivariate models can be calibrated which predict species presence and abundance from the environmental variables. The predicted population sets an objective for the river reach based on the habitat which it provides. This type of model may be used to detect anomalies in observed ecological data in relation to the objective population, anomalies which may be attributable to impacting factors. However, this type of model does not enable the impact of different flow (regimes or prescribed flows) regimes to be explicitly simulated.

Water management in Britain lags a considerable way behind the United States as regards the development of appropriate management models for recommending flow regime measures which consider ecological demands. In the United States procedures for evaluating impacts of streamflow changes were first developed and have advanced considerably in the period 1974-1989. Central to these advances has been the concept of instream flow requirements which recognises that aquatic species have preferred habitat preferences, with habitat defined by physical properties (flow velocity, water depth, substrate and vegetal/channel cover). Because some of these physical properties which determine habitat vary with discharge, so species have different preferences for different discharges. Development of the Instream Flow Incremental Methodology (IFIM) by the Aquatic Systems Branch of the U.S. Fish and Wildlife Service has allowed the quantification of species preferences for the full range of discharges that may be experienced within a river. This quantification of habitat preferences and the relationship with river flow permits the negotiation and setting of optimal flows for ecological management. Setting instream flows in this manner complements purely water-quantity or cost-management objectives by paying cognisance to the physical habitat requirements.

In the period since 1960 within the United States the importance of instream flows has become regarded more widely as essential to maintain and restore values and uses of water for fish, wildlife, ecological processes, and other environmental, recreational and aesthetic purposes (Jahn 1990). By the mid-1980's, at least 20 states provided legislative recognition of instream flows for fish aquatic resources. Data from Lamb and Doersken (1987) in Table 1.1 illustrates that IFIM is now the most widely applied method for determining instream flow requirements for major resource schemes in the United States. The US equivalent of the Dry Weather Flow, the 7-Day, 10 Year (7Q10) Low Flow is used in just 5 states. Along with other simpler methods, such as the Tennant Method, 7Q10 would tend to be applied to minor schemes and basin-wide planning purposes.

Table 1.1 Methods for determining instream flow requirements in the United States and number of States using method

METHOD	NUMBER OF STATES USING METHOD
Instream Flow Incremental Methodology (IFIM)	38
Tenant Method	16
Wetted Perimeter	6
Aquatic Base Flow	5
7-Day, 10 Year Low Flow (7Q10)	5
Professional Judgement	4
Single Cross-Section(R-2CROSS)	3
USGS Toe Width	2
Flow Records/ Duration	2
Water quality	2
Average Depth Predictor (AVDEPTH)	1
Arkansas	1
Habitat quality index	1
Oregon Fish-Flow	1
US Army Corps of Engineering (HEC-2)	1
Source: Lamb and Doersken(1987)	1

The essence of the Instream Flow Incremental Methodology is concisely stated by Bartholow and Waddle (1986):

"The Instream Flow Incremental Methodology is a reasoned approach to solving complex streamflow allocation problems that are often characterised by uncertainty. Application of the IFIM requires an open and explicit statement of management goals, study objectives, technical assumptions, and alternative courses of action. IFIM provides a framework for presenting decision makers with a series of management options, and their expected consequences, in order that decisions can be made, or negotiations begun, from an informed position. IFIM exposes for the decision makers those areas where their judgement is necessary and presents the potential significance of the alternatives they might choose."

By relating ecological demands to discharge, the merit of IFIM lies in providing a quantitative basis which allows river ecologists to negotiate prescribed flows or flow regimes in equivalent terminology to other water resource demands.

1.2 JUSTIFICATION FOR SELECTION OF INSTREAM FLOW INCREMENTAL METHODOLOGY.

The demand for a scientifically defensible method for both resource allocation and environmental impact assessment in the United Kingdom (Petts 1989) may be satisfied by IFIM when it is considered that the scientific rationale of IFIM has been successfully defended against legal challenges in the U.S.. There is therefore scope for the application of IFIM in the United Kingdom to yield long-term benefits to instream flow management. By relating ecological requirements to discharge IFIM allows prescribed flows to be determined and set using values which complement quantity-based statistics. The method has received wide international recognition and has been extensively applied to real water resource problems in the U.S.. The validity of IFIM and PHABSIM for assessing ecologically acceptable flows may be summarised as follows:

a. No other model can predict the impact of changing flows upon fish,invertebrates and macrophytes. Existing habitat models such as Habscore and Rivpacs are not designed for the recommendation of the hydrological regime or prescribed flow.

b. The primary impact of changing flow is upon changing water depth and velocities, both of which are considered as primary variables by IFIM.

c. IFIM predicts physical habitat change, and quantifies this in respect of the ecological value of those habitat loss/gains.

d. Relative values of physical habitat are more important than absolute values.

e. Experience of model elsewhere: US, France, Norway, New Zealand, Australia. Successful defence of the underlying methodology against legal challenges in US.

f. IFIM, by relating habitat to discharge, provides a quantitative basis allowing river ecologists to negotiate prescribed flows in equivalent terminology to other water resource demands.

To question the validity of the IFIM rational is essentially to question whether physical habitat is an important variable to model in the prediction of instream flow requirements for aquatic species. For this reason the onus must lie with critics of the methodology to show that physical habitat is not important in this context.

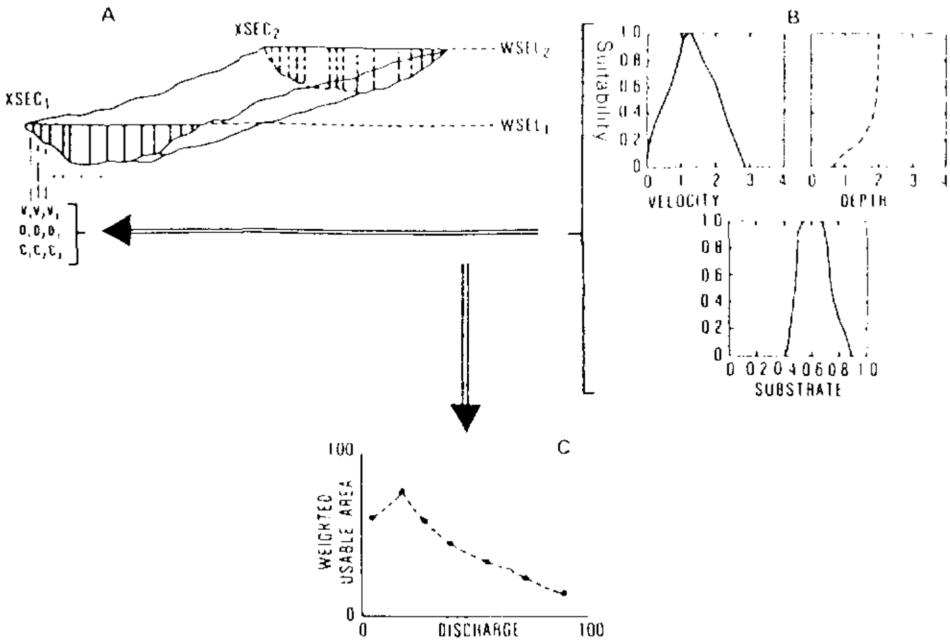
1.3 IFIM RATIONALE AND CONCEPT

The IFIM procedure provides an estimate of habitat loss/gain with changes in discharge. IFIM itself is a concept or at least a set of ideas and PHABSIM is software (Gore and Nestler, 1988).

The underlying concepts of the Instream Flow Incremental Methodology are that:

- IFIM is habitat based, with potential usable habitat being simulated for unobserved flow or channel conditions.
- Evaluation species exhibit a describable preference/avoidance behaviour to one or more of the physical microhabitat variables; velocity, depth, cover or substrate.
- Individuals select the most preferred conditions within a stream, but will use less favourable areas with decreasing frequency/preference.
- Species populations respond to changes in environmental conditions that constitute habitat for the species.
- Preferred conditions can be represented by a suitability index which has been developed in an unbiased manner.

The purpose of the PHABSIM system is the simulation of the relationship between streamflow and available physical habitat where physical habitat is defined by the microhabitat variables. The two basic components of PHABSIM are the hydraulic and habitat simulations within a stream reach using defined hydraulic parameters and habitat suitability criteria, as displayed in Figure 1.1 below.



A schematic representation of the IFIM process. Velocity (V), depth (D), and cover substrate (C) values from various cross sections (XSEC) are combined with water surface elevations (WSEL) at a steady discharge to drive the hydraulic model (steady or dynamic flow) which provides stage-discharge information to PHABSIM [A]. The habitat suitability information [B] is linked to the simulation of cell-by-cell hydraulics to predict (via HABTAT) the amount of weighted usable area at any proposed discharge [C]

Fig 1.1 Structure of PHABSIM model data

Hydraulic simulation is used to describe the area of a stream having various combinations of depth, velocity and channel index (cover or substrate) as a function of flow. Habitat suitability is based on the preference of species for certain combinations of physical parameters above others.

Hydraulic and habitat data are combined to calculate the weighted usable area (WUA) of a stream segment at different discharges based on the preference of selected target species for the simulated combinations of hydraulic parameters.

Physical habitat suitability information for target species, and distinct life stages of those species, can be derived from existing empirical data (including the US Fish and Wildlife Service Curve Library), scientific literature, or direct field sampling.

It is important to realise that the IFIM is a concept, or at least a set of ideas whereas PHABSIM is a model comprising a suite of computer programs. For some IFIM studies PHABSIM may be one of a number of different computer models used to provide information to assist in the decision making process. In some situations output from water quality models or temperature models may augment that from PHABSIM. In scoping an IFIM study it is essential to identify at the outset those factors which are likely to have significant impact on aquatic ecology and which may be limiting to aquatic populations. If, for example, a change of water temperature was identified as the principle result of some proposed development (eg. afforestation or deforestation) then a water temperature model would be the most appropriate model to employ in the IFIM study and PHABSIM would be inappropriate. If, conversely, the chief impact of a resources development was to alter the flow regime (and consequently local velocities, depth, substrate type and available cover) without significantly altering other factors such as temperature and water quality, then PHABSIM could be the sole model employed in the IFIM study.

It is clear that in conducting an IFIM study an ideal goal would be to relate changes in populations to change in the flow regime. Although some studies have successfully demonstrated that PHABSIM may be capable of achieving this goal it must be appreciated that PHABSIM is not in general capable of this task since it predicts change in a weighted measure of physical habitat area (WUA) available to aquatic species and does not predict change in biomass. In some instances a linear relationship between biomass and WUA has been demonstrated (Milhous,R.T.,1988) but it is clear that this is not generally the case since factors other than change in WUA may be limiting to populations. It is essential that, in the absence of equivalent population models, one accepts the limitation of using WUA as the key variable and attempts to take into account as best as is possible factors which are likely to influence the relationship between WUA and populations. Gore and Nestler (1988) make the following statement with regard to this issue:

"PHABSIM is a vehicle for presenting biological information in a format suitable for entry into the water resources planning process. It is not, nor was it ever intended to be, a replacement for population studies, a replacement for basic research into the subtleties of fish or benthic ecology, nor a replacement for biological innovation or common sense. As such, PHABSIM has been found to be a defensible technique for adjudicating flow reservations".

1.4 UK APPLICATION

The first UK application of the IFIM using PHABSIM involved studies at five sites on the rivers Blithe and Gwash under a commission from the DOE (Bullock, Gustard & Grainger,1991). Despite some problems with model calibration, this study demonstrated the potential of PHABSIM as a practical tool for the generation of habitat versus discharge relationships for IFIM studies on UK rivers.

Following this successful initial application, work has continued on the assessment and development of PHABSIM for UK application has continued under the current R&D Project B2.1 Ecologically Acceptable Flows. This work involves studies on ten rivers in England and Wales, chosen to reflect a wide range of different ecologies. In the course of this study some refinements have been made to the data collection procedure. Experience in dealing with practical problems of field data collection has been gained in a number of different river environments.

1.5 PROGRESS TO DATE

(i) Collation of data and information

Extensive searches of relevant hydrological and biological literature have been conducted and relevant data collated. This exercise is still ongoing.

(ii) River/Reach Selection

This is now completed as detailed in Chapter 3.

(iii) Fieldwork and Channel Index Design

This is now completed. Comprehensive details of new techniques are given in Chapter 4.

(iv) Preference Curve Construction

See section 6.1 for details of progress in this area.

(v) Channel survey,flow measurement and sampling

The current position of the data collection procedure for the hydrological studies is given overleaf in Table 1.2.

(vi) Data entry/processing

The above data have all been entered and are currently undergoing final checking.

(vii) Model Calibration

At present we do not have sufficient hydraulic calibration data to test calibration for the preferred combination of hydraulic models. Practical procedures for model calibration, based on expert advice from U.S. Fish & Wildlife Service staff are described in Chapter 7.

(viii) Software Assessment/Development

The most recent upgraded menu-driven version 2.0 of PHABSIM has been obtained from the U.S. Fish & Wildlife Service, loaded and tested. One of the main areas of software development has been in hydraulic data collation, entry and quality control. A new data entry procedure allows the free-formatted entry of data and gives an easily read (and thus checked) file for each portion of the data to assist in the identification of errors. By contrast the existing data entry program RIFG4IN requires strictly formatted input data and the completed data file is very difficult to read.

In addition to developing a new data entry procedure a number of utility programs

PROGRESS OF TASKS

	HEADPIN ELEVATION SURVEY	BED ELEVATION SURVEY	SUBSTRATE/COVER SURVEY	STAGE-DISCHARGE SETS	COMPLETE VELOCITY SETS
EXE	1	1	0	0	1
WYE	1	1	1	0	1
HODDER	1	1	1	0	0
BLITHE	2	1	1	1	1
ITCHEN	1	1	1	0	1
LYMINGTON	1	1	1	0	1
MILL STREAM	4	1	1	3	3
LAMBOURNE	0	0	0	0	0
GWASH	0	0	0	0	0
GREAT OUSE	2	1	1	0	1
LEES BROOK	1	1	1	0	1

Table 1.2 Progress of fieldwork programme

have been developed in conjunction with Dr Robert Milhous. These serve the following functions:

- *To convert substrate/cover values observed using the new classification technique (see 4.8) to values derived from a choice of existing codes for which preference curve data is available.*

- To make preliminary checks of measured depths against bed elevations and computed discharges at each transect for the calibration data sets.

- To convert data compiled using the new data entry procedure to the standard IFG4 format.

- To add additional calibration data sets (in their new format) to the IFG4 file.

These programs are still undergoing final testing and completion of documentation. All are written in FORTRAN and may be run on an IBM PS2. When testing is complete they will be added into the menu-driven structure of PHABSIM.

Assessment of the relative merits of the different hydraulic models is not possible until sufficient calibration data is possible.

1.6 ASSESSMENT OF PROGRESS IN RELATION TO ACTIVITY SCHEDULE

The Activity Schedule from the Project Inception Report is shown in Fig 1.2 overleaf:

Comparing actual achievement with the target achievement from the Activity Schedule at 1.2.92 an estimate of the percentage of the total work required to meet targets that has been met for each task is shown in Fig 1.3 on page 11 below:

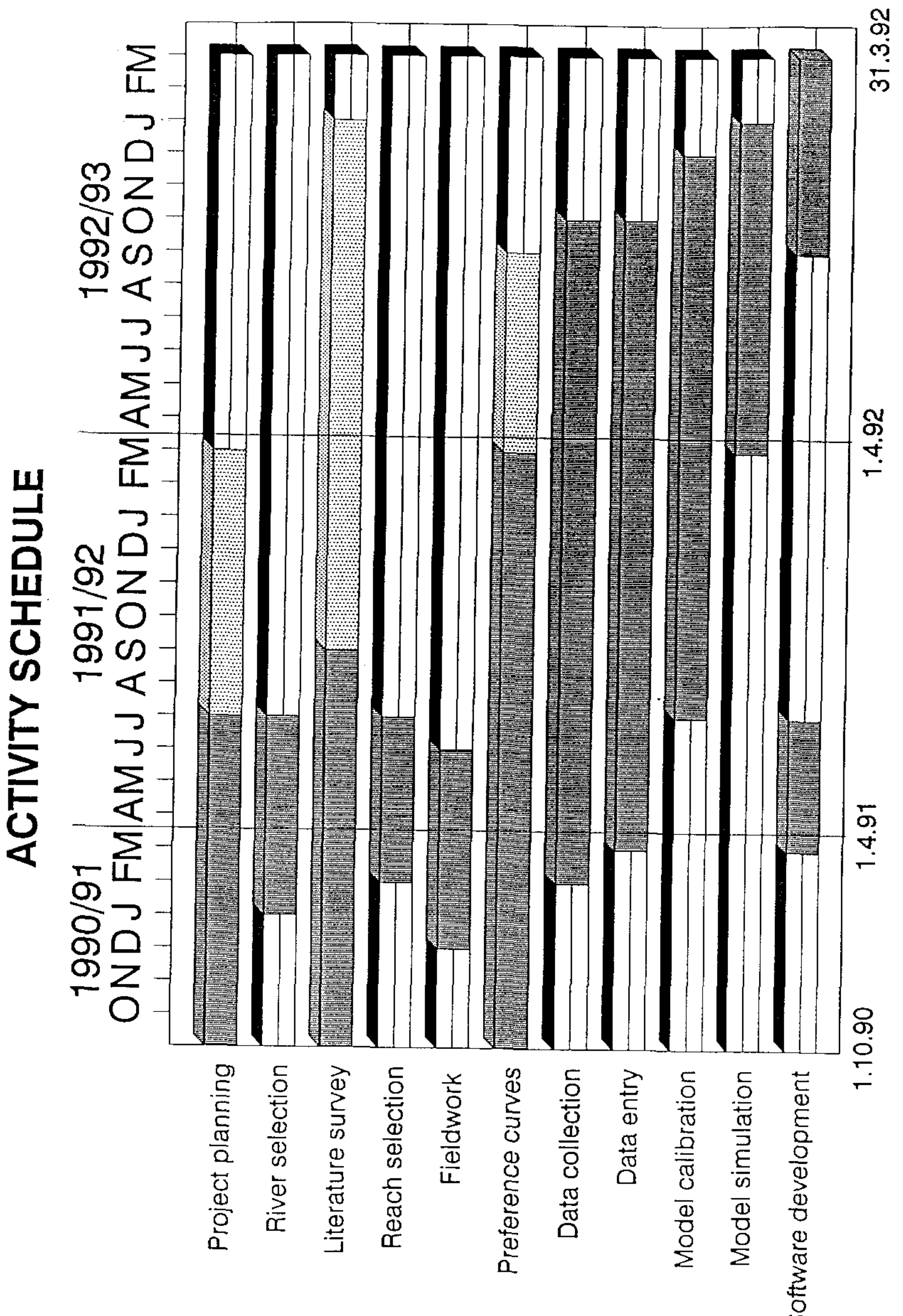


Figure 1.2 *Activity schedule*

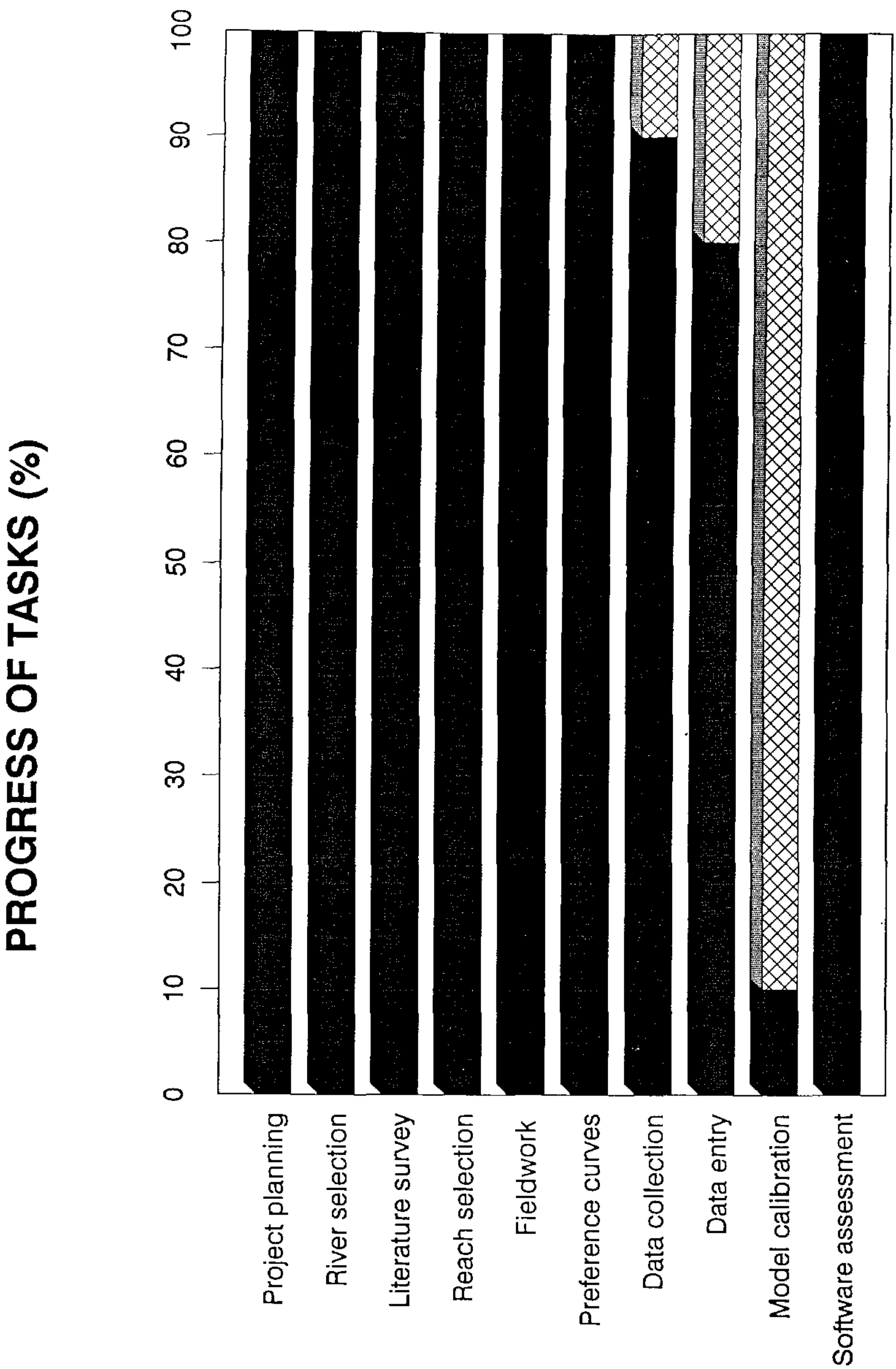


Figure 1.3 *Percentage attainment of each task*

2 Phabsim Model

In this section we will briefly describe the structure and flow of information through the PHABSIM model (see Fig 1). For details of the basic concepts and assumptions underlying the model please refer to Section 1.3,and for rigorous mathematical details to the Project Inception Report, to Bullock, Gustard & Grainger (1991) or to Bovee (1982).

A representation of the basic structure of the PHABSIM model is shown in Fig 2.1 below:

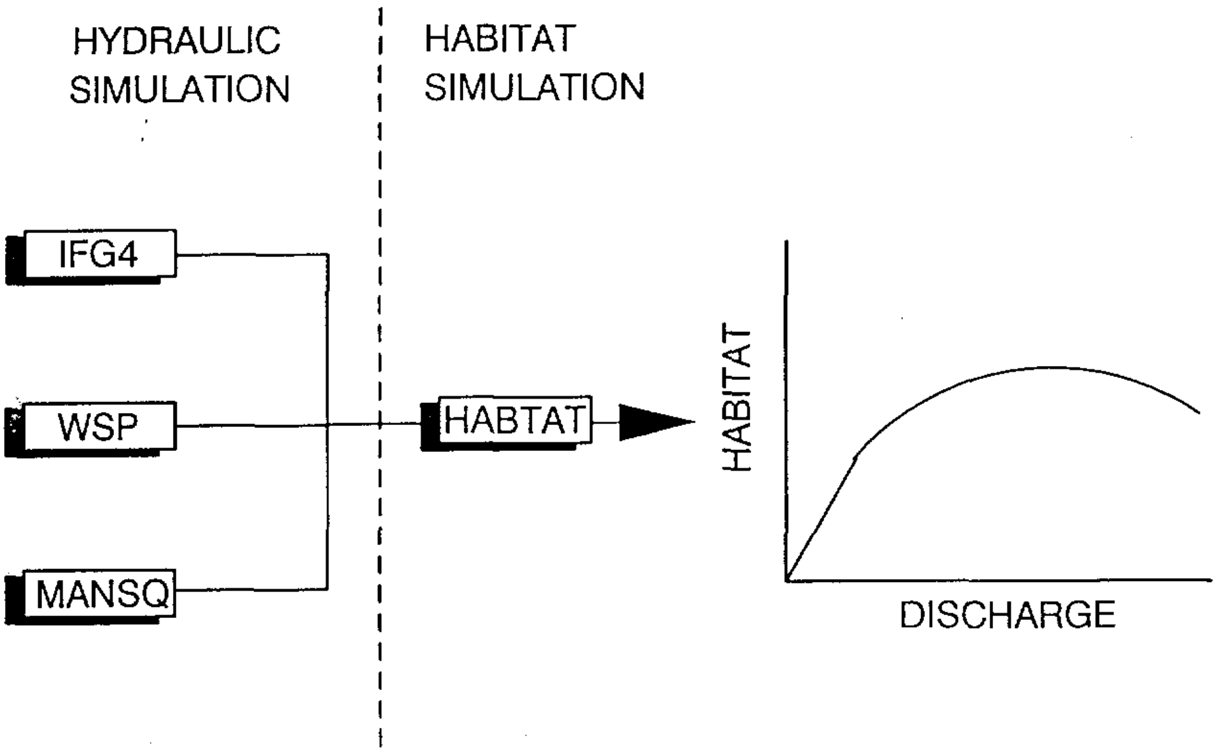


Fig 2.1 *Flow of Information Through PHABSIM model*

There are two distinct stages in the simulation process, hydraulic simulation, followed by habitat simulation. In the hydraulic simulation phase one (or a combination) of the hydraulic models is calibrated using observed values of depth, and velocity for at least one calibration discharge. Once calibration is complete the calibrated model is used to predict depths and velocities at all simulation discharges of interest.

Observations of substrate and cover values do not enter into calculations performed in the hydraulic simulation phase. Values may be entered into the data file but they are not required or used until the habitat simulation phase. Values are assumed to remain constant as discharge varies.

Once predicted values of depth and velocity are available for all simulation discharges and values of cover/substrate have been added to the habitat model input file the habitat modelling stage begins. The basic habitat model contained in PHABSIM is HABTAT. There are other models but these all perform the same basic methodology. For each of the simulation discharges of interest then modelling process is as follows:

Through the assignment of weights (see 4.9 for details) and reach lengths (see 4.4) a cell area is defined for each data point used in the hydraulic simulation phase. A plan view of the reach is made up of a grid of these cells. For edge cells this area is clearly dependent upon discharge-predicted depths from the simulation phase are used in the area calculation .Associated with a point Xi on any given transect we thus have values of depth (di), velocity (Vi), a substrate/cover value (SCi), and an associated cell area Ai. For this point the basic habitat calculation is:

$$WUA\ i = Ai \times CSI(di, Vi, SCi)$$

giving the weighted measure of available physical habitat associated with the given data point for this particular simulation discharge. The function CSI is known as the Composite Suitability Index. This function combines information from suitability indices (preference curves) which describe the relative suitability to the target species of the predicted cell variables di, Vi and SCi. Specific details of the functional forms of CSIs which may be selected are given in 7.4 below.

For the given simulation discharge this process is repeated at each data point and the results of these calculations are summed to give a total Weighted Usable Area. Repeating this process for a number of different simulation produces the required WUA vs Q relationship for use in the IFIM decision making process.

2.1 HYDRAULIC MODELLING

The hydraulic models contained within PHABSIM are calibrated with observed field data and used to simulate depths and velocities at different discharges selected by the user. The study reach is represented by a grid of cells whose boundaries are defined by a number of transects placed along the reach, perpendicular to the direction of flow, and a number of points positioned laterally across each transect (see Fig 2.2). The simulated depths and velocities predicted at a particular point across a transect are assigned to a cell area whose boundaries are defined by the mid-points of the distances to adjacent points on the transect (see Fig 2.3) and the mid points of the distances to the next up and downstream transects (see Fig 2.2) overleaf.

PHABSIM hydraulic simulation programs assume that the hydraulic variables measured at a transect extend halfway to adjacent transects up and downstream.If this is not the case, upstream weighting factors should be applied. Weighting factors are used by the habitat simulation programs, not the hydraulic simulation programs. Details of the assignment of these weights is discussed in section 4.9 below.

PHABSIM contains three basic hydraulic simulation programs; IFG4, MANSQ, and WSP. For the simulation discharges IFG4 predicts the water surface elevation using a simple stage/discharge relationship. As is the case with all three models the water surface profile is assumed to remain constant across each transect. IFG4 predicts velocities on a cell-by-cell basis using Manning's equation and a simple mass balance adjustment.

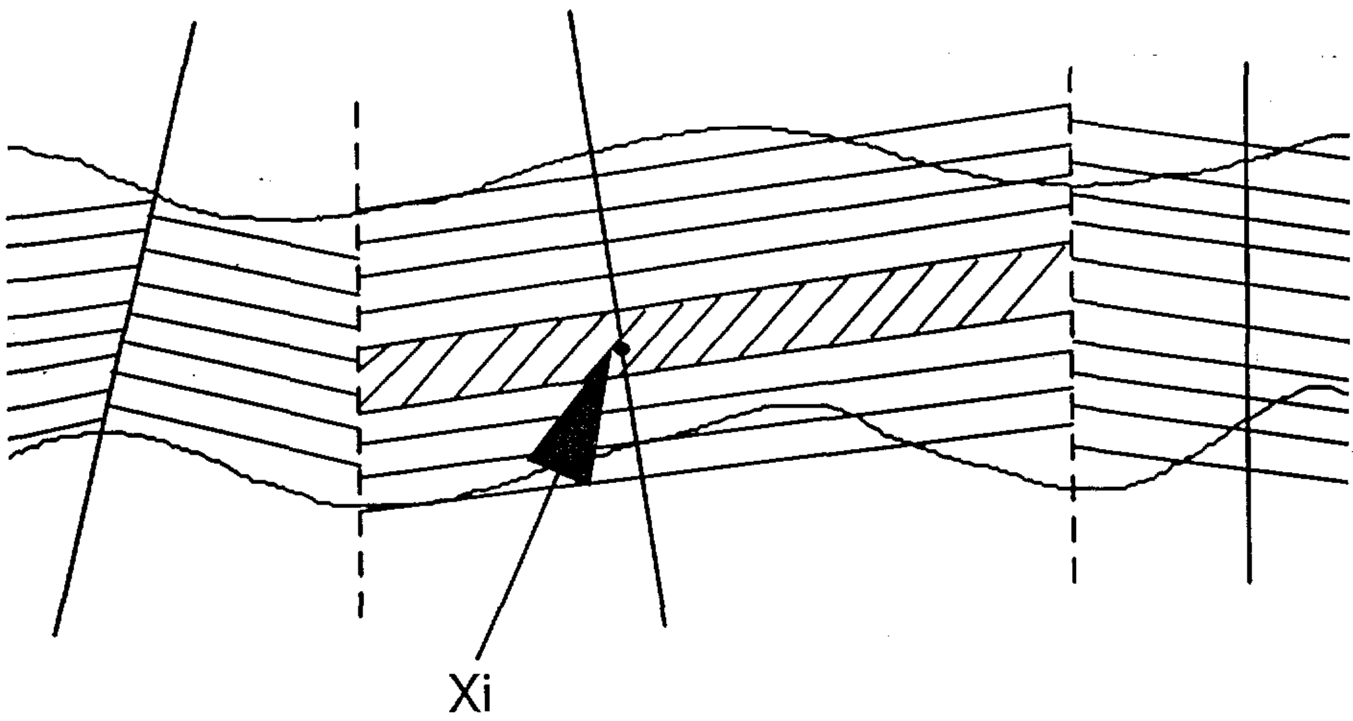


Figure 2.2 Plan view of cells used by hydraulic models

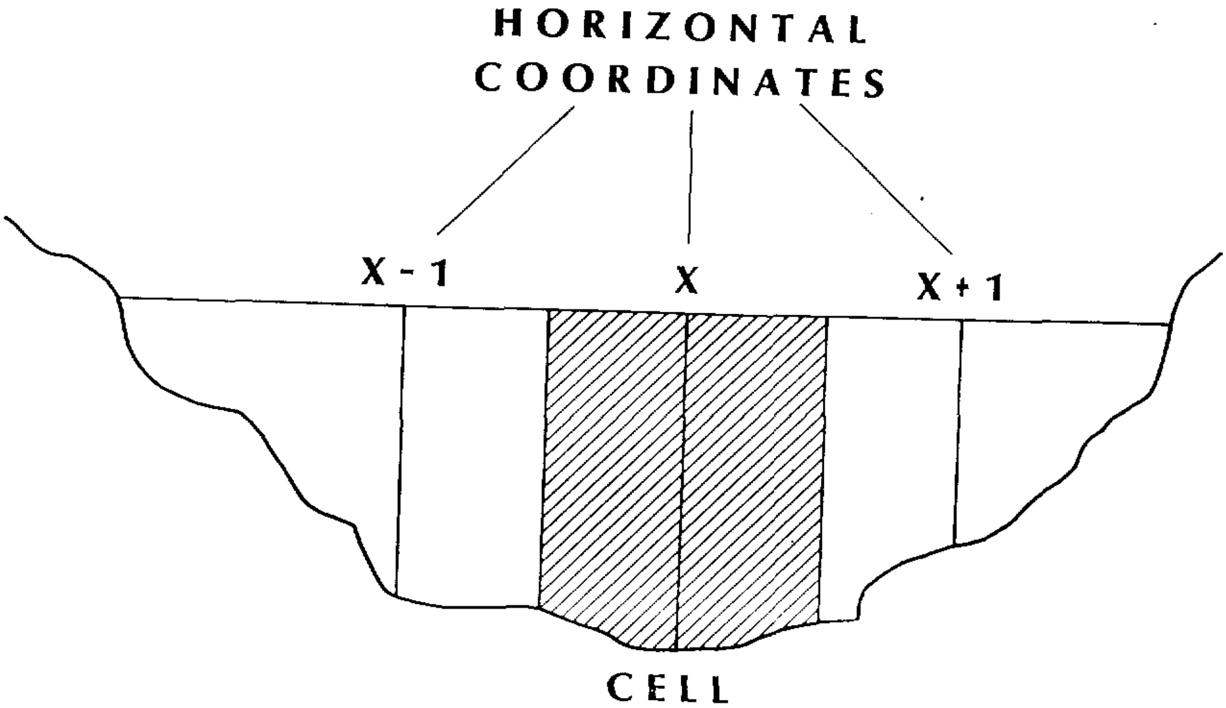


Figure 2.3 Cell areas defined by survey points placed across a transect.

MANSQ uses the solution of Manning's equation to predict water surface elevations but does not predict velocities. MANSQ may be used when IFG4 fails to predict sensible water surface elevations.

WSP is a standard step backwater model which predicts water surface elevations. WSP requires the stage/discharge relationship at the most downstream section to be known-this may be supplied using IFG4. WSP uses an energy balance model to project water levels from the most downstream transect to all transects upstream. Like MANSQ, WSP predicts water surface elevations only and cannot be used to simulate velocities.

An important difference in the structure of the three models is that in IFG4 and MANSQ each transect is modelled independently of its neighbours whereas WSP treats simulation variables at each transect as being dependent upon corresponding values at the next up and downstream transects. IFG4 performs well in high gradient streams where there is no variable backwater effect. For lower gradient streams where backwater effects are present it is necessary to use a combination of the IFG4 and WSP models.

As the hydraulic models remain to be thoroughly tested for a range of different types of UK rivers our recommendation at this stage is to collect sufficient field calibration data to satisfy the data requirements of all three models in order that the user maintains the maximum available choice of hydraulic models.

2.2 HABITAT MODELLING

IFIM is based on the assumption that aquatic species exhibit discrete and quantifiable preferences for a range of the microhabitat variables depth, velocity, available cover and substrate type. The principle habitat model available within PHABSIM is the HABTAT model. For each selected target species HABTAT requires a numerical representation of the suitability to the species of values of these microhabitat variables over the whole range of values predicted by the hydraulic modelling programs. The basic form of this representation is in the form of a habitat suitability curve, also referred to as a preference curve (see Note 1 below). For each of the microhabitat variables depth, velocity, substrate and cover a preference curve must be supplied for each life stage of the selected target species. The development and validation of preference curves is discussed in further detail in Section 6.1 of this report.

The most recent version of PHABSIM requires habitat suitability information for depth, velocity and "channel index". Here, the channel index can be a coded measure of available cover, a coded observation of substrate type or any other habitat suitability index designed by the user. One of the main limitations to the user is that the HABTAT program uses only one channel index, thus cover or substrate may be used independently, but a simulation cannot simultaneously incorporate preference information for cover and substrate. The development of PHABSIM to simultaneously incorporate measures of cover and substrate is seen as a high priority and will be one of the areas of focus for the current R&D project. Until the form of channel indices describing cover and substrate characteristics has been finalised we recommend following the procedure described in section 4.8, below, in the data collection exercise. in some situations it may not be deemed necessary to use all of this data in the simulation, but following this approach will ensure that sufficient data is available, at the expense of gathering some data which may later prove redundant.

Another requirement of the habitat simulation procedure is the assignment of weighting factors to each transect. Basically these weights are defined to describe the relative distribution of areas of differing habitat types between adjacent transects. Values of weights are assigned after field observation of the distribution of areas of different habitat types. This topic is discussed in more detail in section 4.9 below.

The recognition of the distribution of areas of different habitat types is also important in the process of mapping results from simulations using data from the representative study reach to a larger portion of the stream being studied. Once again this matter is discussed in section 4.8 below.

Note 1

Preference curves are strictly speaking curves derived from utilisation data adjusted by availability data. Such curves have faced criticism in the past for not making good biological sense.
Suitability Indices may use data from other sources, eg. expert opinion hence the terms "preference curve" and "suitability index" are not strictly speaking equivalent. For the purpose of this report we shall not dwell on this difference.

2.3 HYDROLOGICAL MODELLING

The basic output from PHABSIM simulations is the weighted usable area vs discharge relationship. This relationship allows the user to identify an "optimal" discharge by locating the peak of the weighted usable area curve, and gives a measure of the relative reduction in weighted usable area for non-optimal discharges. However, in an IFIM study, we are generally interested in how the availability of physical habitat varies over the whole flow regime experienced, or perhaps over the range of flows experienced within a particular season. This is certainly the case when we are considering the setting of Ecologically Acceptable Flows. In order to conduct analyses of this type it is clear that we must also have available as input to the modelling process a description of the flow regime. Hence, in the choice for a study site for application of IFIM an important consideration is the availability of historical flow data.

In the current R&D study we have selected study sites so that they are within approximately 10km of a gauging station. It is preferable that the gauging station should have a continuous record of flow data for five years or more. Details of gauged flow data available at each of the study sites is given in Chapter 3.

The availability of flow data is also very useful in the modelling process as it may be used in the verification of discharge estimates made in the field by current metering.

It is important to recognise the necessity to approximate any inflows between the study site and the nearest gauging station.

2.4 PHABSIM DATA REQUIREMENTS

In this section we define the minimum data requirements for the hydraulic and habitat models contained within PHABSIM. Detailed description of the data collection procedure is given in
Chapter 4.

a) Hydraulic Data Requirements

Hydraulic Simulation Programs: Minimum Data Requirements

IFG4

(i) Survey of x,y coordinates of the bed elevation for each transect (maximum 100 points per transect). The x,y coordinates represent the horizontal distance and the vertical elevation difference from the headpin representing the start of the transect. Within PHABSIM these are converted to a cross-sectional profile of channel bed elevations. It is a convention within PHABSIM that the most downstream transect be labelled transect number 1 and that x distances across the transect be measured moving from left to right looking upstream. Coded observations of cover and substrate must be recorded for each surveyed point. The transect which represents the most downstream end of the study reach should be located at a hydraulic control, upstream of which there is a unique stage-discharge relationship.

(ii) Measurement of inter-transect distances and assigned upstream weighting factor (see sections 4.4,4.9 for details).

(iii) Measurement of water surface elevation and discharge at a minimum of three calibration flows. The measurement of velocity at each surveyed point across the transect during at least one of the calibration flows, preferably at the highest of the three calibration discharges.

MANSQ

(i) As (i) above.

(ii) As (ii) above.

(iii) Measurement of discharge and water surface elevation at a minimum of one calibration flow.

WSP

(i) As (i) above.

(ii) As (ii) above.

(iii) Measurement of discharge at all transects for one calibration flow and at the most downstream section only for a minimum of three calibration flows.

b) Habitat Data Requirements

Habitat simulation program: minimum data requirements

HABTAT

For each target species life stage HABTAT requires the following data:

(i) Set of suitability indices for one or more of the following:
depth
velocity
substrate
cover

(ii) Set of hydraulic information describing the depth and velocity characteristics for each cell as a function of discharge. This information is supplied as output from the hydraulic simulation programs.

(iii) Coded observation of cover and substrate at every survey point. These values are supplied by field observation and are assumed to be independent of discharge. In order to account for seasonal variability separate seasonal observations of substrate and cover may be made and corresponding simulations run.

c) Hydrological Data Requirements

Hydrological data is required if one is to interpret the weighted usable area vs discharge relationship in the context of the historical flow regime. we recommend the following as sufficient data for such an exercise:

(i) Record of daily flows of at least five years duration.
(ii) Record of daily stage of at least five years duration.

The stage record is not necessary for the interpretation of output but is useful for verifying stage-discharge relationships predicted by the hydraulic simulation programs.

Although it is clearly beneficial that data be available from a gauging station close to the study site this will clearly not be possible in all cases. In the absence of gauged flow data an appropriate technique for estimating flows at an ungauged site may be employed.

3 River/reach selection

A selection of study reaches on rivers throughout England and Wales was identified which could be studied for the application of the IFIM technique (Figure 3.1 overleaf), and will lead to the recognition of the viability of the method. This sample of rivers was chosen so that it would be representative of the range of river types present in England and Wales, thus facilitating extrapolation to other rivers.

River and site selection was initially guided by ecological criteria by using the ten ecological groups defined by the RIVPACS survey (Wright, J. F., et al. 1988.). This survey examined the macroinvertebrate fauna found at a very large number of sites throughout the U.K. each site being sampled in the spring, summer and autumn, the species lists for each season being combined to produce a complete, yearly, list. This data was then analysed using the TWINSPAN classification procedure which divides the sites into groups according to the fauna found. This process produced the ten major groups of rivers used in this survey.

For each of the ten RIVPACS groups a list of rivers and sites was produced to ensure that the full range of and habitat types will be examined. These habitat types and the initial site list are summarised in appendix A. It is also important to be able to obtain up to date flow data for the sites in question, so that the data obtained during field visits can be checked for accuracy and also as an aid to hydrological modelling. Thus any rivers that do not have an operating gauging station were eliminated. It must also be possible to relate the hydrological data to the site involved, therefore sites that do not have a gauging station within a distance of ten kilometres of the sample area have been removed from the lists, (unless there are no alternative rivers). Sites may also have been excluded if, for example, the quality of the gauging station data was low of if there were problems of high artificial influences on the flows.

The problem of the increase in the amount of fieldwork required when studying large rivers was also taken into account, thus, where possible, rivers that have a catchment area in excess of 150 km2 were excluded in favour of sites with smaller catchments. However, this was only done where smaller alternative sites existed and without reducing the range of river types sampled. Consequently some of the rivers have much larger catchments than the critical size outlined above.

Aside from the need to cover the full range of hydrological and ecological river types there was also a need to examine sites were problems occur that are relevant to other sites in the U.K.. For instance, a river where the flow is regulated by sluice gates, such as the Gt. Ouse; a river that is influenced by a reservoir such as the Blithe and the Gwash; a chalk stream with or without nearby water abstractions, and so on. Conversely, it was also important to ensure that natural rivers were sampled so that the sample was representative and so that data is obtained on sites that may undergo future resource development. Finally, some sites were selected that did not fulfil all of the above criteria fully. This was because of the availability of existing data from other work which would produce benefits outweighing any potential problems that may occur.

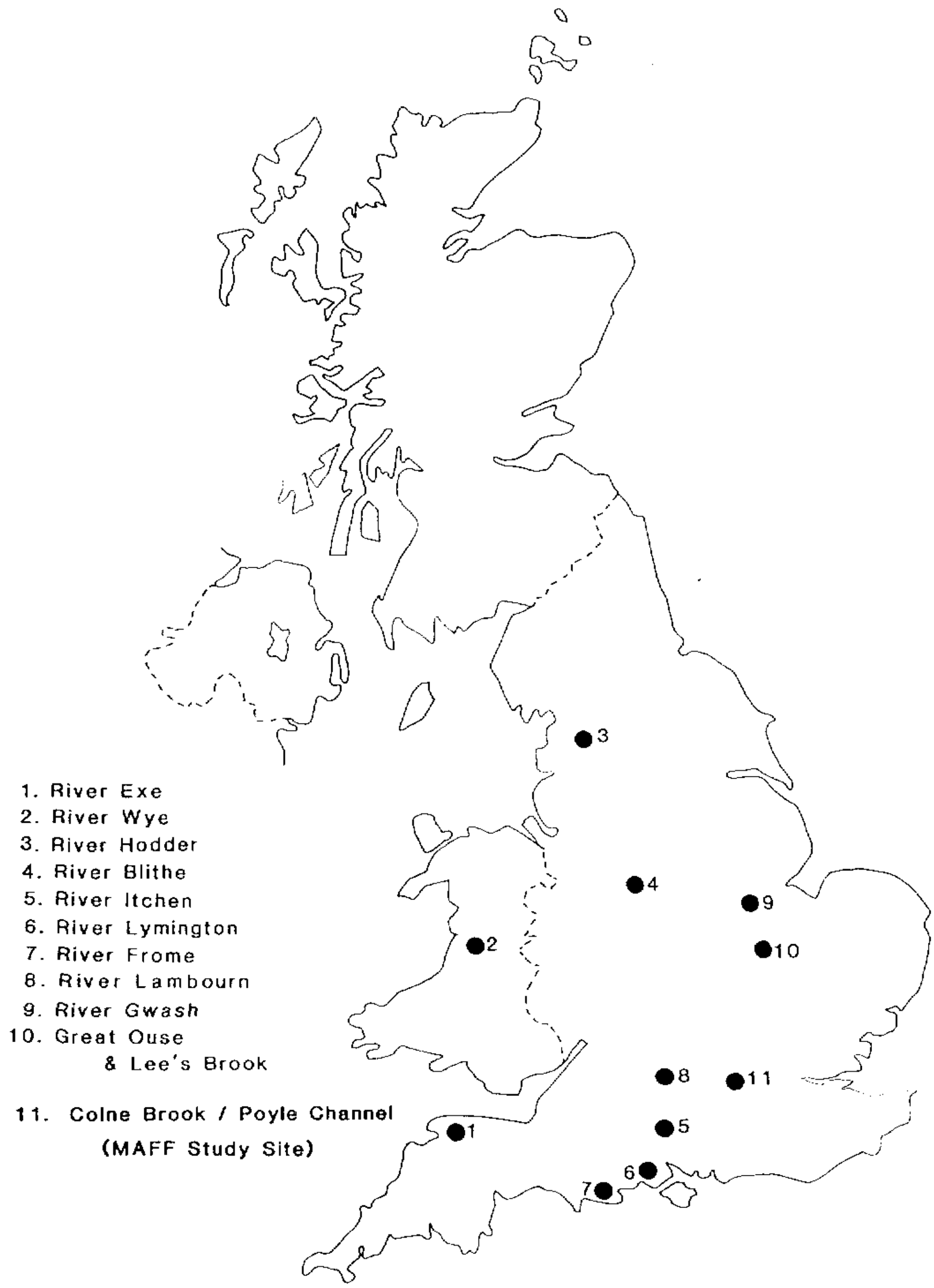


Figure 3.1 Location of study sites

The final list of sites along with reasons for their selection, other than those outlined above, is given below:

RIVPACS Group No.	Site Grid Reference.	Site Name.
Group 1	SS 792406	R. Exe at Warren Farm
Group 2	SN 847823R.	Wye at Pant Mawr
Group 3	SD 655487	R. Hodder at Hodder Bank
Group 4	SK 109189R.	Blithe at Hamstall Ridware
Group 5	SU 467213R.	Itchen U/S of Highbridge
Group 6	SU 302033R.	Lymington U/S of Balmerlawn
Group 7	SY 873866R.	Frome at I.F.E. East Stoke
Group 8	SU 435701R.	Lambourn at Hunt's Green
Group 9	TF 041105R.	Gwash at Belmesthorpe
Group 10	TL 220697	and Gt. Ouse S.E of Brampton and Lee's
	TL 233702	Brook W of Godmanchester.

Figures 3.2-3.11 showing site locations are included at the end of this chapter.

Group 1: The River Exe at Warren Farm (South West NRA).
(OS Landranger map no. 180)

This site is in approximately the same location as the RIVPACS sampling site (Gr. SS791407) and is about 20.5 km from the nearest gauging station (at Pixton SS935260, stn. no. 045009) as shown in fig 3.2. The site itself is part of the Warren Farm estate and was chosen because it is representative of the types of features and habitats found in the Exe in this area. The river here is larger than at any possible upstream sites, thus facilitating study. This site was chosen in preference to the sites on the R. Hodder because the Hodder is likely to be selected as the group 3 site and it was felt that more benefit could be gained by using the Exe and gaining more spatial variability in site distribution.

Group 2: The River Wye at Pant Mawr (Welsh NRA).
(OS Landranger map no. 136)

There are three RIVPACS sampling sites on the Wye fig 3.3. These are at: Pont Rhydgaled (SN840825): Dolhelfa (SN921738): and Llanwrithwl (SN976640). The Pant Mawr site lies up river of Llangurig towards the most upstream of these sampling points (Pont Rhydgaled) and is representative of the types of habitat and physical features found throughout this stretch of river. The site has the advantage that work has been undertaken on other projects in the area, such as the work on channel cross section stability by Dr. Graham Leeks at IH Plynlimon and also in the HABSCORE study. It lies approximately 1/2 km downstream of the Pant Mawr gauging station (SN843825, Stn. no. 055010). This site was selected over other possible sites on the R. Severn, R. Tees and S.Tyne because of the large amount of existing data from other projects.

Group 3: The River Hodder at Hodder Bank (North West NRA).
(OS Landranger map no. 103)

The Hodder Bank site on the River Hodder lies downstream of the RIVPACS site at Cross of Great Bridge (SD 702590) and also of the gauging station at Stock's Reservoir (SD 719546 stn. no.071002) as shown in figure 3.4. There is also a further gauging station at Hodder place, downstream of the site. This site was chosen in preference to the sites on the River Ehen following consultation with North West region NRA, as the Ehen is affected by drawdown of Ennerdale Lake and compensation flows during dry periods. The gauging station at Braystones is also badly affected by weed growth during the summer months. Therefore, it was decided to select the Hodder as it has a more natural flow (despite being downstream of a reservoir) due to the influence of Crossdale Brook and the River Dunsop, and two gauging stations.

Group 4: The River Blithe at Hamstall Ridware (Severn Trent NRA).
(OS Landranger map no. 128)

This site is in the same area as the RIVPACS sampling site and is approximately 200m downstream of the Hamstall Ridware gauging station (SK109192, Stn. no. 028002). This location (fig 3.5) was chosen as it was the subject of a previous I.H. study on PHABSIM modelling and as such a large amount of data has already been collected here.

Group 5: The River Itchen U/S of Highbridge (Southern NRA).
(OS Landrange map no. 185)

This site lies immediately upstream of the gauging station at Highbridge (SU467213, Stn. no. 042010) (fig 3.6), thus giving access to discharge data that may be directly related to the flows measured at the site. The site was selected, after consultation with the Southern region NRA, instead of sites on the Rother in order to examine the problems faced by chalk streams more closely, as was the Lambourn. Unfortunately there are no RIVPACS sites in this area but there have been extensive fishing surveys which are still being undertaken and which will provide valuable back up data.

Group 6: The River Lymington U/S of Balmerlawn (Southern NRA).
(OS Landranger map no. 196)

This reach is approximately 200m downstream of the RIVPACS study site at Balmerlawn (SU297036) and is 2.5 km from the nearest gauging station at Brockenhurst (SU318019, Stn. no. 042003) as shown in fig.3.7. This site was chosen over the R. Rother and the Gt. Eau as it is closer to a gauging station and the hydrological record is longer than at the other sites.

Group 7: The River Frome (Mill Stream) at The Institute of Fresh Water Ecology, East Stoke.
(OS Landranger map no. 194)

The group 7 RIVPACS study site (SY866867) lies 1km upstream of the selected representative reach, with the nearest gauging station being approximately 50m upstream of the reach (SY873867, Stn. no. unknown)(fig 3.8). This site was selected in preference to the W. Avon, the Candover Brook and a group 7 site on the R. Lymington as it is, and has been, the subject of study by IFE and as a result large amounts of data are available for the site. The Mill Stream also has the benefit that the flow can be controlled, thus allowing the more detailed study that has been proposed for this site.

Group 8: The River Lambourne at Hunt's Green (Thames NRA).
(OS Landrange map no. 174)

This site was chosen in order to further address the problems of chalk streams. Like the Itchen it does not have a RIVPACS site in the vicinity, but it also has the benefit that other studies have taken place in the area, in particular at Bagnor (fig 3.9). The site has two gauging stations at Welford (SU 411731, Stn. no. 039031) and Shaw (SU470682, Stn. no. 039019), as shown in fig 3.9.

Group 9: The River Gwash at Belmesthorpe.
(OS Landranger map no. 130)

Again, this location was chosen as it was the subject of a previous I.H. study on PHABSIM modelling and as such a large amount of data has already been collected here (fig 3.10). There are no RIVPACS sites on this river but it is characteristic of nearby rivers that do have such sites on them. The nearest gauging station is also at Belmesthorpe (TF038097, Stn. no. 031006), about 1km downstream.

Group 10: The Gt. Ouse S.E. of Brampton and at Lee's Brook W. of Godmanchester.
(OS Landranger map no. 153)

This site was selected in conjunction with The Institute of Terrestrial Ecology at Monk's Wood and Anglian NRA at Brampton, and is in an area where a large amount of ecological and channel cross section data exists (fig 3.11). It is necessary to study both the Gt. Ouse and the Lee's Brook side channel in order to develop a proper hydrological model. Although this will involve extra work on this river, it is felt it is necessary as the Gt. Ouse is braided over a widespread area and thus it is important to select a truly representative reach, it is also important to gain experience of working on and modelling a large highly controlled river. The nearest RIVPACS site is at Roxton Lock (TL160535) which is about 20km upstream of the proposed sites, however, the other available data outweighs any problems this may cause. The closest gauging station is at Offord (TL216619, Stn. no. 033026) 6km upstream, it may also be possible to get further data from a stage recorder at Brampton sluice.

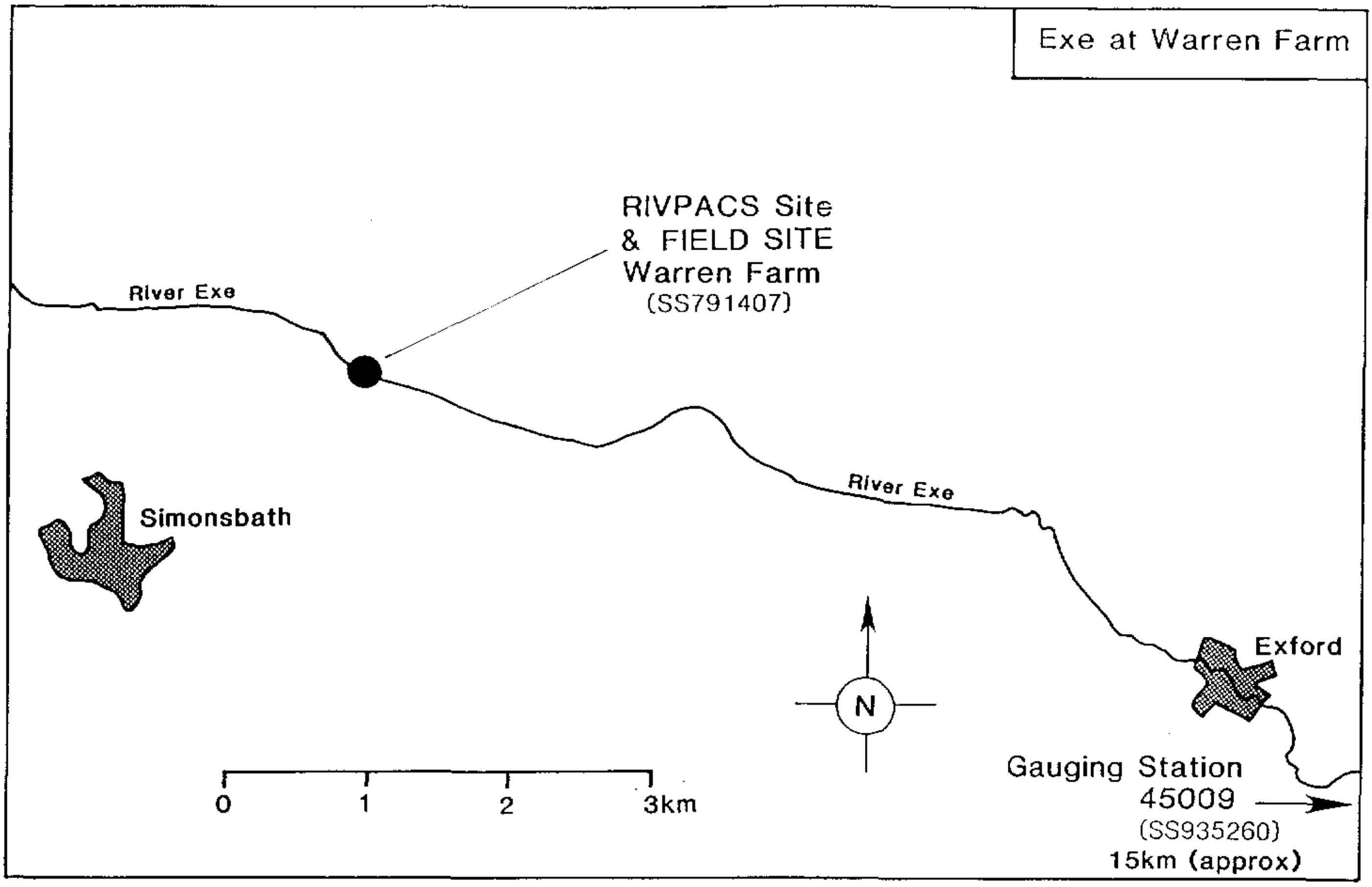


Fig 3.2: River Exe study site.

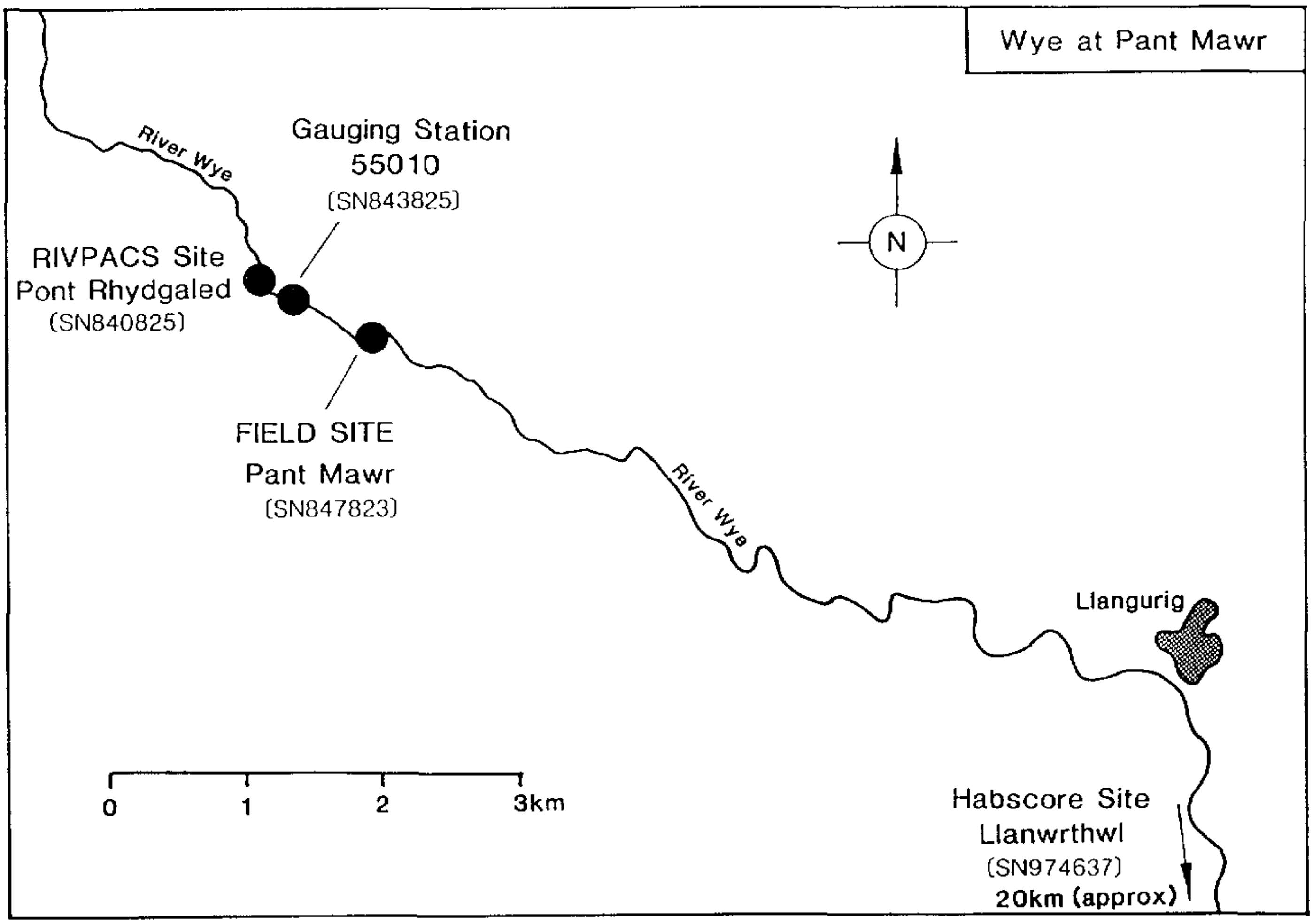


Fig 3.3: River Wye study site.

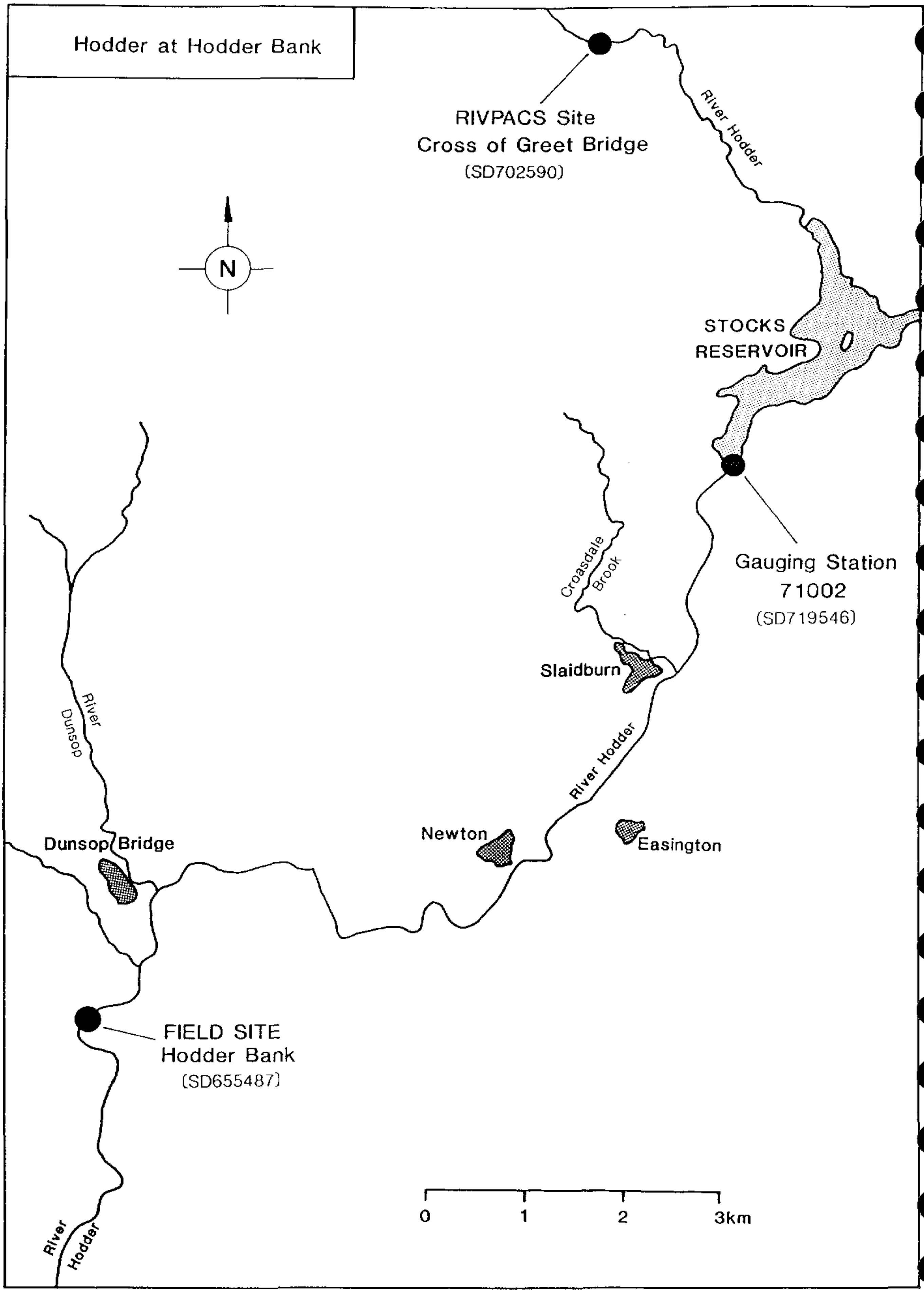


Fig 3.4: River Hodder study site.

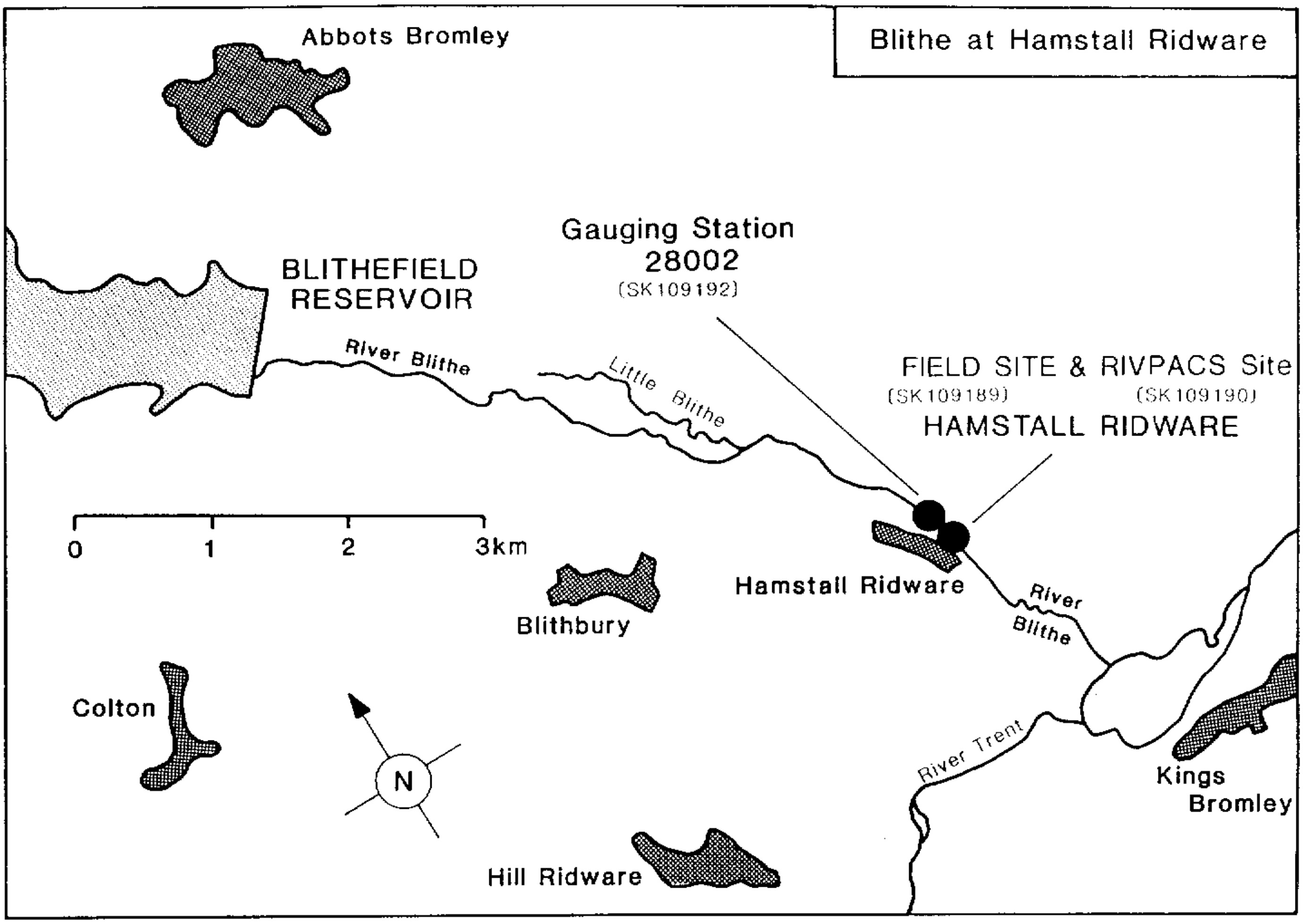


Fig 3.5: River Blithe study site.

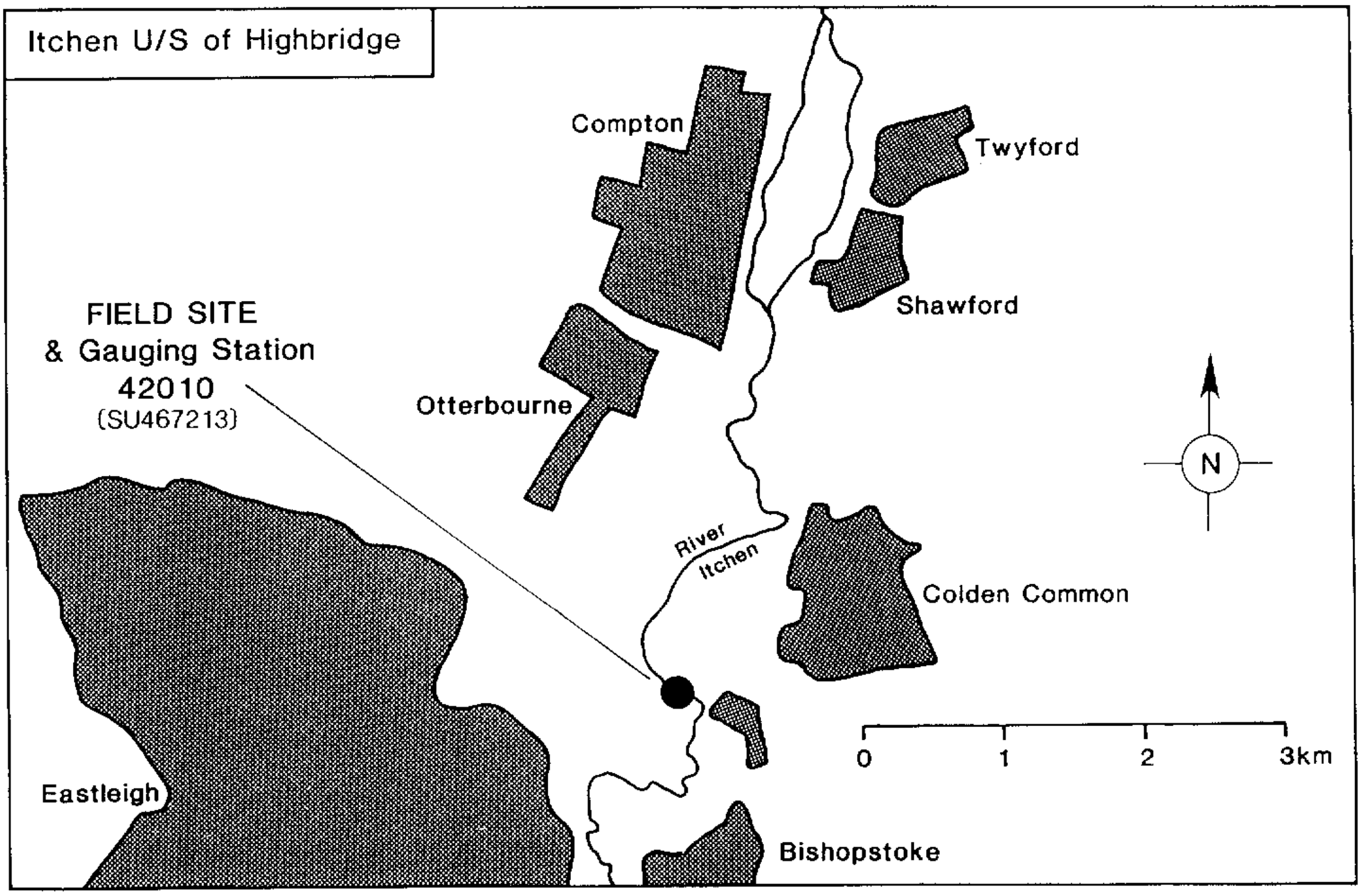


Fig 3.6: River Itchen study site.

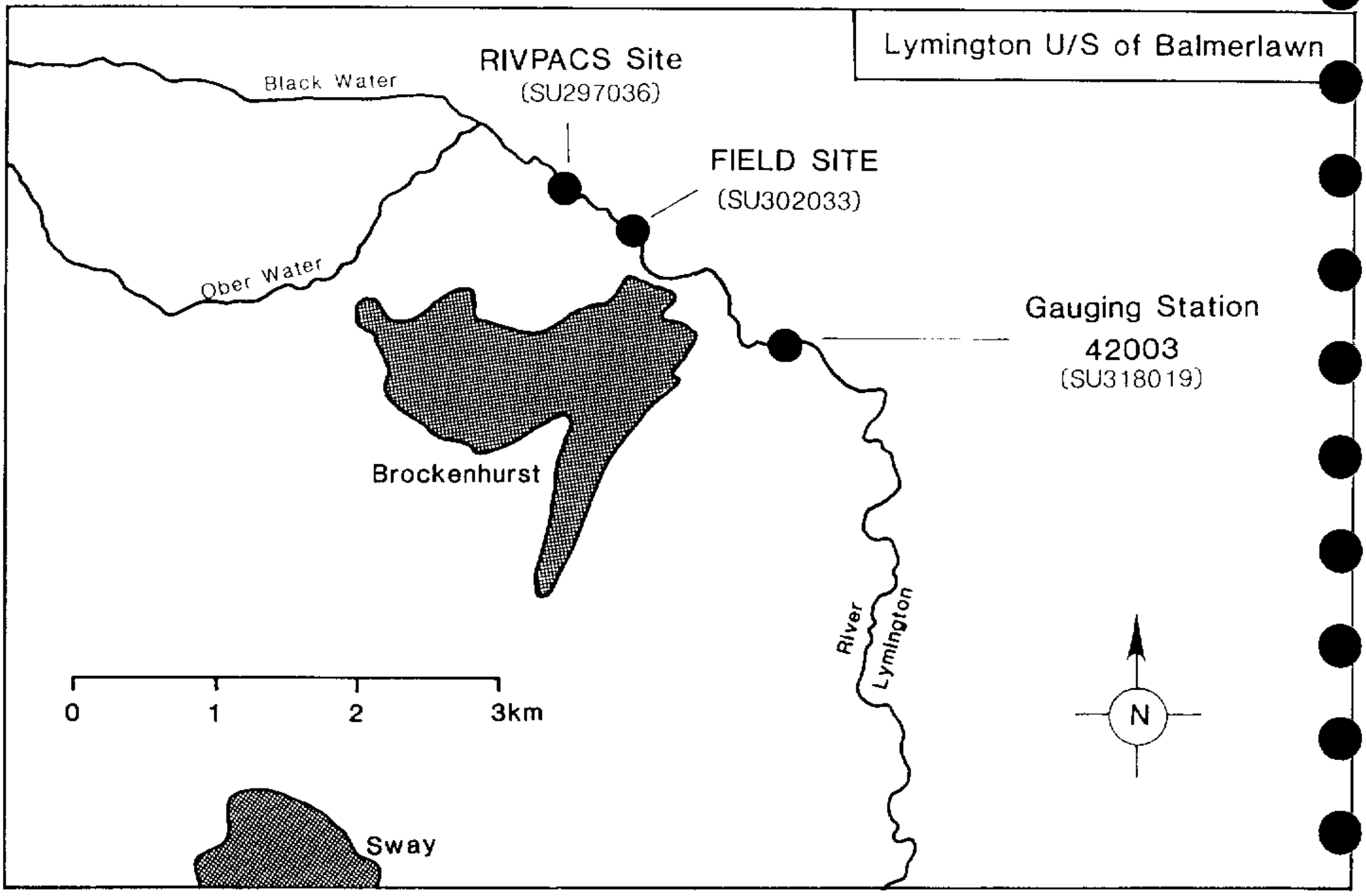


Fig 3.7: River Lymington study site.

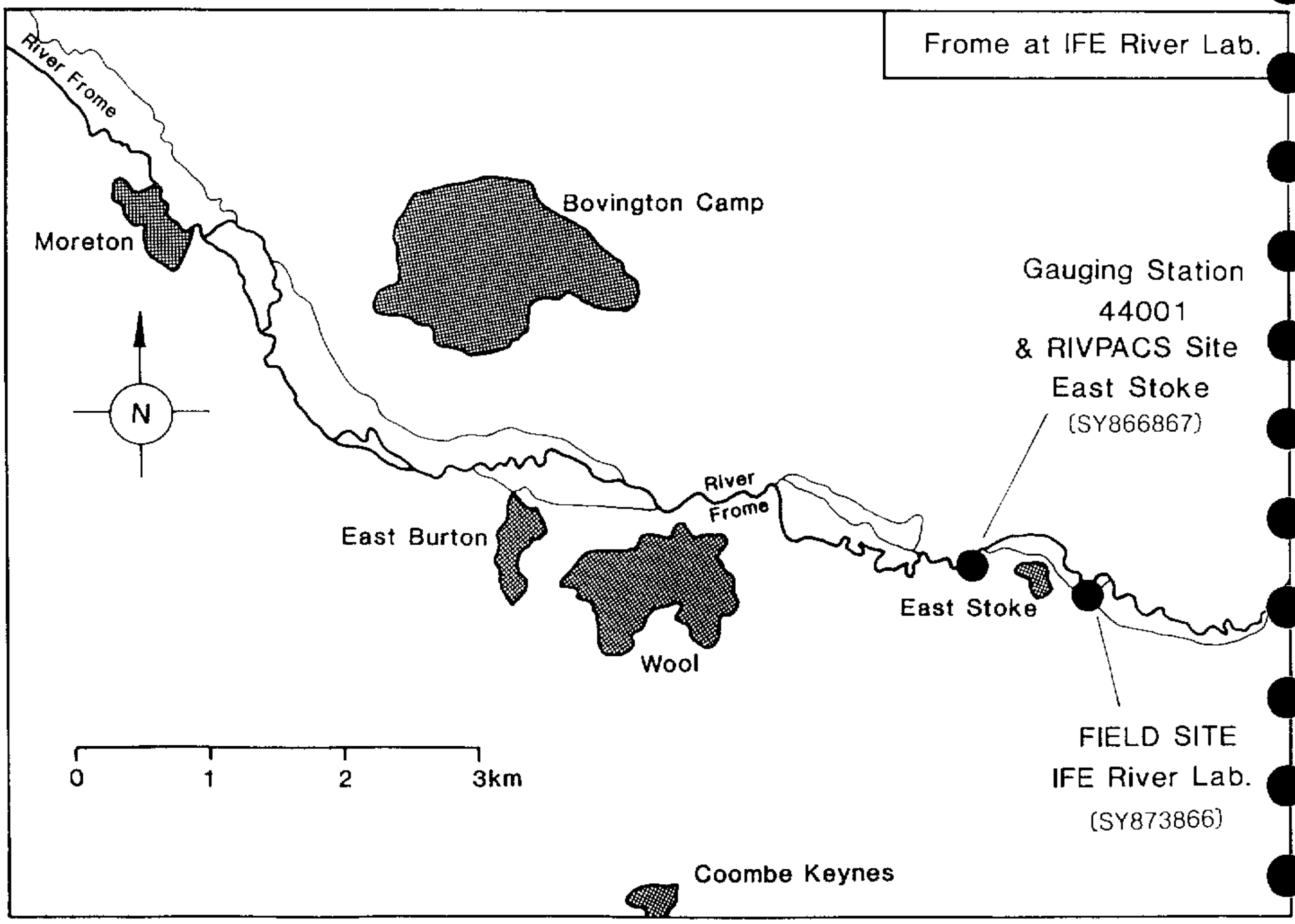


Fig 3.8: River Frome (Mill Stream) study site.

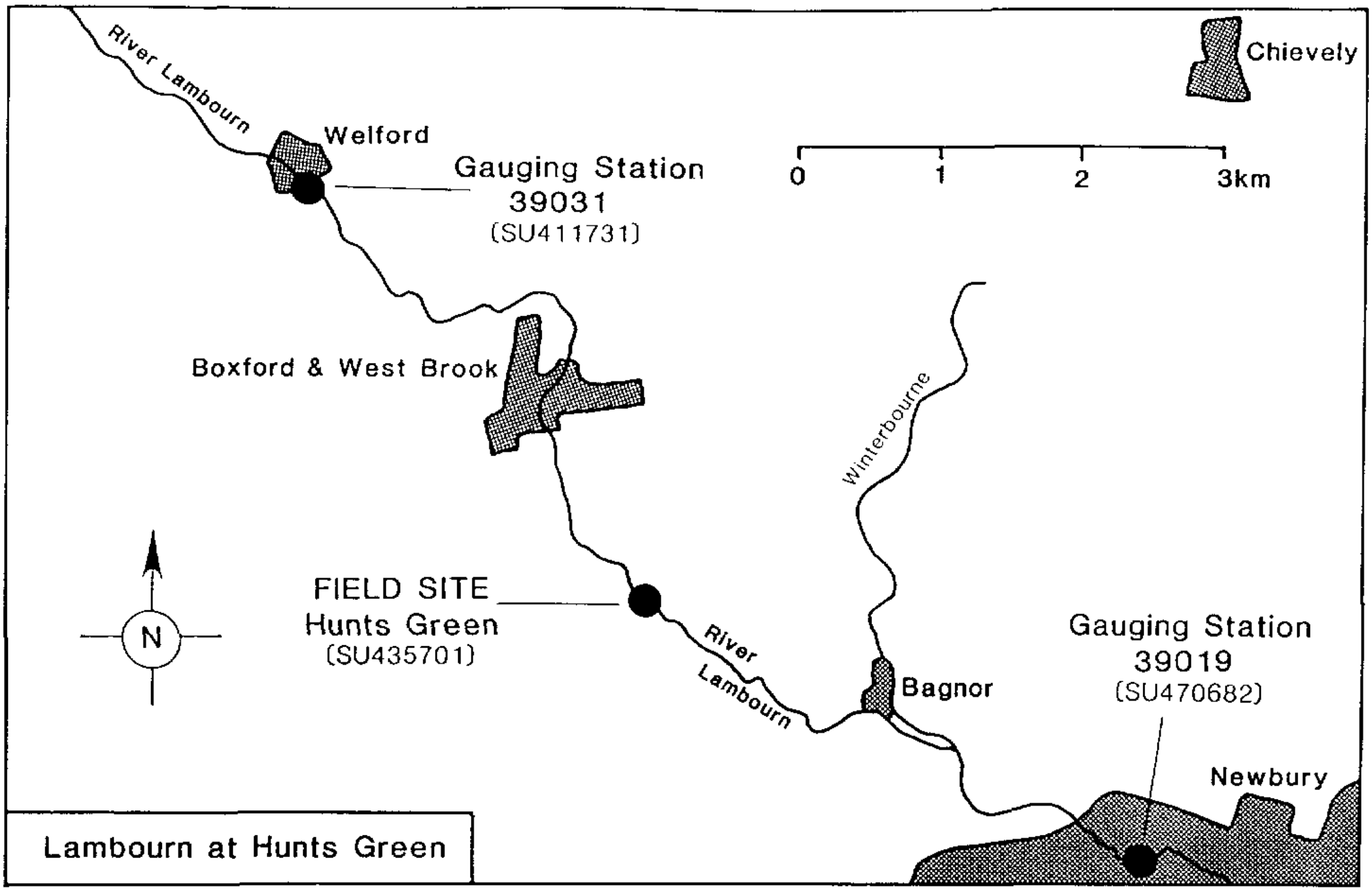


Fig 3.9: River Lambourne study site.

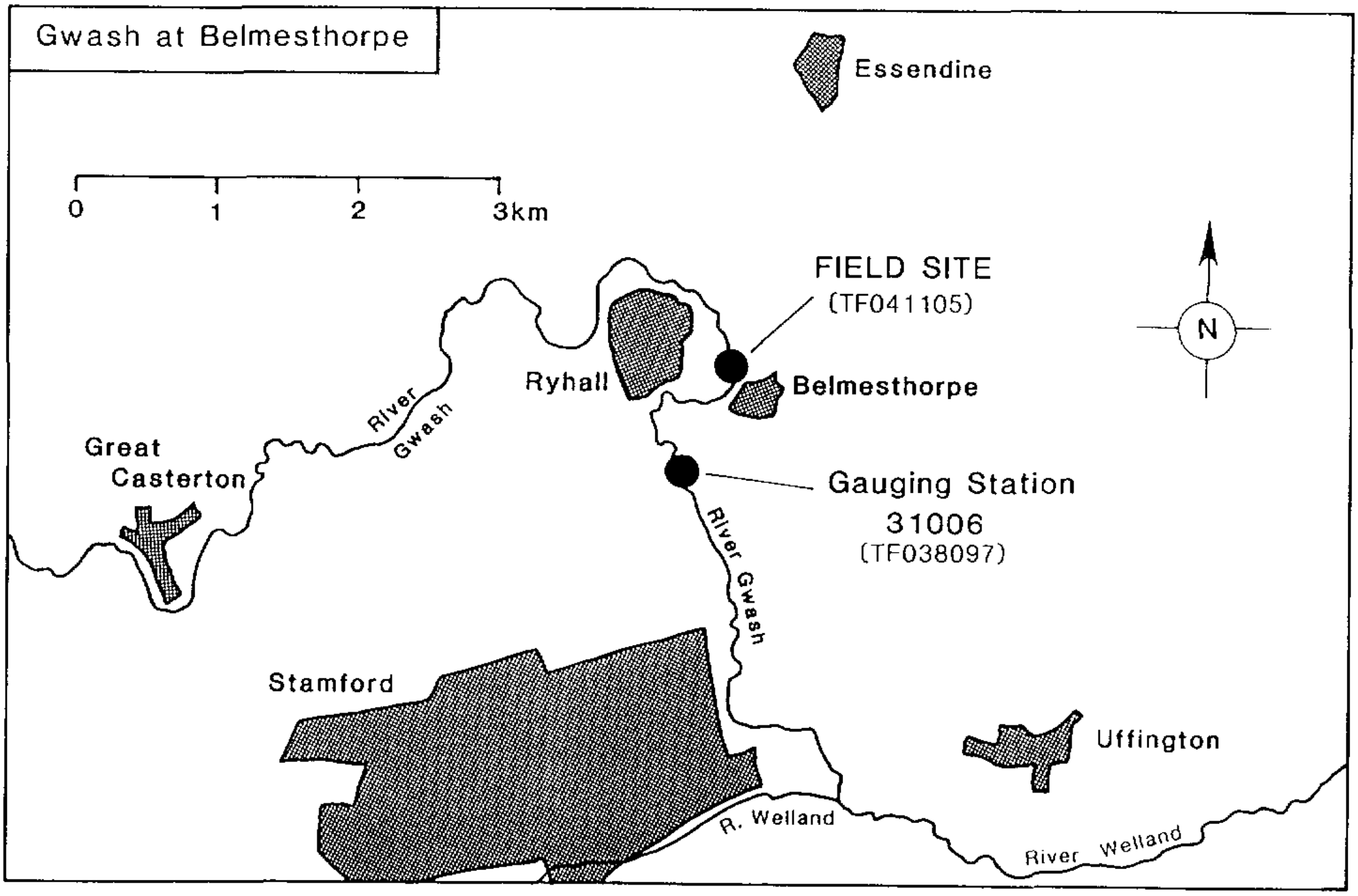


Fig 3.10: River Gwash study site.

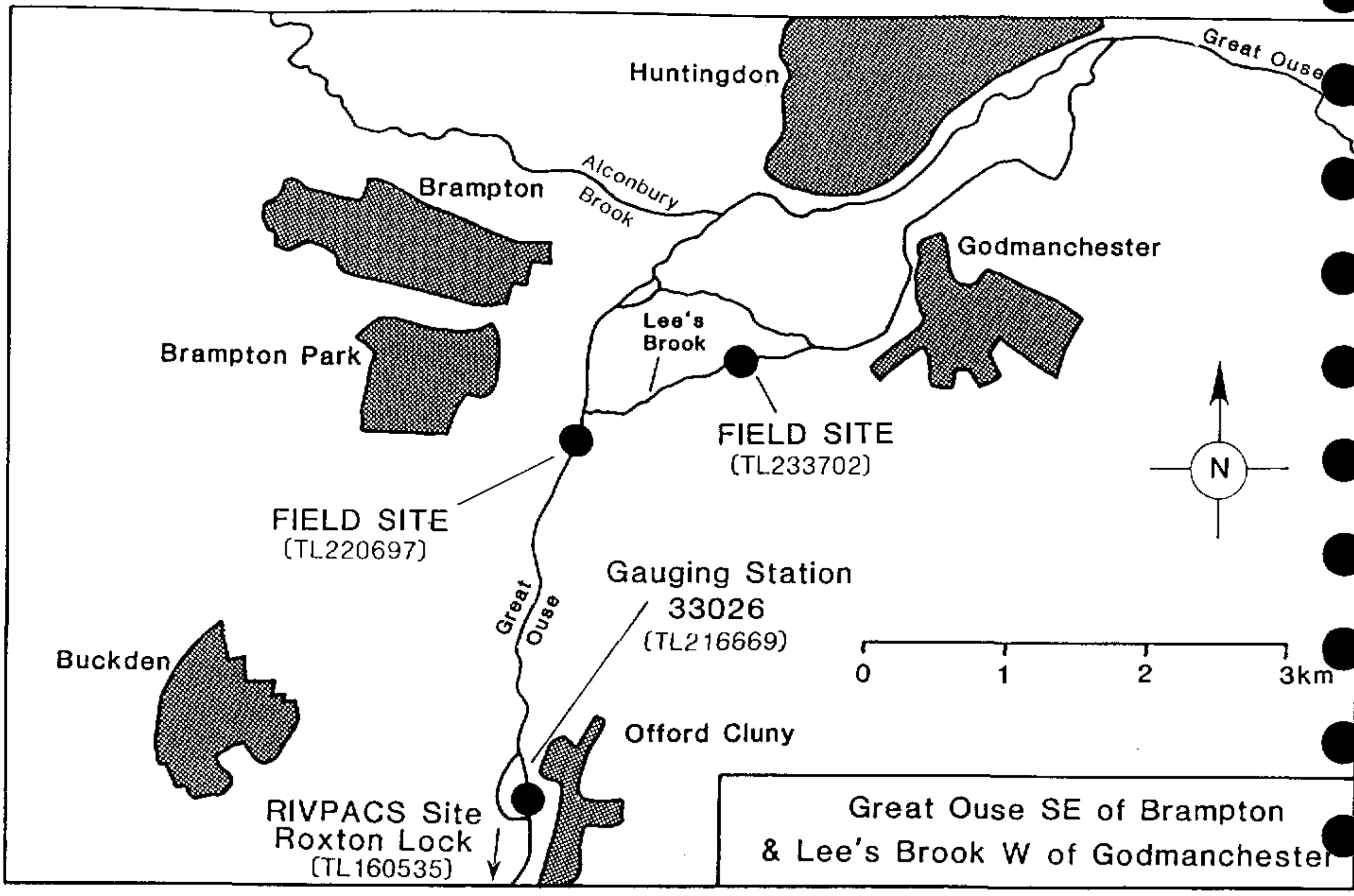


Fig 3.11: Gt. Ouse and Lee's Brook Study sites.

4 Data collection procedure for application of phabsim

In this section we describe in detail a step-by-step procedure for collection of field data in the application of IFIM using PHABSIM.

Although the current study is intended to assess the methodology, and intentionally avoids sites with specific current operational problems, it has been suggested that individual NRA regions may wish to begin collection of data in a format compatible with the data requirements of PHABSIM, before results of the current assessment are available. Chapters 4 and 5 deal specifically with this matter, giving advice, on the basis of current experience of applying the model to UK rivers, to assist in the data collection exercise.

It must be stressed that it is possible that the final report will identify situations in which IFIM is inappropriate as well as those in which it is appropriate. Likewise it is possible that recommendations for data collection may alter as the project evolves. Bearing this in mind the recommendations made here are such that, if followed, they will provide sufficient data for successful application of IFIM once data requirements for specific situations have been finalised. For future applications to specific problems data requirements may be reduced; the approach recommended here maximises generality at the expense of collecting some data which may prove unnecessary in certain situations.

For those readers concerned solely with practical data collection procedures we suggest moving ahead directly to Chapter 5. This chapter is intended to provide a more detailed account of the data requirements of specific computer programs contained within the PHABSIM model. This information is aimed at individuals who are responsible for project planning and running simulations rather than solely data collection.

4.1 STUDY REACH SELECTION

In the process of scoping an IFIM study we must identify a length of river over which we require conclusions drawn from the IFIM study to be valid. Clearly the more homogeneous the river is in terms of its hydrological and ecological characteristics, the more easily we may extrapolate results from simulations over the selected study reach. Depending upon the goal of the IFIM study we may wish the study reach to be representative of the larger length of river, or we may wish to focus on a location we consider to be of critical importance to the study. Consequently we shall discuss two approaches to study site selection, the critical reach approach and the representative reach approach:

(1) Critical Reach Approach

This approach is appropriate in a situation where it is possible to identify, through existing data, an area of the river which is known to be most sensitive to changes in flow and critical to the success of a particular species life-stage. If for example it is believed that the availability of spawning area is the limiting factor to recruitment of a particular fish species then the selection of a reach covering the known spawning area would be most appropriate as the study reach for an IFIM study designed to specify a flow regime optimal for recruitment of the species. The critical reach should meet two basic criteria:

a) The reach should be highly sensitive to changes in stream flow. The rate of change of width, depth and velocity with respect to discharge should be greater for the critical reach than for other portions of the river. Generally the most sensitive reaches with respect to discharge are elevated portions of the channel such as riffles and gravel bars.

b) The critical reach must also act as a biological control. The target species in the IFIM study must be known to be directly limited by the type of habitat present in the critical reach for a particular life stage. For example if the availability of spawning area is known to be limiting to trout populations then a convex gravel bar would be an appropriate choice of critical reach for the IFIM study.

(2) Representative Reach Approach

If it is not possible to identify the availability of a particular habitat type to a particular species life-stage as the limiting factor to success of the species we must sample the relationship between the flow regime and all of the different habitat types present in the length of river to which IFIM conclusions are to be applied. For a single species different habitat types may be limiting to different life stages at different times of the year, and if the IFIM study addresses more than one target species different habitat types may be limiting to populations of the different species. In either case it becomes imperative that our study site represents the full range of habitat types present in the larger length of river.

The process of selecting a representative reach requires the identification of the variety of different habitat types present in the larger stretch of river. In addition to identifying different geomorphological features, eg. pools and riffles, we must identify the distribution of areas having cover,eg. overhead cover, undercut banks, or floating aquatic plants, and areas thought to be of special ecological importance,eg. backwater refuges.

The level of detail in which this surveillance is undertaken will obviously be limited by the availability of resources for the study. Clearly a full topographical survey, species distribution maps and aerial photography are all desirable, but in practice we may limit input at this stage to visual surveillance from bridges and from the bankside where access is possible. Existing data and expert local opinion may be used to supplement the visual survey when resources are limited.

Having identified the variety of different habitat types present in the larger stretch of river we proceed to choose a reach within the stretch which contains examples of all of these habitat types. Clearly the more homogeneous the larger stretch of river the easier this task will become and the shorter the length of the nominated representative reach.

An extra consideration in selecting the exact location of the study reach is the requirement of the hydraulic models within PHABSIM that the most downstream transect be placed at a hydraulic control, upstream of which there is a unique stage-discharge relationship. Whilst it is highly desirable to fulfil this consideration to aid success in the modelling process it may not always be possible to do so without the reach becoming unrepresentative, eg. a reach immediately upstream of a weir may not be representative of those areas further up and downstream.

In the course of current studies a typical length for the representative reaches chosen is around 500 metres.

Having selected the reach for study we next proceed to choose the locations of the transects at which we will sample microhabitat variables.

4.2 TRANSECT PLACEMENT

The first step in the establishment of a PHABSIM study site is the selection of locations to position transects for the measurement of microhabitat variables. The placement of transects must reflect the data requirements of both the hydraulic models and habitat models used in the PHABSIM simulation. Transects must be placed such that they are perpendicular to the direction of flow. To achieve this goal the following procedure is recommended:

(i) Locate most downstream transect.

The hydraulic models within PHABSIM require the most downstream transect to be placed at a hydraulic control, upstream of which there is a unique stage-discharge relationship. A hydraulic control is defined as a physical feature, natural or man-made, upstream of which there is a unique stage-discharge relationship. Typical examples are weirs, riffle sections or channel constrictions. Controls are reflected by a break or inflection in the water surface. It is important to recognise that a control will not always be orientated at right angles to the channel banks. If a control runs diagonally across the channel a transect should be placed diagonally along the control, not at right angles to the channel banks.

(ii) Locate most upstream transect.

The representative reach is chosen such that it contains all of those habitat types present in the larger stretch of interest. The extent of the reach will thus be dictated by the requirement that all of these habitat types are sampled by the placement of transects within the reach. Thus the most upstream transect should be chosen so as to minimise the total length of the reach whilst satisfying the demand that all habitat types are sampled.

The most recently published user's guide for PHABSIM (Milhous 1990) advises that the most upstream transect also be located at a hydraulic control, although this is not a specific requirement of the hydraulic models within PHABSIM.

(iii) Locate all additional controls.

Having defined the upper and lower limits of the study reach it is essential that transects are placed at all hydraulic controls present within the reach. This is necessary to aid success in the hydraulic simulations. It is also recommended that a transect be placed at any bends which occur in the reach.

(iv) Locate additional habitat types.

Clearly the transects placed in steps (i) and (ii) will sample some of the different habitat types present within the reach, but rarely will all types be sampled. The next step is, therefore, to place a number of additional transects so as to sample any habitat types which are not sampled by those transects placed in steps (i) and (ii).

(v) Transects for discharge measurement.

When running PHABSIM simulations we require the best estimate of discharge for each of the calibration flows. When measuring the discharge in the field using a current meter we expect that the best estimate of discharge will be at a transect through which the flow is steady, parallel to the channel banks, with a fairly uniform depth of water about 0.5 to 1.0 metres, ie. in a run (or glide) section. Having placed transects following steps (i) to (iv) we recommend ensuring that at least two transects are placed in positions where we can expect a good estimate of discharge, by addition of extra transects if necessary.

(vi) Head of pools.

For reaches containing pool-riffle sequences it is recommended that transects be placed at the head of pools, well into the transition zone toward the pool, since the head of the pool will migrate upstream with decreasing flow. This is to assist in ensuring a good hydraulic representation of the reach.

Clearly the number of transects which will be required to satisfy the criteria outlined in steps (i)-(vi) will vary with the complexity of the study reach in terms of hydraulics and habitat types. From experience gained in UK PHABSIM studies to date around ten transects is generally the minimum number with fifteen to twenty being required in a more complex than average situation.

4.3 HEADPIN ELEVATION SURVEY

Positions of the transects selected for sampling should be marked on both banks with permanent headpins. In order to establish the relative elevations of the headpins it is necessary to carry out a standard levelling loop. We only require this information for one headpin at each transect hence it is advisable to carry out this survey from whichever bank it is easiest. It is advisable to tie in the elevations of the headpins to a fixed datum level (eg. a nail driven into a tree or a point marked on a bridge) so that it is possible to check for any disturbance to the headpins over time.

4.4 REACH LENGTHS

Once the transects have been located and their positions marked with headpins the distances between adjacent transects must be measured. Taking these measurements at an early stage in the field study is advisable as it can assist greatly in the relocation of headpins. The distances between headpins at adjacent transects must be measured on both banks of the channel. Distances on the left and right banks are then averaged and assigned to the appropriate transect. The reach length value assigned to a particular transect is defined as the averaged distance to the next transect downstream. Hence the reach length assigned to the most downstream transect (No 1 by PHABSIM convention) is zero.

4.5 BED ELEVATION SURVEY

Bed elevations relative to some fixed datum level must be surveyed at every sampling point across each transect. The first step in this process is the selection of the positions of the sampling points at each transect. Points are chosen to satisfy, as well as is practically possible, the following criteria:

(i) The profile of the channel bed must be adequately described. Points should be chosen to coincide with breaks in the slope of the channel bed.

(ii) Variation in substrate/cover across the channel must be adequately described. Points should be placed at points where there is a noticeable change in substrate/cover type.

(iii) Sufficient points must be used to give a reliable estimate of discharge through the transect. It is recommended that no more than ten per cent of the total discharge should pass through any of the cells defined by the mid-points between adjacent sampling points. Points should be added such that all cells satisfy this criterion, using a visual estimate of discharge through each cell.

It is important to remember that these criteria should be satisfied at all of the calibration flows. If, as is often the case for ease of working, the initial survey is conducted at a low summer flow, sufficient points must be placed outside the stream to ensure that higher flows can be modelled with comparable accuracy. Headpins must be located above the anticipated bank full level.

It is a convention within PHABSIM that the horizontal x distances of the sampling points be measured moving from left to right looking upstream, ie. the x coordinate of the left headpin looking upstream is 0.0. Bed elevations at each point may be measured relative to any fixed datum level-the elevation of one of the headpins is a convenient datum level for this purpose.

4.6 MEASUREMENT OF DISCHARGE

We require the mean column velocities at the sampling points at a number of calibration flows in accordance with the data requirements of the hydraulic models within PHABSIM. Technical details are discussed in section 5.3 below. In order to satisfy the minimum data requirements of all of the models it is necessary to measure velocities at all sampling points within the stream at every transect for one of the calibration flows. It is recommended that this flow be the highest of the set of calibration flows. In order that the data set be as consistent as possible this complete set of velocities should be measured over as small a time period as is practically possible. Certainly it is recommended that velocities at different transects be measured on the same day and that the order of measurement is recorded.

Since we require, in the hydraulic modelling process, the development of a stage-discharge relationship at the most downstream transect, it is advisable to measure discharge at this transect for every calibration discharge (minimum of three). At every calibration flow we require a best estimate of discharge. If a complete set of velocities is not being recorded at a particular calibration flow then velocities should be measured at those transects identified (see 4.2 above) as the most likely to yield reliable discharge estimates.

4.7 WATER SURFACE ELEVATIONS

The water surface elevation relative to some fixed datum level must be measured at each of the calibration flows. At each transect the water surface elevation should be measured at the left side, centre and right side of the stream. These values are then averaged to give an average water surface elevation for each transect. It is recommended that a full set of water surface elevations be measured before measurement of discharge is commenced. Once discharge measurement is completed water surface elevations should be re-measured so that any variation over time can be recognised. This is particularly important when a complete set of velocities is measured over a number of hours or if there is a possibility of flow being altered, eg. by the altering of sluice gate settings.

4.8 OBSERVATION OF COVER AND SUBSTRATE

As mentioned above the most recent version of PHABSIM available from the U.S. Fish & Wildlife Service uses a single channel index which the user can define to be either substrate or cover. Incorporation of both indices simultaneously is the subject of current research. The current version of PHABSIM gives the user flexibility in the choice of channel index and the choice of coding system used to record the characteristics of the channel index. Essentially any coding system may be used as long as coded observations are in the form of real numbers. When designing such a code the necessity of developing a corresponding preference curve, relating species preference to the discrete coded observations, must be recognised. A coding system which is too simple may not adequately describe changes in the channel index, but if the code is too complex an enormous amount of resource input may be necessary to develop corresponding species preference curves. The coding systems for observation of cover and substrate characteristics used in the initial UK application of PHABSIM were developed by Trihey and Wegner (1981) and are described in tables 4.1 and 4.2 overleaf:

Table 4.1 Conditional cover classification scheme

Cover	Description
0	No physical cover
1	0 - 25% of the cell affected by object cover
2	25 - 50% of the cell affected by object cover
3	50 - 75% of the cell affected by object cover
4	75 - 100% of the cell affected by object cover
5	0 - 25% of the cell has overhanging vegetation
6	25 - 50% of the cell has overhanging vegetation
7	50 - 75% of the cell has overhanging vegetation
8	75 - 100% of the cell has overhanging vegetation
9	0 - 25% of the cell has undercut bank
10	25 - 50% of the cell has undercut bank
11	50 - 75% of the cell has undercut bank
12	75 - 100% of the cell has undercut bank
13	0 - 25% of the cell affected by object cover combined with overhanging vegetation
14	25 - 50% of the cell affected by object cover combined with overhanging vegetation
15	50 - 75% of the cell affected by object cover combined with overhanging vegetation
16	75 - 100% of the cell affected by object cover combined with overhanging vegetation
17	0 - 25% of the cell affected by object cover combined with undercut bank
18	25 - 50% of the cell affected by object cover combined with undercut bank
19	50 - 75% of the cell affected by object cover combined with undercut bank
20	75 - 100% of the cell affected by object cover combined with undercut bank
21	0 - 25% of the cell has a combination of undercut bank and overhanging vegetation
22	25 - 50% of the cell has a combination of undercut bank and overhanging vegetation
23	50 - 75% of the cell has a combination of undercut bank and overhanging vegetation
24	75 - 100% of the cell has a combination of undercut bank and overhanging vegetation
25	0 - 25% of the cell has a combination of object over, undercut bank and overhanging vegetation
26	25 - 50% of the cell has a combination of object cover, undercut bank and overhanging vegetation
27	50 - 75% of the cell has a combination of object cover, undercut bank and overhanging vegetation
28	75 - 100% of the cell has a combination of object cover, undercut bank and overhanging vegetation

SOURCE: Trihey E.W. and Wegner D.L. 1981

Table 4.2 Substrate classification scheme

1	Plant
2	Mud
3	Silt (<0.062 mm)
4	Sand (0.062 - 2 mm)
5	Gravel (2 - 64 mm)
6	Rubble (64 mm - 250 mm)
7	Boulder (250 mm - 4000 mm)
8	Bedrock (solid rock)

SOURCE: Trihey E.W and Wegner D.L. 1981

In the course of the current R&D project a new substrate and cover classification has been developed by the authors in association with Dr Bob Milhous of the U.S. Fish & Wildlife Service, Dr Patrick Armitage and Dr Mike Ladle of IFE Riverlab.

The scope of the current R&D program is extremely broad- to assess the methodology for application to UK rivers with a wide range of different hydrological and ecological characteristics for a number of fish, macroinvertebrate and macrophyte species. In order to devise a code which can be applied successfully in this variety of different conditions it was necessary to maximise generality at the expense of collecting some data which may prove unnecessary in certain situations. If an IFIM study were addressing a more specific problem it may be desirable to simplify the code and thus reduce data collection resource input. This is particularly likely if the study focuses on a particular species life-stage; having identified those elements of the channel indices which are important in defining the species habitat requirements the code may be simplified accordingly. Unless particular reasons have been identified for using a more simple coding system we recommend recording field observations of substrate and cover using the new codes defined below.

Since PHABSIM assumes the channel index to be independent of flow it is only necessary to observe cover and substrate characteristics once during the IFIM study. However, if seasonal variability of these characteristics is pronounced, and considered important to the study, repeat observations and separate simulation runs for different seasons would be appropriate. An example of such a situation is in rivers which are affected to a large extent by seasonally varying weed growth.

Some of the observations required in the coding system require estimates in terms of percentage presence of a particular characteristic over the given area of observation. The cell areas to which PHASBSIM will ultimately assign these values are determined by the assignment of weights (see 4.9 below). For the purpose of field observation we suggest that the area over which observation is made is restricted to the area "close" to the survey point at which the observation is being made. We regard this area as extending approximately 1 metre around the survey point. Careful placement of transects, survey points and assignment of weights should ensure that the habitat characteristics in the reach are realistically described by this "point sampling" approach. Directly observing channel index characteristics over the whole area of cells implicitly defined within the PHABSIM habitat simulation programs is practically almost impossible considering the physical dimensions of these cells. Details of how coded values of channel indices are recorded are given in section 5.4 below.

4.9 ASSIGNING WEIGHTS

The habitat modelling programs within PHABSIM require the assignment of weights (upstream weighting factors) which describe the relative distribution of different types of habitat through the reach. In order to assign values of these weights it is necessary first to identify the major habitat types (eg. pool, riffle, run etc.) present in the study reach. Having completed this task it is then necessary to estimate what proportion of the stream between transects is made up of each of these habitat types. The assignment of these weights to values of habitat variables sampled at each transect in effect defines a grid of cells over which these values are assumed to apply. Unlike in the hydraulic simulation programs these cells do not have boundaries mid-way between adjacent transects. Only in the case where all weights are defined as 0.5 do the boundaries of the cells used in the hydraulic and habitat simulations coincide.

The habitat models contained within PHABSIM combine simulated values of depth,velocity and substrate/cover with habitat preference data to give Weighted Usable Area, a weighted measure of available habitat in feet squared per 1000ft of reach length.

The hydraulic programs predict depth, velocity and substrate at each survey point across each transect. In the WUA calculation performed within the habitat models it is necessary to define the cell areas over which these point values are to apply. The habitat models automatically assume that values predicted at a point Xi are assumed to extend half way to the neighbouring points Xi-1 and Xi+1 on the transect (see Fig 4.1).

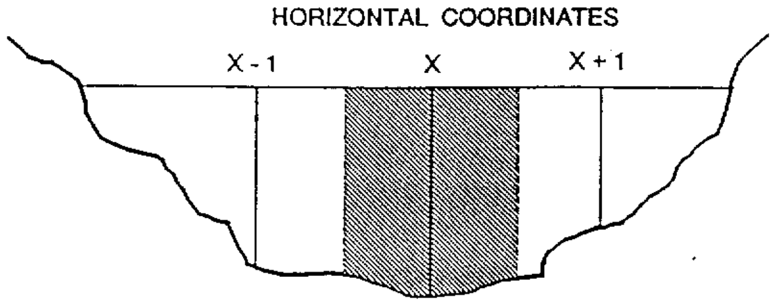


Fig 4.1 ***Cell areas defined by survey points placed across a transect.***

The distance up and downstream to which the values predicted at Xi are assigned is controlled by the values given as data for the weight (upstream weighting factor) assigned to the transect. This is based on field observation of changes in habitat types between neighbouring transects. The method of assigning weights is different for the two techniques of data collection; representative reach (dependent transects) or habitat mapping (independent transects).

Representative Reach Approach

We shall illustrate the assignment of weights in this case using an example with three transects, as shown in Fig 4.2 below, where transect 1 is at the downstream end of the reach. Suppose the inter-transect distances (averaged between measurements made on the left and right banks) are as follows:

Transects	Distance
1-2	100m
2-3	200m

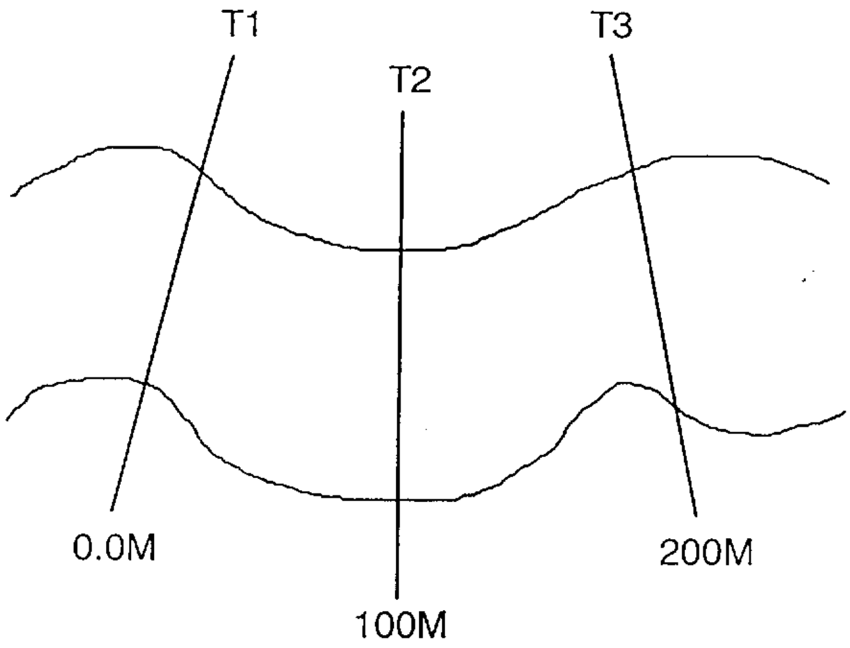


Fig 4.2 Position of transects in example representative reach

By convention the reach lengths assigned to each transect are as follows:

Transect	Reach Length
1	0.0
2	100.0
3	200.0

When field data is collected observations are made of the type of habitat represented by the data collected at each transect and how the types of habitat vary between transects. Generally we think of habitat "types" in terms of pools,riffles,runs etc. In assigning weights we must make a subjective decision as to what proportion of the stream between adjacent transects is best represented (in terms of habitat type) by data collected at the upstream transect ,rather than at the downstream transect. Careful placement of transects, avoiding rapid changes in habitat types between transects is clearly beneficial in making this assessment.

Following our example let us suppose firstly that we have decided that the habitat at transect 1 extends 50 m upstream. Consequently we regard the remainder of the stream between transects 1 and 2 to be more closely described in terms of habitat by the data collected at transect 2. Likewise suppose we decide that the habitat at transect 2 extends 160m upstream to transect 3, the remaining 40m between transects 2 and 3 being better represented by the habitat type at transect 3. Having made these judgements we would proceed to assign a value of the weight to be applied at each transect as follows:

Transect	Weight
1	0.5
2	0.8

In essence the weight assigned to each transect controls the extent of the upstream distance to which values of microhabitat variables measured (and predicted) are applied in the WUA calculation performed by the habitat models. In our example we may visualise the "cell areas" defined by our choice of weights to be as shown in Fig 4.3 below.

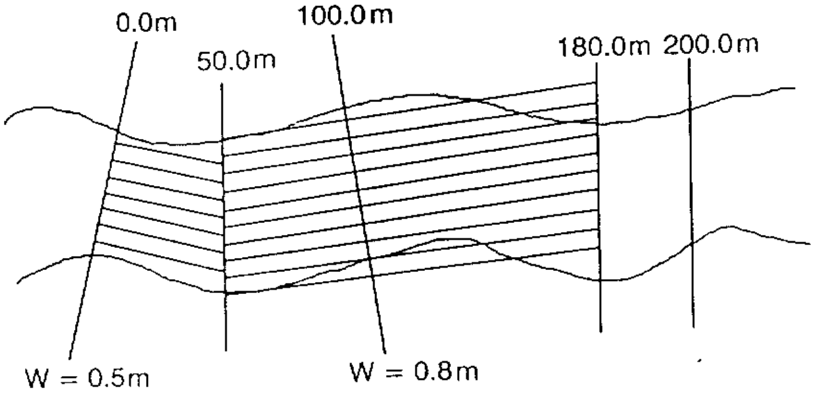


Fig 4.3 Cell areas defined by assignment of weights

Each cell contains one survey point: in the WUA calculation values of microhabitat variables measured (and predicted) at the survey point in the cell are assumed to be constant over the whole cell area at any given discharge. Note that although cell area may change with discharge the weight remains constant with varying discharge.

Habitat Mapping Approach

If data has been collected using a habitat mapping approach we have independent transects and we do not measure the distance between adjacent transects. Consequently we must use a different approach for the assignment of reach lengths and weights at each transect. Firstly we decide the extent of the stream over which we wish to map data sampled in different habitat types. We then observe the different habitat types present in this length of stream and estimate the proportions of this length best represented by each habitat types. Clearly if we have placed transects carefully we should have at least one transect corresponding to each type of habitat.

In order to demonstrate the assignment of reach lengths and weights in this case let us use another example. Suppose we have collected data at ten independent transects and that the distribution of habitat types over the length of stream of interest is as follows:

Habitat Type	% Occurrence
Run	20
Pool	60
Riffle	20

Now suppose the number of transects representing each of these habitat types is as follows:

Habitat Type	No of Transects
Run	3
Pool	4
Riffle	3

In assigning appropriate reach lengths and weights for the WUA calculation we use the concept of an "idealised reach" of a given length. Suppose in this example we arbitrarily fix the length of this idealised reach to be 100m. From our field observation of the real reach of interest we require the idealised reach to represent the following distribution of habitat types:

Habitat Type	Length of Idealised Reach Represented
Run	20.0m
Pool	60.0m
Riffle	20.0m

We now arbitrarily set the value of the weight for each transect to be equal to 1.0. This means that for a given transect values of microhabitat variables at data points across the transect are assumed to apply over the whole of the distance to the next transect upstream. We now place transects in the idealised reach and define the reach lengths so that the distribution of habitat types within the idealised reach reflect that present in the real reach of interest. Since the result of the WUA calculation is given in metres squared per 1000m of reach length the WUA computed using this approach will be independent of the arbitrary choice of idealised reach length. In our example we would define reach lengths to be assigned to transects in the idealised reach as follows:

a) Transects representing "run" type habitats

20.0m of the 100m idealised reach is to be represented by run type habitats. Since we have three transects representing this habitat type we may imagine these to be equally spaced over this 20.0m. Thus to each transect we would assign a reach length of 6.66m . In the idealised reach the position of these transects,R1,R2,R3 is shown in Fig 4.4 below.

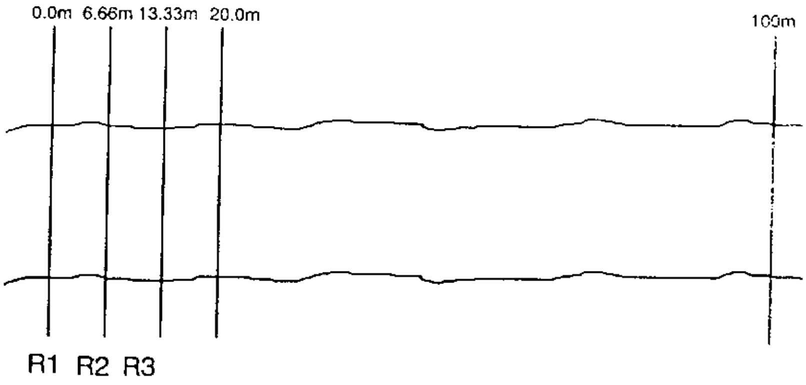


Fig 4.4 "Run" transects in idealised reach

We then proceed to follow the same approach for the transects representing the remaining habitat types.

This technique of mapping results from sampled transects in different habitat types to a particular reach of interest may also be used in the process of transferring results obtained at a specific study site to a larger length of the stream of interest.

5 Field survey techniques and equipment

The guide to fieldwork techniques given below shows the standard methods used in data collection for this type of study. In the course of the current R&D project some of these methods are being refined and developed. As yet these methods are not completely proven, therefore, the advice below relates to the most tried and tested field survey techniques. For information on the latest methodologies, or for using equipment not described here please contact the authors.

5.1 FIELDWORK PLANNING

When beginning field data collection for a PHABSIM study it is vital to start by carefully planning the work that one is about to do. This will pay dividends by ensuring that the work runs as smoothly as possible and minimises time that may be wasted through having incorrect equipment etc. In the initial stages, then it is essential to consider the site that you are to work on and examine any previous work that may have taken place there and to study existing data.

Access to data concerning the flora and fauna found at a site may be very useful not only when selecting the target species for the study, but also in the further development of the suitability indices for those species. In addition to this it is important to consider this information when planning the survey work. For example, if studies involving flora in a river channel have shown that a site is particularly affected by seasonal weed growth then the work must take this into account as it will have major implications for the stage/discharge relationship through the year. Hence, it is advantageous, to select study reaches in areas where much relevant data has been collected in the past, for example sites sampled for macroinvertebrates during the RIVPACS survey can be found on many rivers throughout the U.K. and the data obtained would be useful in this work. Other sources of useful information include Universities, other research institutes etc. as well as from within the regional NRAs.

Another important factor to consider during the initial reach selection process is the size of the catchment at a prospective site. This has quite large implications in the expense and time taken to study a site. If the catchment size is much over 150 km2 then it is likely that the survey work will involve the use of a boat and/or a cableway system at some point, especially when measuring high flows, with a consequent increase in manpower requirements and thus expense. If a reach is marginal as far as this is concerned then it is worthwhile examining the hydrological records and walking or wading the reach to check what equipment and manpower investment will be needed (see 5:7 for advice on working on large rivers).

Having selected the river copies of detailed maps of the area (such as the OS 1:2500 scale) should be obtained from the Ordnance survey to provide details of nearby benchmarks, site accessibility, hazards such as power lines etc. They may also give one further information concerning the size of the river channel etc. and will be an invaluable aid when producing sketch maps of the location of transects and so on.

Before embarking on a field survey make sure that you have the correct equipment (see 5.8 for the equipment check list), with duplicate gear as back up if any parts of the apparatus is easily broken or is liable to break down. Remember it is better to be over equipped than to have to abandon work, or to put survey staff in physical danger, through the lack of proper equipment.

5.2 LEVELLING

It is assumed that the user of this guide will have levelling experience. However, it is useful to know the type of work that will be required and the necessary accuracy needed to complete the work satisfactorily.

Perhaps the best type of level for this work is the 'automatic' level as these are highly accurate, quick to set up and use and inaccuracies caused by slight movements of the tripod during the survey etc. are minimised. The level should have a vertical accuracy of + or - 1.5mm over a double levelling run of 1 km or better (as is achievable with most modern levels) and it is advantageous if it is waterproof. The levelling staff should be at least 4m in length, as light as possible and narrow in section so that gusts of wind will affect it as little as possible. The staff should either incorporate a permanently attached bulls eye spirit level bubble or a separate hand held bulls eye bubble should be provided.

Levelling is used to obtain headpin elevations, channel cross-sections, and water surface elevations. Each of these measurements require slightly different approaches as outlined
below:

A: Headpin elevations. The purpose of this is to provide a point of known elevation on each of the transects so that the ground elevations of each point on the cross sections may be calculated. This is achieved by running a simple levelling loop incorporating all of the headpins on the most convenient side of the river. Headpin elevations should be taken to at least + or - 0.5cm
and the misclosure should be within normally acceptable limits, ie. + or - 12 (k)0.5 where k is the length of the circuit in km and the result is in millimetres. When the survey loop has been completed the misclosure should be calculated as soon as possible (preferably in the field) so that any mistakes can be quickly and easily corrected.

B: Channel cross section survey. This provides the channel cross-section profile data.

In this case it is best to set up the level close to the headpin (but not so close that its elevation cannot be read), where it is easy to communicate to the person holding the staff. The elevation of the headpin is taken first and then the elevation of each point along the transect is measured so that there relative heights may be obtained. Horizontal distances are measured by using a tape measure in the usual way. Horizontal distances should be measured to the nearest 30 cm at least and vertical distances should be measured to a minimum accuracy of + or - 5.0 cm.

C: Water surface elevations. For these measurements the level should be set up as in B above, ie. where communication between the surveyors is easy. Firstly, the headpin elevation is taken. Then the water surface height is measured relative to the pin in the following manner:

1: The person holding the surveying staff (levelling assistant) moves to a suitable measuring point and holds the staff upright just above the water.

2: The level operator focuses the level on the staff and indicates that he or she is ready.

3: The levelling assistant then slowly lowers the staff until it just penetrates the water (a meniscus is just formed between the base of the staff and the water), then holding the staff as steady as possible, shouts 'ready' to the level operator.

4: The level operator takes the reading.

This process may require some practise and it helps if the staff involved are experienced at surveying in general. The measurements should be repeated approximately three times at both banks and in the middle of the river. If the measurements at each point are widely different then it is advisable to take more readings, although one should expect some variation in the water height from one side of the river to the other. The water surface elevations should be measured to the nearest 0.5 cm at least.

When taking the water surface elevations and velocity readings it is important to have a stage board of some kind sited near or within the reach so that any variation in the flow during the survey can be seen and noted.

5.3 CURRENT METERING

It is assumed that, once again, the user of this guide does not require an all encompassing guide to current metering. Consequently, all the usual prerequisites to accurate current metering apply in addition to any advice given here.

Measurement of the water velocities is, perhaps, the most time consuming part of the data collection procedure. It is essential, therefore, that there is more than one person in the team current metering at any one time. This obviously requires more than one current meter. Ideally all of the current meters used in the study should be of the same type and should have been recently calibrated so that all of the meters give accurate readings. Perhaps the best type of current meter for this study are those which use electromagnetic induction to get velocity readings rather than the normal 'impellor' type. This is because they are unaffected by weeds etc. that may be growing in the channel. They also tend to be calibrated for life, they are much less difficult to maintain and less prone to breakage.

For each cell only the mean velocity is required, therefore, current meter readings are usually taken at 0.6 of the depth (from the water surface) over 30 seconds. Often, though, this may not give an accurate enough representation of the mean velocity due to turbulence or the presence of weeds etc. In this case, readings at other depths may be taken at the surveyors discretion and the mean velocity calculated from these. At each point both the depth of the water and the velocity should be noted.

5.4 APPLICATION OF COVER/SUBSTRATE CODE

For each survey point the following characteristics should be estimated:

A:	Small object cover	(<200mm)	percent	0 to 100
B:	Large object cover	(>200mm)	percent	0 to 100
C:	Overhanging vegetation cover		percent	0 to 100
D:	Instream vegetation		index	0 to 100.00
E:	Undercut bank (Y or N)		existence	0 or 1
F:	Substrate		index	0 to 12000.00
G:	Substrate packing		index	0 to 100

Note, that when making the above measurements that percentages should only be taken in units of 10 percent (it is unrealistic to expect a greater accuracy than this when taking visual measurements).

As stated in (4.8) it should only be applied to an area of 1 meter surrounding each survey point. To avoid confusion when taking the measurements it is suggested that the same staff carry out all of the readings in a survey. This aids consistency in the measurements and also saves time as the staff involved should develop a routine. It will also help if the readings are taken in a consistent order like that given on the survey sheets (appendix B). Readings should be taken for all of the cells, both those in the water and those which may be submerged at higher flows. Further information concerning each characteristic is given below:

A: Small object cover. This refers to any small objects (<200mm approximately house brick size or less) which lie on the river bed and banks, and may give cover to small fish and invertebrates. Readings are taken as a percentage in units of 10%.

B: Large object cover. This refers to any large object (>200mm larger than house brick size), as above, which may give cover to larger fish etc. Readings are taken as above.

C: Overhanging vegetation cover. This refers to vegetation external to the river, which may provide shade or cover. The most common example of this is overhanging trees. Readings are taken, again, in percentage terms as in A and provide a measure of the shading of the cell by the vegetation.

D: Instream vegetation. This refers to the presence of aquatic vegetation that may be growing in the river. In the cells that are outside the river there will probably be no aquatic veg. therefore readings of 0 should be entered. The vegetation index is derived from the following:

No instream vegetation	=	1
Streaming type vegetation	=	2
Reed type vegetation	=	3
Floating vegetation	=	4
Streamer & reed vegetation	=	5
Streamer & floating vegetation	=	5
Reed & floating vegetation	=	6

Here, streaming vegetation refers to plants growing on the river bed or sides, that are not emergent (unless the plants are very prolific and the river flow very low). Reed type vegetation refers to emergent vegetation (not just reeds) as are usually found growing on the channel margins. Floating vegetation is that which may grow from the bed or banks of the river and forms floating vegetation "mats" with open water underneath.

The index is written as XYD.Z, where X is the dominant vegetation type; Y is the subdominant; D is the total coverage of vegetation in units of ten percent (range = 0 to 9), and Z is the percentage of the total vegetation taken up by the dominant. For example, a cell with 30% of the stream bed area covered by vegetation, of which most (60%) is streaming and the remainder is floating, would have the following values: X=1, Y=3, D=3, and Z=60 producing an index of 133.60. If there is only one type of vegetation, and therefore Z would equal 100%, then it should be recorded as X0D.00 rather than X0D.100.

The possibility of all three types of vegetation existing at a point is catered for by taking the dominant two together, such as streamers and reeds (index of 4) and then the least common,
in this case floating veg.(index of 3).

E: This refers to the presence or not of undercutting of the banks at the channel margin. If the banks are too vegetated to easily recognise this then a suitable stick should be used to determine if the bank is undercut. This is best done by wading and not from the bank, where the ground may collapse underfoot if undercutting has occurred.

F: Substrate index. The substrate index is derived from the following:

Plant detritus/organic material	=	1
Clay (<0.02mm)	=	2
Silt (<0.06mm)	=	3
Sand (0.06-2.0mm)	=	4
Gravel (2-16mm)	=	5
Pebbles (16-64mm)	=	6
Cobble (64-256mm)	=	7
Boulder (>256mm)	=	8
Terrestrial vegetation	=	9
Man made bank material	=	10

The term plant detritus/organic material refers to dead vegetation such as leaves etc. Terrestrial vegetation refers to such things as grass, stinging nettles and trees which may be found within the cells. Man made bank material refers to situations where the channel structure has been altered by man through the use of concrete etc.

As an approximate guide clay and silt may be distinguished in the field since clay grains stick together and silt does not, also clay has a rather more 'buttery' feel that silt does when rubbed between the fingers.

The index should be written in the form X0Y.Z; where X is the number of the most prevalent grain size and Y is the second most common, the two being separated by a zero. Z is the percentage of the total bed surface covered by the most prevalent material. As with the vegetation index, if there is only one type of substrate then it is written as X00.00 rather than X00.100.

It is recommended that the person taking the substrate measurements has some experience of sediment size analysis. It is also valuable to predetermine the sizes of each sediment size band. If in doubt physically measure the sediment with a suitable implement.

G: Substrate packing. This is an estimation of the amount of packing of the sediment in percentage terms. It is not necessarily dependant on grain size, although clay and silts are likely to be more loosely packed than boulders. It is estimated by moving the substrate by kicking etc. If the substrate is solid then its packing would be in the 90-100% band if the substrate had the consistency of a liquid (ie. was very loosely packed) then its index would be close to 0%. A rough guide to this estimation is given as follows:

0-20%	- Very loose, minimum effort required to disturb the substrate.
20-40%	- Loose.
40-60%	- Medium, some effort needed.
60-80%	- Compact.
80-100%	- Very compact, very difficult to disturb the substrate.

5.5 RECORDING DATA

It is essential that data is collected in a clear, orderly, fashion so that it may easily be utilised by staff other than those who collected it. Pencil should be used for writing on data sheets as it is unaffected if the record sheet gets wet. Mistakes should be clearly crossed out and corrections made alongside. Notes of any non-routine procedures should be made at the time of the survey. If in doubt clearly note everything as it is surprising what may be forgotten by the time the data is processed. The use of standard data sheets is strongly recommended and examples of these are given in appendix (**). The collected data should be logically filed on return from the field visit and processed as soon as possible. A note should also be taken of the person who wrote down the data so that any inconsistencies, for example in handwriting, can hopefully be corrected. The importance of good record keeping cannot be over emphasised and it is impossible to take too many notes, even if they are not all used in the end.

5.6 FIELDWORK ON LARGE RIVERS

Work on large rivers leads to many problems and often requires different approaches to the data collection than outlined above. The size of the river affects fieldwork in three main ways:

1: Channel width. If the channel is very wide (eg. >50m) the accuracy of readings taken with a level may decrease to a point that is unacceptable. It will also become very difficult or impossible to get accurate distance measurements using a tape measure. In this type of situation it is recommended that more accurate type of surveying equipment such as a Total Station Electronic Distance Measuring equipment (EDM) is used for surveying heights and distances. This has the benefit that highly accurate readings may be taken over long distances and that all of the measurements required to locate a survey point are taken at one time. However, the use of this type of equipment will require a computer and the correct software to analyze the data and to calculate variables, such as the distance between survey points, required in the course of the remaining fieldwork. It will also require improved methods of communication between survey staff (such as the use of hand-held CB radios) as they may be more than shouting distance apart.

2: Channel depth. If the channel is deeper than may be safely wadeable then the use of a dry-suit and/or boat may be necessary. It is expected that the user of this guide will have experience of using small boats, and will therefore not require instruction here. The usual method for positioning a boat (usually a small rubber dinghy) is to place a rope or wire across the river and then to use this to move the boat to the required point on the transect. For this it is best to have two people in the boat, one to hold the boat in position and the other to operate the relevant measuring equipment. In high flow conditions it may be necessary to combine this with the use of an outboard motor. In these circumstances great attention must be payed to safety to ensure that the field staff are not endangered. Where the channel is not particularly wide and a level is being used, it may become apparent that the surveying staff is not long enough to be read at the channel thalweg. In this situation it is possible to firstly measure the water depth using the staff, and then take a reading of the water surface level (as above) and from this calculate the bed elevation. Where an EDM is being used it is possible to obtain extensions for the target prism staff to ensure that it is long enough, although a similar approach to the above may be possible by using a levelling staff to measure the water depth and then surveying the water height using the EDM.

The measurement of cover and substrate will also be difficult in deep water as it is usually impossible to see the river bed. In this case it may be possible to estimate the readings by probing with staff or rod. Alternatively it may be necessary to use a corer/grab to take samples from the bed.

3: Water velocities. It is recommended that the main, initial, channel survey is undertaken at low velocities. However, when measuring calibration flows it may be necessary to work when the river is at a high flow. In this case work should be undertaken from a boat or portable cableway system. Do not attempt to wade the river. Current metering may be undertaken using a cable suspension system, from which the current meter may be lowered into the water. Again in these circumstances pay close attention to safety.

5.7 EQUIPMENT CHECKLIST

Below is a list of equipment required to conduct a PHABSIM study:

General:

- Waders (both thigh and chest waders).
- Wellington boots.
- Waterproofs.
- Maps.
- Clipboard.
- Survey sheets and notebooks.
- Polythene bags to keep notebooks and survey sheets in.
- Pencils and sharpener.
- Tent pegs (for securing tape measure end).
- Barrier cream (to protect the hands of people working in the river, it also helps to protect against Wiles disease) Antiseptic soap. Water container and fresh water (to wash hands afterwards).
- First aid kit.
- Puncture repair kit for waders and dry suits etc.
- Sledgehammer.
- Metal detector.

Carrying bag or rucksack.
Safety line.
Hand held 2 way radios.
Dry suit.
Knife.
Life Jackets (even when not working from a boat it is advisable to have lifejackets available for wading).

Surveying Equipment:
Level (preferably automatic type)
Tripod.
Surveying staff.
Bulls eye bubble spirit level for staff.
At least two 30 or 50m Tape measures.
Marker flags.
Marker stakes (eg. Permamarks).
EDM, target prism, tripod, staff, data logger/portable computer (for working on large rivers or for producing highly accurate site maps).
Batteries for above.

Current metering.
At least two current meters (preferably electromagnetic).
Wading rods for above.
Batteries for above.
Portable cableway system (for large rivers).

Boat Work.
Rubber dinghy (preferably with wooden floor).
Pump and puncture repair kit.
Outboard motor & fuel.
Oars.
Lifejackets.
Rope (at least 50m depending on river size)
Anchors and chain.
Anchor stakes.
Cable anchoring system (put across the river to help position the boat).

5.8 ESTIMATE OF COST OF DATA COLLECTION FOR IFIM STUDIES

Below is an estimate of the cost of data collection expressed in man hours. As a guide to the effect of river size on necessary expenditure the cost has been estimated for both a small river and a large river. It must be stressed that this is only an approximate guide based on the authors experience. Unless otherwise stated each time is calculated for a site with 10 transects in it, each transect having 15 points.

	Small River	Large River	No. of staff
Initial site visit and reach selection	7 hrs	7 hrs	2
Transect placement and installation of markers	4 hrs	4 hrs	2
Headpin elevation survey inc. reach length survey	3 hrs	4 hrs	2
Bed elevation survey (per transect)	½ hr	1 hr	2
Measurement of velocities and water surface elevations (per transect)	1 hr	1 hr	3
Observation of cover and substrate (per transect)	½ hr	2 hrs	2
Site record note taking, eg. sketch maps, video, photographic records etc	3 hrs	3 hrs	2

Note that some of the measurements may be combined thus saving some time. For example the bed elevation survey could be done simultaneously with the observation of cover and substrate requiring 3 people for approximately 1 or 2 hours for small and large rivers respectively.

5.9 GUIDE TO FAUNA SAMPLING FOR IFIM STUDIES

It is still too early in the project to provide specific guidelines for acquiring data. The aims of this study have included the need to assess the feasibility of using PHABSIM to predict invertebrate responses to habitat loss. With this in mind only broad recommendations can be made.

At each site an assessment of the habitat variability should be made and invertebrate samples collected from each microhabitat. This will provide data on the typical faunal community of each microhabitat. In the present study 5 habitat types have been recognised. Guidance notes on sampling are given below.

a. Invertebrate sampling

Identify five micro-habitats which fit as near as possible, into the following categories:

A - SLACK, an area with no flow.
B - MARGINAL, often in marginal plants or in their roots, flow is usually minimal.
C - RIFFLE.
D - WEED, often varies between rivers, sample the weed only not the substrate but record the nature of the substrate and the type of weed.
E - DEEPER/SLOWER, an area within the reach where deposition occurs.

Each sample was taken in a fifteen second period, the depths were recorded in centimetres. **Surface flow velocity** was most easily measured in seconds per meter then converted to standard flow velocities according to the following tabulation.

Velocity category	secs. per meter	cm per sec.
1	> 10	< 10
2	4 - < 10	> 10 - 25
3	2 - < 4	> 25 - 50
4	1 - < 2	> 50 - 100
5	< 1	> 100

Substrate type was recorded according to the following categories:

Boulders	> 256 mm
Cobbles	> 64 - 256 mm
Pebbles	> 16 - 64 mm
Gravel	> 2 - 16 mm
Sand	> 0.0625 - 2 mm
Silt	> 0.004 - 0.0625 mm
Clay	</= 0.004 mm

Percentage substrate cover for each micro-habitat was noted as was the composition of the substrate of the whole reach.

To record the compaction of the substrate the following categories were composed according to the effort required to disturb it, this gives a general idea of the compaction over the whole reach.

1 - Very loose, minimum effort required to disturb the substrate.
2 - Loose.
3 - Medium, some effort needed.
4 - Compact.
5 - very compact, very difficult to disturb the substrate.

The sample data (after processing) can be used to supplement data on habitat preferences of various taxa and also assess the possible affects of discharge changes on faunal communities. For example, if the marginal area is likely to be exposed due to abstraction it could be assumed that the marginal community will be displaced. Riffle areas may be reduced and species associated with such areas could be affected. However, this can be a gross simplification and the strongly dynamic nature of invertebrate communities means that there will be a continued adjustment to conditions and frequently local hydraulic conditions are more important determinants of faunal composition than the proportion of flow abstracted. The effects will therefore be very river or site specific. Thus, generalisations may not be applicable in the case of invertebrates. However until it is shown conclusively that invertebrate data are not relevant, samples should be collected in the manner described. They will provide useful data on the "importance" of different microhabitats and add to the bank of knowledge on habitat preferences. In addition they can be used to test the predictions made by PHABSIM which will be based on habitat suitability curves for selected species, characteristic of different microhabitat conditions.

b. Fish sampling

At each site an estimate will need to be made of fish population numbers. The most suitable method for achieving this is the multiple catch method. The reach should be fished sufficient times to ensure an adequate drop off in catch to occur; this will normally be at least three times. For each species to be modelled this population will need to be subdivided into adult and juvenile fish. The age structure will, therefore, also need to be determined.

The area to be electrofished should be chosen with regard to the practicalities of electrofishing. Suitable electric fishing methods should be used to ensure a constant and relatively large proportion of the fish present in the reach are caught at each fishing. The reach should be isolated by setting stop nets at the top and bottom of the reach to be fished.

If fish location maps (FLMs) are to be produced, disturbance along the bank of the reach to be fished should be kept to a minimum, especially before the first fishing. Again if FLMs are to be produced the fishing team should try - within the constraints of efficient fishing - not to drive the fish ahead of the anodes. This can be avoided by not having the anodes continually energised, but instead energising them intermittently, if possible targeting likely fish habitats/locations.

Where large numbers of minor fish species are present they may be subsampled by catching them in a short section of the reach only. An estimate of minimum species density can then be calculated for that area and extrapolated to the section as a whole.

Fish lengths (fork length) of each fish from each fishing should be recorded. Whilst it may be possible to determine the ages of smaller fish from length-frequency distributions, scales should be taken from all the larger fish and a selection of smaller fish and ages determined in order to verify such assumptions.

Fish should be returned alive to the river at the end of the last fishing.

6 Ecology

6.1 HABITAT PREFERENCES - CALCULATION OF HABITAT PREFERENCE CURVES

a) Invertebrates

Methods

The most accurate estimates of habitat preferences are derived from detailed analyses of distribution patterns of species with respect to specific variables measured at the point at which a faunal sample is taken (Gore & Judy 1988). Such techniques are time-consuming and costly but are ultimately necessary for developing the model. In the absence of such data cruder estimates have to be used.

Large data bases which record both the occurrence of fauna and the physical features of the sites provide the raw material for preliminary assessments of habitat preferences. The Institute of Ecology has over the last 12 years identified about 600 species from more than 400 substantially unpolluted sites throughout Great Britain (Wright et al. 1988). The physical and chemical characteristics of these sites have also been recorded. Together these two blocks of data (distributional information and physico-chemical features) have been used to assess the habitat preferences of selected species.

At a site, benthic fauna is taken from all available habitats usually in proportion to their occurrence, and a sample consists of all the material collected in a three minute period. This method therefore does not take account of distribution patterns within the site and the results express occurrence with respect to mean values of variables such as substratum, velocity, and depth. This reduced precision is offset to a certain extent by the large number of records for the selected species.

In addition to the presence absence data for individual species, information on the relative abundance of families is also available. In some cases a family may only contain one dominant species and here it is possible to use these abundance data to show preferred conditions for maximum abundance.

In a previous study for the Department of the Environment, habitat preferences of five species of invertebrate were calculated from the I.F.E. data base (Armitage & Ladle 1989). The selections excluded catholic species and included animals with narrower ecological limits because these are more likely to respond to changes in habitat. The species examined in this study were:- the stoneflies *Leuctra fusca* and

Isoperla grammatica, two caddis-flies *Polycentropus flavomaculatus* and *Rhyacophila dorsalis* and the pea-mussel *Sphaerium corneum*.

The present study has added to this list by including a further ten species. These have been chosen according to the following criteria:- occurrence in at least 15% of the sites in the data base, representative of a range of habitats, and at least some selections should provide abundance data. The species are listed below together with available data (occurrence=O, abundance=A).

Crustacea	
Gammarus pulex	(O)
Crangonyx pseudogracilis	(O)
Gammaridae[1]	(O), (A)
Stoneflies	
Leuctra inermis	(O)
Leuctridae[2]	(A)
Chloroperlidae[3]	(O), (A)
Mayflies	
Heptagenia sulphurea	(O)
Heptagenia lateralis	(O)
Rhithrogena semicolorata	(O)
Ephemeridae[4]	(O), (A)
Habrophlebia fusca	(O)
Caddis-fly *Sericostomatidae*[5]	(O), (A)

[1 includes two species; 2 includes all other *Leuctra* species found with *L.inermis*; 3 includes *Chloroperla torrentium* and *C. tripunctata*; 4 includes four species with *Ephemera danica* dominant; 5 includes 2 species with *Sericostoma personatum* dominant.]

Results

Results of habitat preference curve calculations appear at the end of this section. Tables 6.1-6.8 present data on habitat preferences of the taxa under investigation and these data are repeated as curves in Figs 6.1 to 6.16. The occurrence, and abundance data (when available) are presented for three habitat variables, substratum (as PHABSIM codes), velocity (cm per second), and depth (cm). The distribution of categories of these variables in the data set is illustrated in Fig 6.17.

Crustacea:- *Gammarus pulex* is common and widespread in Great Britain. *Crangonyx pseudogracilis* is an introduced species which inhabits rivers, canals, ponds lakes and reservoirs and tolerates saline and polluted water. Both species have similar habitat requirements but *C. pseudogracilis* has a slightly greater preference than *G. pulex* for slow velocity, deep water and fine substratum. *Gammaridae* abundance shows slightly more focused preference curves than does occurrence.

Stoneflies:- *Leuctra inermis* is a common and widespread species with a preference for fast flows, shallow depths and coarse substrates. The velocity curve is not focused and suggests a wide range of tolerance. In contrast, optimum depth and most particularly substrate lie within fairly narrow bands. In an effort to determine if abundance values tended to narrow the optimum ranges of the physical parameters; abundance data for the family *Leuctridae* were plotted. The family contains five species in all and although two of these *L. nigra* and *L. geniculata* favour less torrential habitats *Leuctridae* occurrences are dominated numerically by *L. inermis* which is why the family curve reflects the species curve so closely. No increases in focusing of the curves were noted with abundance data.

Chloroperlidae is another family of stonefly with a preference for fast shallow coarse bottomed streams. However it has a broad range of occurrence and the curves are not finely focused. Even the use of abundance data fails to reduce this lack of focusing.

Mayflies:- Five species of mayfly were examined. Two, *Rhithrogena semicolorata* and *Heptagenia lateralis* show preference for torrential type streams. Both species have rather focused curves for depth and substrate preferences but velocity curves are not appreciably focused. *Heptagenia lateralis* shows the most rigorous habitat requirements of the two species. A third species also in the family Heptageniidae - H. sulphurea - is generally found in larger streams but the species shows a wide range of occurrence.

Habrophlebia fusca is a species of small streams. The habitat preference curves show moderately focused curves for velocity and depth but tolerance to a wide range of substrate conditions.

Ephemeridae are burrowing mayflies. The family contains four species in our data set with *Ephemera danica* the most widespread and abundant species. Velocity and depth are very unfocused and it would be difficult to identify a single peak. Depth shows a bimodal distribution in preference which reflects the species widespread occurrence in deep water sites. The chief control over distribution appears to be substrate which is shown in the focused habitat preference curve. The use of abundance data reduced the bimodality of the depth curve and focuses the substrate curve even more.

Caddis flies:- *Sericostomatidae* contains two species *Sericostoma personatum* and *Odontocerum albicorne* with *S.personatum* as the most widely occurring and abundant form. Velocity and substrate curves are non focused but there does appear to be a closer relation of occurrence and abundance with depth.

Discussion

The taxa tested occurred over a relatively wide range of conditions and this may reflect the composite nature of the samples which were not microhabitat specific. This suggests again that occurrence data collected from such samples is not the best way to obtain detailed information on habitat preference. However the results conform to the generally accepted (from the literature) view of the habitat requirements of the tested species and are the most cost effective way of obtaining data on physical habitat requirements of species and families.

The lack of finely focused curves for *velocity*, depth and substrate for the majority of species tested may also reflect the very heterogeneous nature of most river beds which allows species to occupy small niches which although differing greatly in velocity, shear stress and particle size may be in very close proximity to one another. Examples are the surface of a boulder and the downstream side of that boulder. Two niches close to one another but experiencing quite different velocity and shear stress. In addition the biofilm which develops on the boulder surface will vary with locus with respect to current flow.

Another factor which may contribute to the lack of focused curves is the nature of the river. This relates directly with the niche aspect above in that some streams will have a wider range of niches than others. This point was raised in a previous report to the Institute of Hydrology for the Department of the Environment (Armitage & Ladle 1989) where it was suggested that the fauna of some rivers will react less to environmental change than will that of more 'susceptible' rivers. A susceptible river may be one that has less niches/ habitat variability and less fluctuations in natural discharge which could act as re-setting mechanisms to recreate habitat diversity.

Another point raised in the 1989 report cited above must be made again. The invertebrate community at a site is a dynamic complex of interactions and the attempt to describe habitat preference only with reference to three or four variables is unlikely to be wholly successful. The concept of cover although a useful one for fish is not particularly so for invertebrates. Here the substrate descriptors are in effect measures of cover. With respect to substrate a feature of major importance to the benthic community is the settlement of fine particulate material. This material which is partly biological in origin can determine the nature and abundance of invertebrates in rivers. It is important that attempts are made to establish the relationship between flow characteristics and channel morphometry and the dynamics of fines. The situation is complicated by the fact that managed flow changes may not be sufficiently great to alter the basic substrate type but would allow the deposition of a thin layer of fines. This would result in faunal change.

The combination of niche specific distribution, quick response to changing conditions, and recolonization from upstream sources or via tributaries, means that the response of invertebrate communities to for example, reduced flows may not be clear in all but the most extreme cases. Habitat loss in relation to reduced discharge may not be accompanied by changes in the invertebrate community as measured by occurrence of species. Instead it will be necessary to relate communities with specific microhabitats and determine the effects of discharge changes on these microhabitats in order to assess possible changes in the benthos. Emphasis on the use of habitat classifications has recently been made by Kershner & Snider (1991) and Harper et al. (1991) and the uniformity of microhabitat communities in eight rivers throughout the country is investigated in another section of this report.

Taxon	Ephemeridae				Ephemeridae		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	7	0.19	0.52	18	0.50	0.44
10-25	64	23	0.36	0.97	72	1.13	1.00
25-50	146	54	0.37	1.00	149	1.02	0.90
50-100	148	39	0.26	0.71	105	0.71	0.63
>100	52	19	0.37	0.99	56	1.08	0.96
TOTALS	446	142			400		
Depth							
0-25	180	74	0.39	1.00	196	1.09	1.00
25-50	157	52	0.33	0.84	156	0.99	0.91
50-100	62	9	0.15	0.37	35	0.56	0.52
100-200	42	5	0.11	0.28	10	0.24	0.22
200-300	5	2	0.15	0.39	3	0.60	0.55
	446	142			400		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	21	0.21	0.46	38	0.39	0.24
6	107	23	0.21	0.44	58	0.54	0.33
5	145	64	0.44	0.94	187	1.28	0.77
4	32	15	0.47	1.00	68	1.66	1.00
3	40	17	0.43	0.91	45	1.13	0.68
2	13	2	0.13	0.28	4	0.27	0.16
1	11	0	0.00	0.00	0	0.00	0.00
	446	142			400		

Table 6.1 Habitat suitability data: Ephemeridae

Taxon	*Heptagenia sulphurea*				*Heptagenia lateralis*		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	0	0.00	0.00	0	0.00	0.00
10-25	64	8	0.13	0.26	3	0.05	0.38
25-50	146	29	0.20	0.40	19	0.13	1.00
50-100	148	43	0.29	0.58	16	0.11	0.85
>100	52	26	0.50	1.00	4	0.08	0.62
	446	106			42		
Depth							
0-25	180	30	0.16	0.41	22	0.12	1.00
25-50	157	44	0.28	0.72	14	0.09	0.75
50-100	62	24	0.39	1.00	5	0.08	0.67
100-200	42	7	0.17	0.44	1	0.02	0.17
200-300	5	1	0.20	0.51	0	0.00	0.00
	446	106			42		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	29	0.30	0.91	6	0.06	0.21
6	107	35	0.33	1.00	30	0.28	1.00
5	145	30	0.21	0.63	6	0.04	0.14
4	32	5	0.16	0.48	0	0.00	0.00
3	40	7	0.18	0.55	0	0.00	0.00
2	13	0	0.00	0.00	0	0.00	0.00
1	11	0	0.00	0.00	0	0.00	0.00
	446	106			42		

Table 6.2: Habitat suitability data: Heptagenia

Taxon	*Rhithrogena semicolorata*				*Habrophlebia fusca*		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	3	0.08	0.11	7	0.19	0.61
10-25	64	22	0.34	0.45	20	0.31	1.00
25-50	146	67	0.46	0.61	32	0.22	0.71
50-100	148	104	0.70	0.93	18	0.12	0.39
>100	52	39	0.75	1.00	6	0.12	0.39
	446				83		
Depth							
0-25	180	102	0.57	0.95	57	0.32	1.00
25-50	157	94	0.60	1.00	17	0.11	0.34
50-100	62	33	0.53	0.88	6	0.10	0.32
100-200	42	6	0.14	0.23	3	0.07	0.22
200-300	5	0	0.00	0.00	0	0.00	0.00
	446	235			83		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	86	0.88	1.00	11	0.11	0.41
6	107	82	0.77	0.88	13	0.12	0.44
5	145	53	0.37	0.42	39	0.27	1.00
4	32	9	0.28	0.32	7	0.22	0.81
3	40	5	0.13	0.15	8	0.20	0.74
2	13	0	0.00	0.00	3	0.23	0.85
1	11	0	0.00	0.00	2	0.18	0.67
	446	235			83		

Table 6.3: Habitat suitability data: Rhithrogena semicolorata, Habrophlebia fusca

Taxon	*Leuctra inermis*				Leuctridae		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	1	0.03	0.08	5	0.14	0.08
10-25	64	9	0.14	0.38	56	0.88	0.53
25-50	146	44	0.30	0.81	219	1.50	0.90
50-100	148	50	0.35	0.95	245	1.66	1.00
>100	52	19	0.37	1.00	83	1.60	0.96
	446	123			608		
Depth							
0-25	180	61	0.34	1.00	313	1.74	1.00
25-50	157	45	0.29	0.71	214	1.36	0.78
50-100	62	15	0.24	0.71	71	1.15	0.66
100-200	42	2	0.04	0.12	10	0.24	0.14
200-300	5	0	0.00	0.00	0	0.00	0.00
	446	123			608		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	55	0.56	1.00	257	2.62	1.00
6	107	55	0.51	0.91	277	2.59	0.99
5	145	13	0.09	0.16	74	0.51	0.20
4	32	0	0.00	0.00	0	0.00	0.00
3	40	0	0.00	0.00	0	0.00	0.00
2	13	0	0.00	0.00	0	0.00	0.00
1	11	0	0.00	0.00	0	0.00	0.00
	446	123			608		

Table 6.4: Habitat suitability data: Leuctra inermis, Leuctridae

Taxon	Chloroperlidae				Chloroperlidae		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	3	0.08	0.17	6	0.17	0.18
10-25	64	17	0.27	0.59	31	0.48	0.52
25-50	146	48	0.33	0.72	111	0.76	0.82
50-100	148	68	0.46	1.00	137	0.93	1.00
>100	52	21	0.40	0.87	40	0.78	0.84
	446	157			325		
Depth							
0-25	180	72	0.40	1.00	162	0.90	1.00
25-50	157	59	0.37	0.93	119	0.76	0.84
50-100	62	21	0.34	0.83	36	0.58	0.64
100-200	42	5	0.12	0.30	8	0.19	0.20
200-300	5	0	0.00	0.00	0	0.00	0.00
	446	157			325		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	52	0.53	0.84	101	1.03	0.72
6	107	67	0.63	1.00	154	1.44	1.00
5	145	32	0.22	0.35	61	42.00	0.29
4	32	4	0.13	0.21	5	16.00	0.11
3	40	1	0.03	0.05	2	0.05	0.03
2	13	1	0.08	0.13	2	0.15	0.10
1	11	0	0.00	0.00	0	0.00	0.00
	446	157			325		

Table 6.5: Habitat suitability data: Chloroperlidae

Taxon	Sericostomatidae				Sericostomatidae		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	7	0.19	0.33	24	0.67	0.44
10-25	64	28	0.44	0.76	87	1.36	0.89
25-50	146	58	0.40	0.69	184	1.26	0.83
50-100	148	76	0.51	0.88	225	1.52	1.00
>100	52	30	0.58	1.00	75	1.44	0.95
	446	199			595		
Depth							
0-25	180	97	0.54	1.00	304	1.69	1.00
25-50	157	81	0.51	0.94	238	1.51	0.89
50-100	62	17	0.27	0.50	36	0.58	0.34
100-200	42	4	0.09	0.17	17	0.37	0.22
200-300	5	0	0.00	0.00	0	0.00	0.00
	446	199			595		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	50	0.51	0.93	109	1.11	0.67
6	107	59	0.55	1.00	178	1.66	1.00
5	145	63	0.44	0.83	217	1.50	0.90
4	32	17	0.53	0.96	53	1.66	1.00
3	40	9	0.23	0.42	37	0.93	0.56
2	13	1	0.08	0.13	1	0.08	0.05
1	11	0	0.00	0.00	0	0.00	0.00
	446	199			595		

Table 6.6: Habitat suitability data: Sericostomatidae

Taxon	*Crangonyx pseudogracilis*				*Gammarus pulex*		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	24	0.67	1.00	26	0.72	0.82
10-25	64	20	0.31	0.46	56	0.88	1.00
25-50	146	21	0.14	0.21	115	0.79	0.90
50-100	148	21	0.14	0.21	104	0.71	0.81
>100	52	14	0.27	0.40	37	0.71	0.81
	446	100			338		
Depth							
0-25	180	24	0.13	0.16	150	0.83	1.00
25-50	157	32	0.20	0.25	116	0.73	0.88
50-100	62	13	0.21	0.80	40	0.65	0.78
100-200	42	27	0.64	1.00	28	0.67	0.81
200-300	5	4	0.80		4	0.80	0.96
	446	100			338		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	7	0.07	0.09	54	0.55	0.55
6	107	9	0.08	0.10	71	0.66	0.66
5	145	41	0.28	0.36	127	0.88	0.88
4	32	10	0.31	0.40	28	0.88	0.88
3	40	15	0.38	0.49	40	1.00	1.00
2	13	10	0.77	1.00	12	0.92	0.92
1	11	8	0.73	0.95	6	0.55	0.55
	446	100			338		

Table 6.7: Habitat suitability data: Crangonyx pseudogracilis, Gammarus pulex

Taxon	Gammaridae				Gammaridae		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	32	0.88	0.96	184	5.10	0.93
10-25	64	59	0.92	1.00	340	5.30	0.96
25-50	146	116	0.79	0.86	803	5.50	1.00
50-100	148	107	0.73	0.79	612	4.10	0.75
>100	52	43	0.83	0.90	247	4.80	0.87
	446	357			2186		
Depth							
0-25	180	154	0.86	0.86	928	5.20	0.44
25-50	157	120	0.76	0.76	811	5.20	0.44
50-100	62	46	0.74	0.74	238	3.90	0.33
100-200	42	32	0.76	0.76	150	3.30	0.28
200-300	5	5	1.00	1.00	59	11.80	1.00
	446	357			2186		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	58	0.59	0.59	210	0.55	0.55
6	107	73	0.68	0.68	331	3.09	0.40
5	145	133	0.92	0.92	1130	7.79	1.00
4	32	31	0.97	0.97	165	5.16	0.66
3	40	40	1.00	1.00	226	5.65	0.75
2	13	13	1.00	1.00	82	6.30	0.85
1	11	9	0.82	0.82	42	3.82	0.49
	446	357			2186		

Table 6.8: Habitat suitability data: Gammaridae

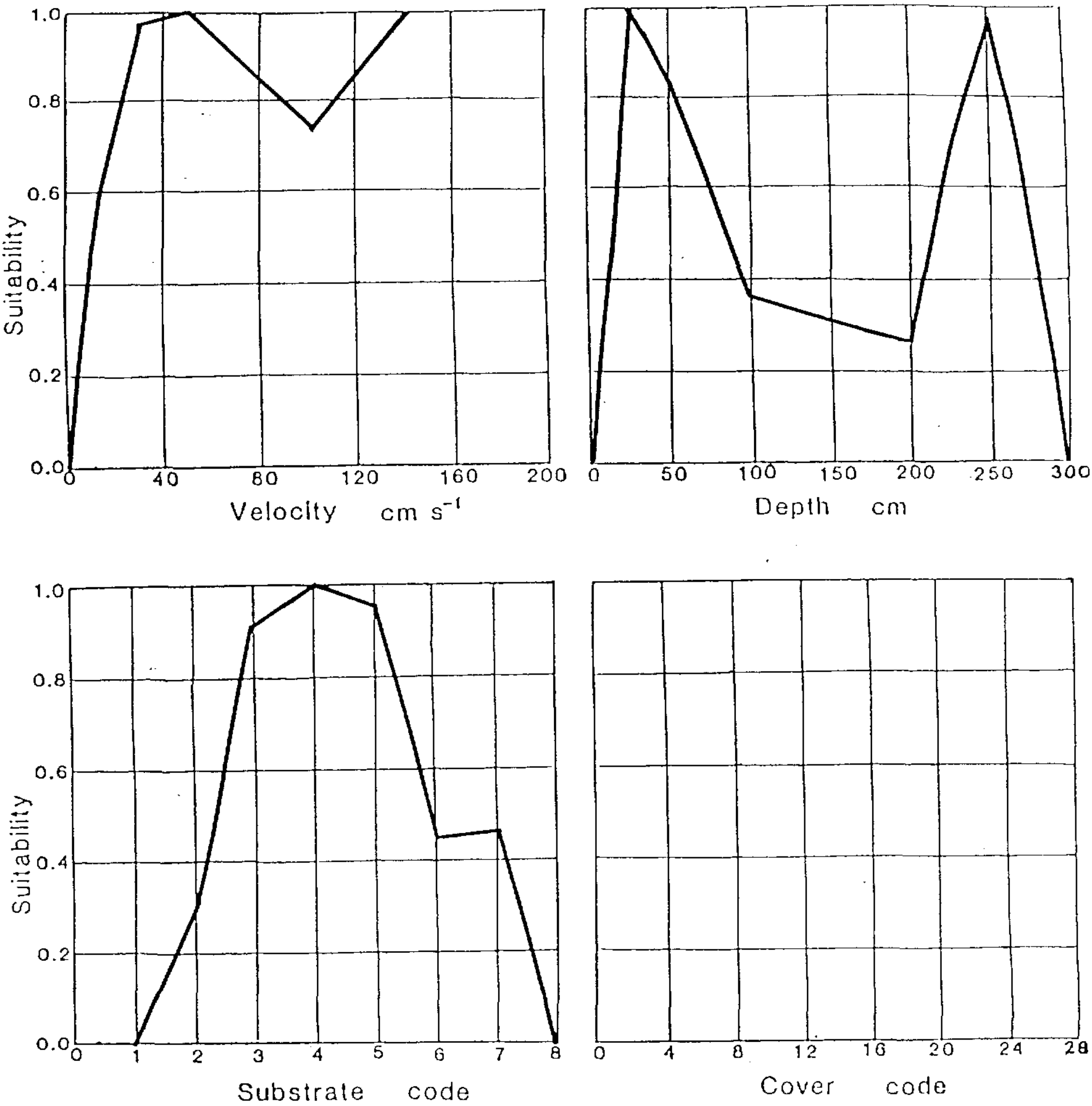


Figure 6.1: Habitat suitability curves: Ephemeridae occurence

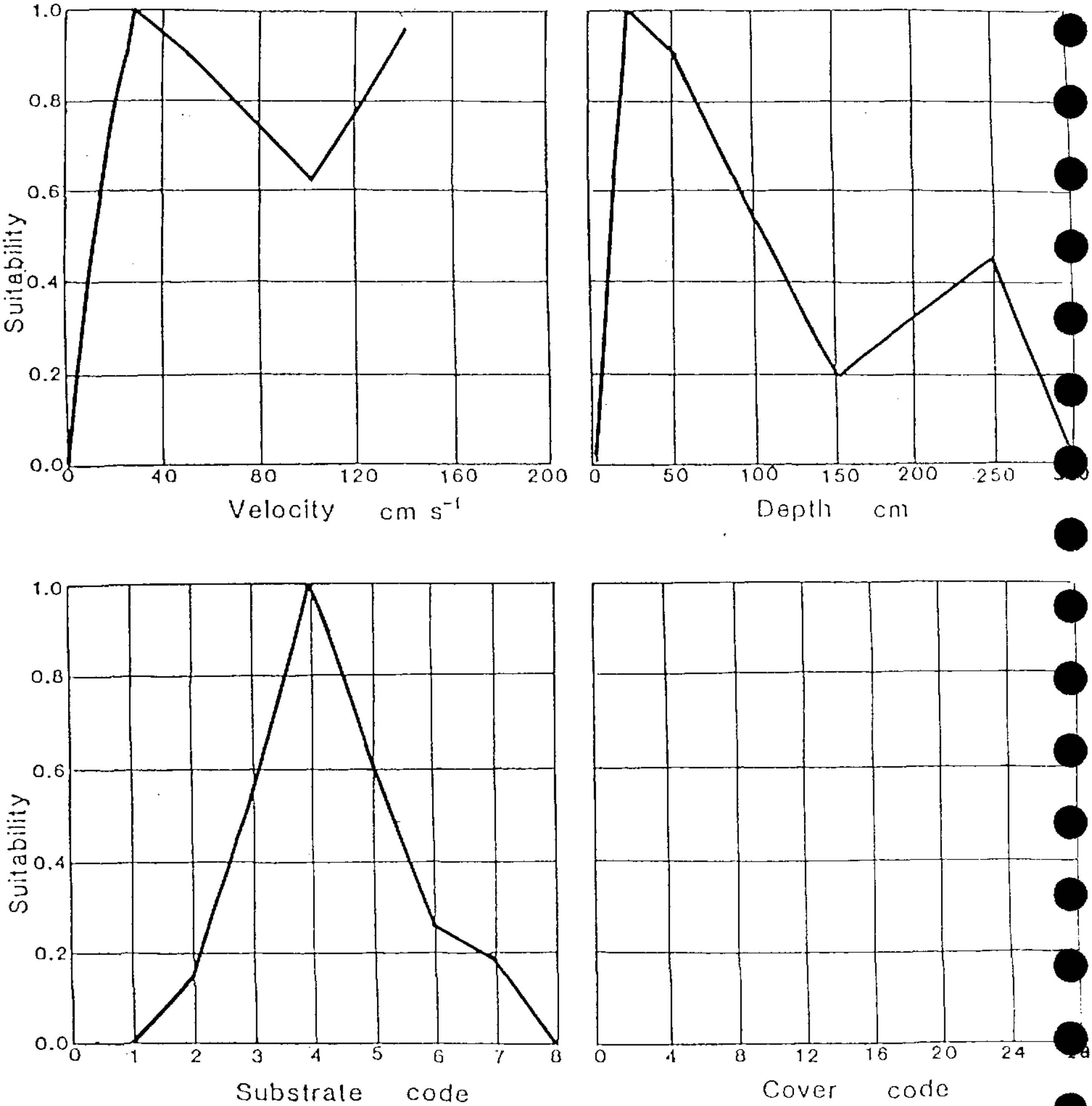


Figure 6.2: Habitat suitability curves: Ephemeridae abundance

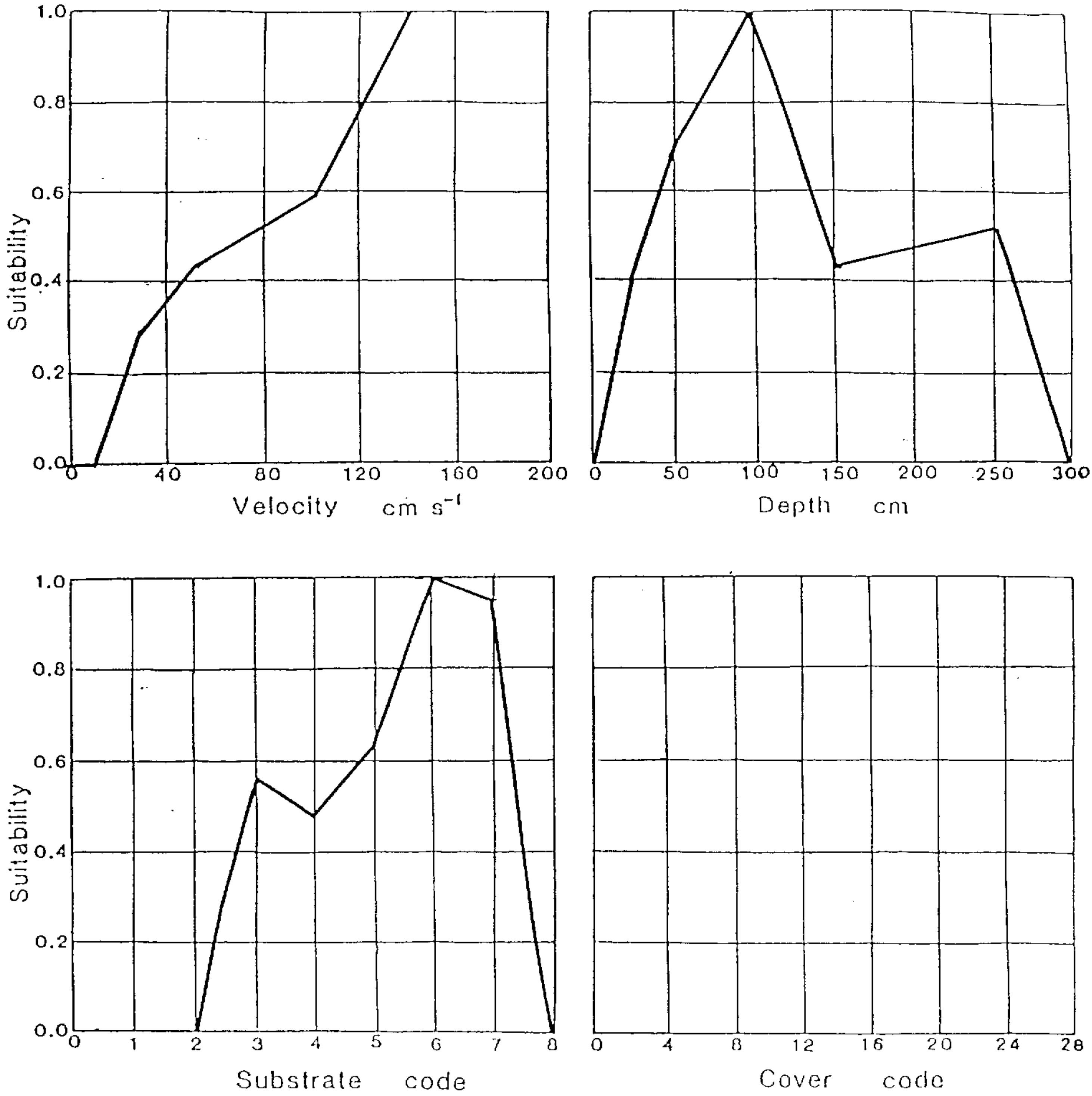


Figure 6.3: Habitat suitability curves: Heptagenia sulphurea occurence

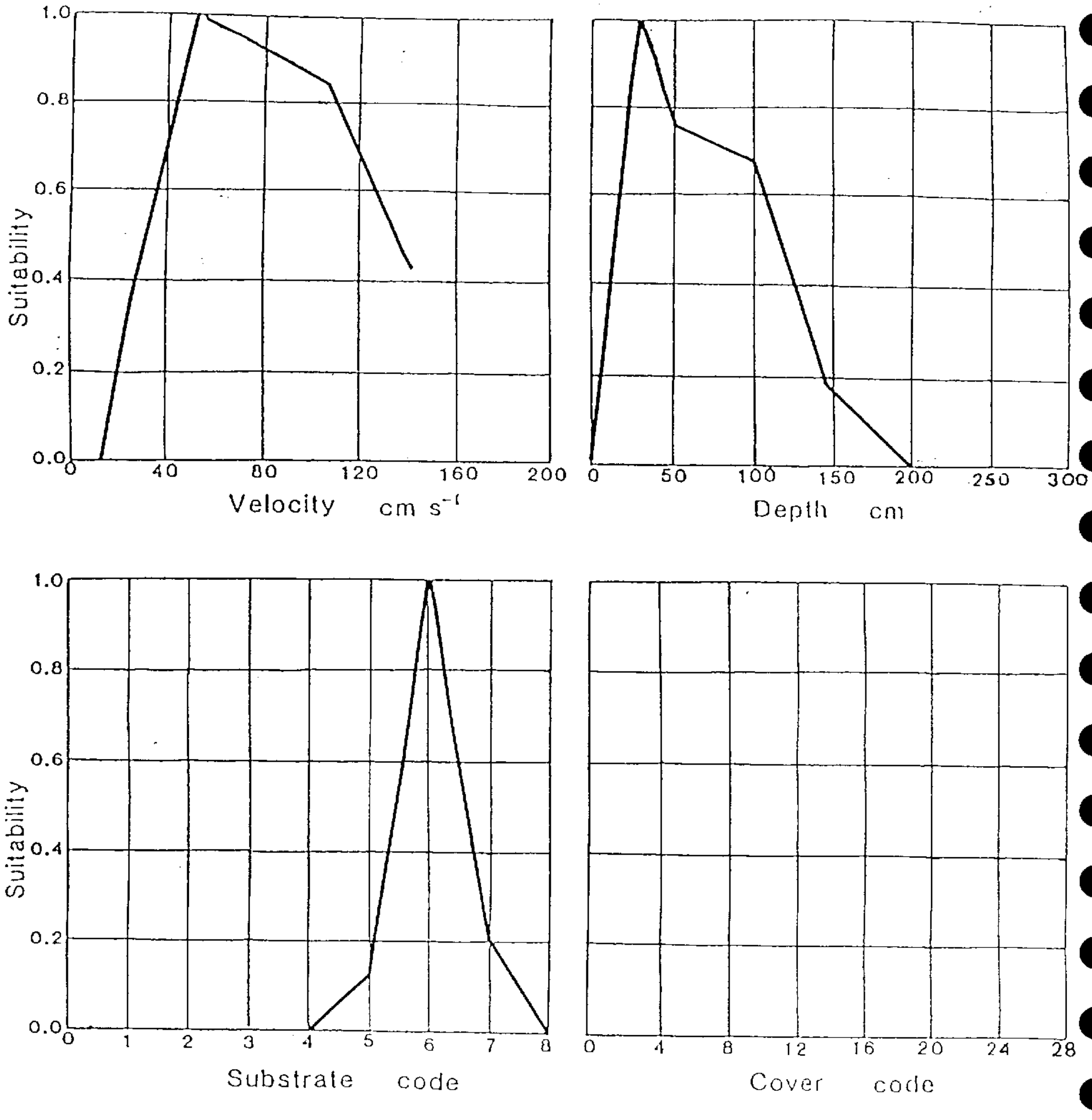


Figure 6.4: Habitat suitability curves: Heptagenia lateralis occurence

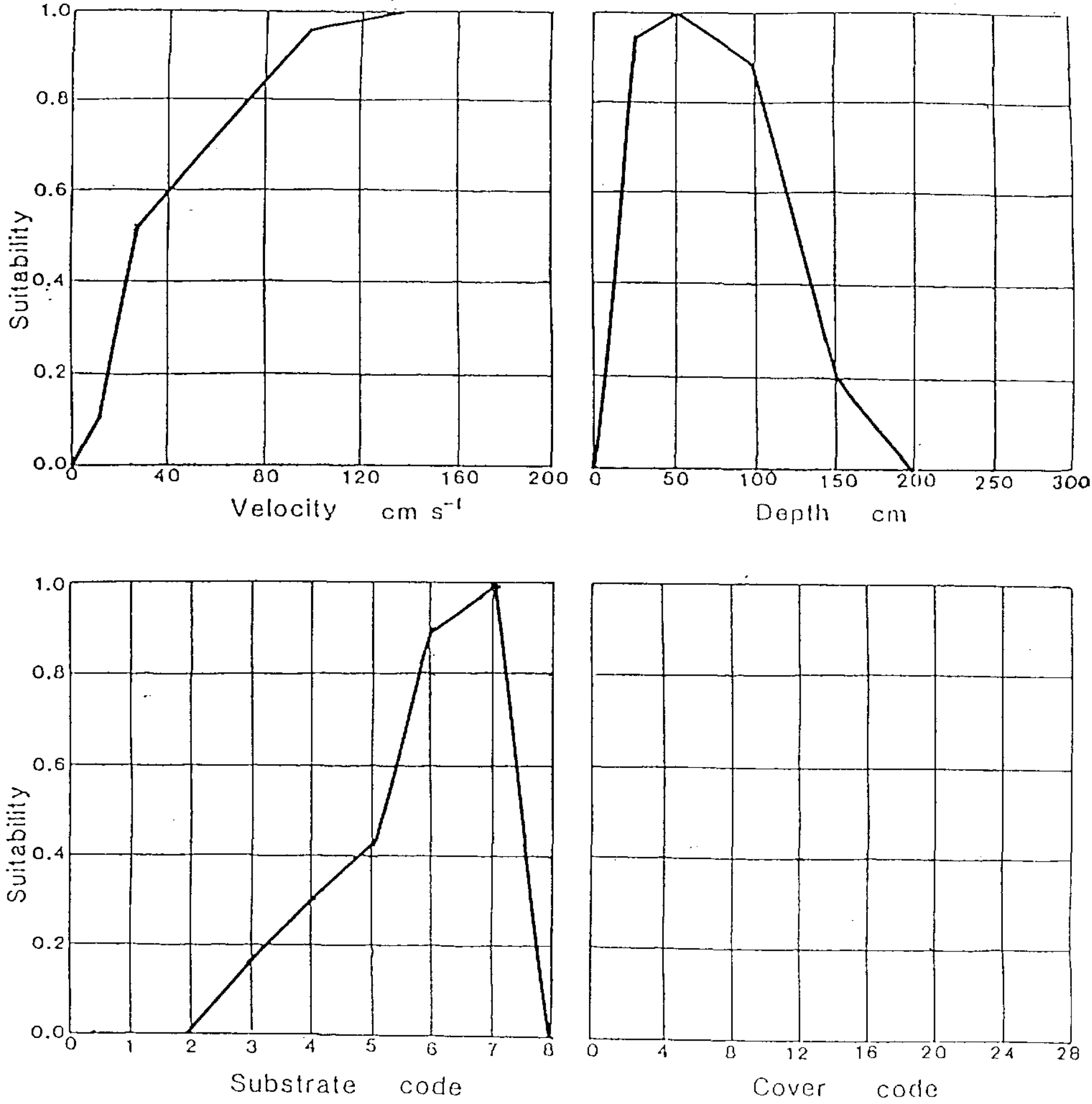


Figure 6.5: Habitat suitability curves: Rhithrogena semicolorata occurrence

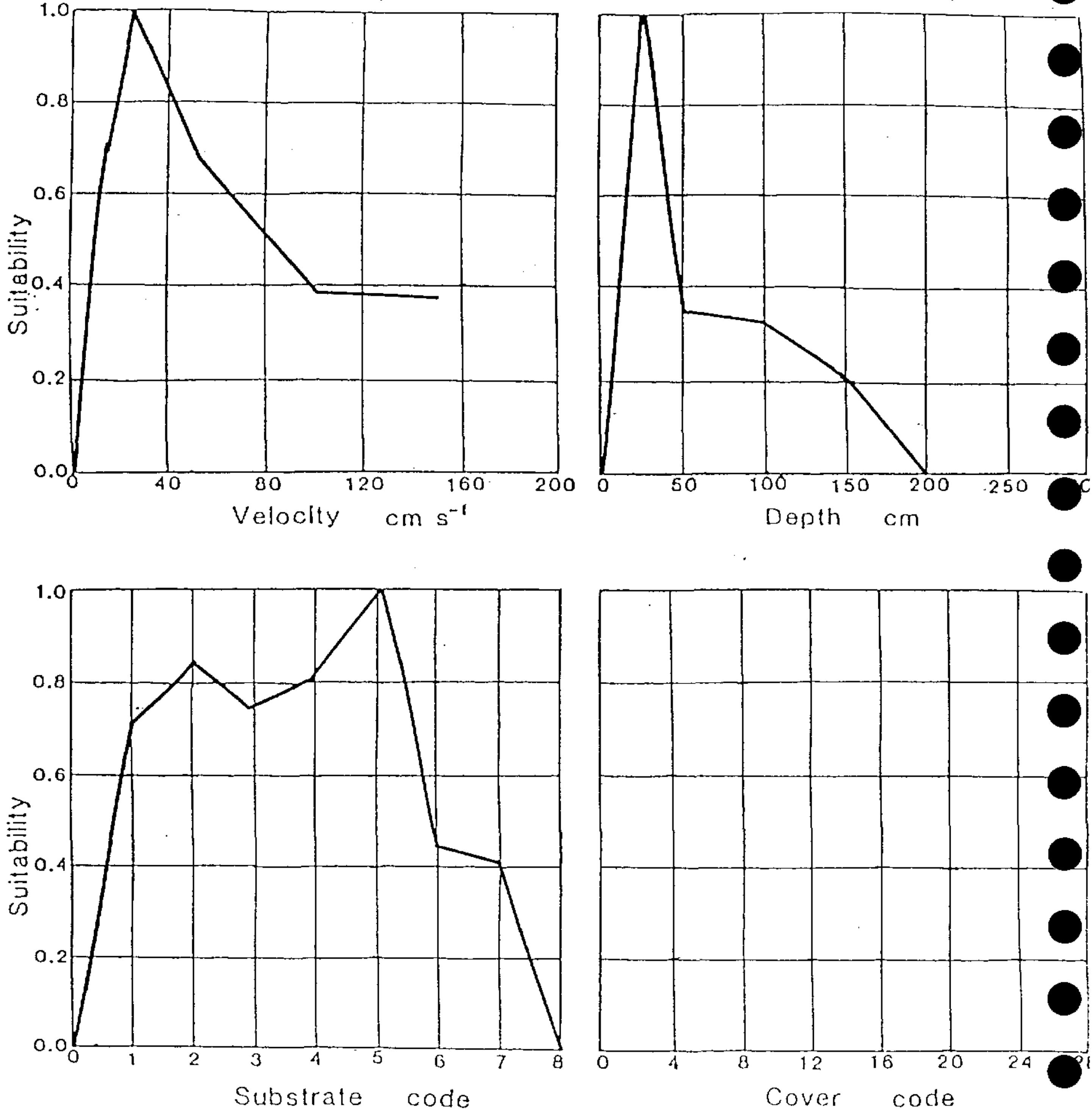


Figure 6.6: Habitat suitability curves: Haberophlebia Fusca occurrence

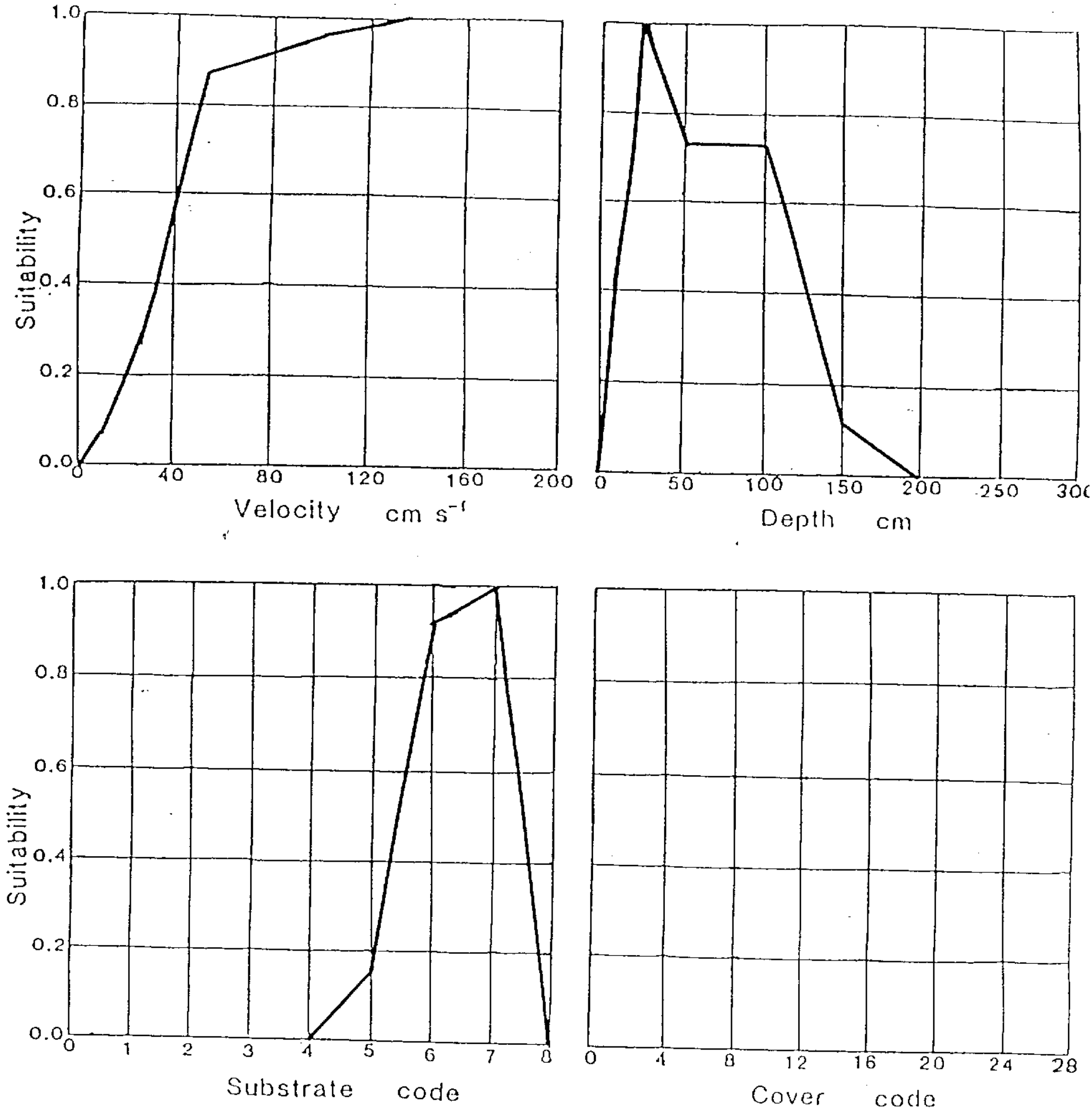


Figure 6.7: Habitat suitability curves: Leuctra Inermis occurrence

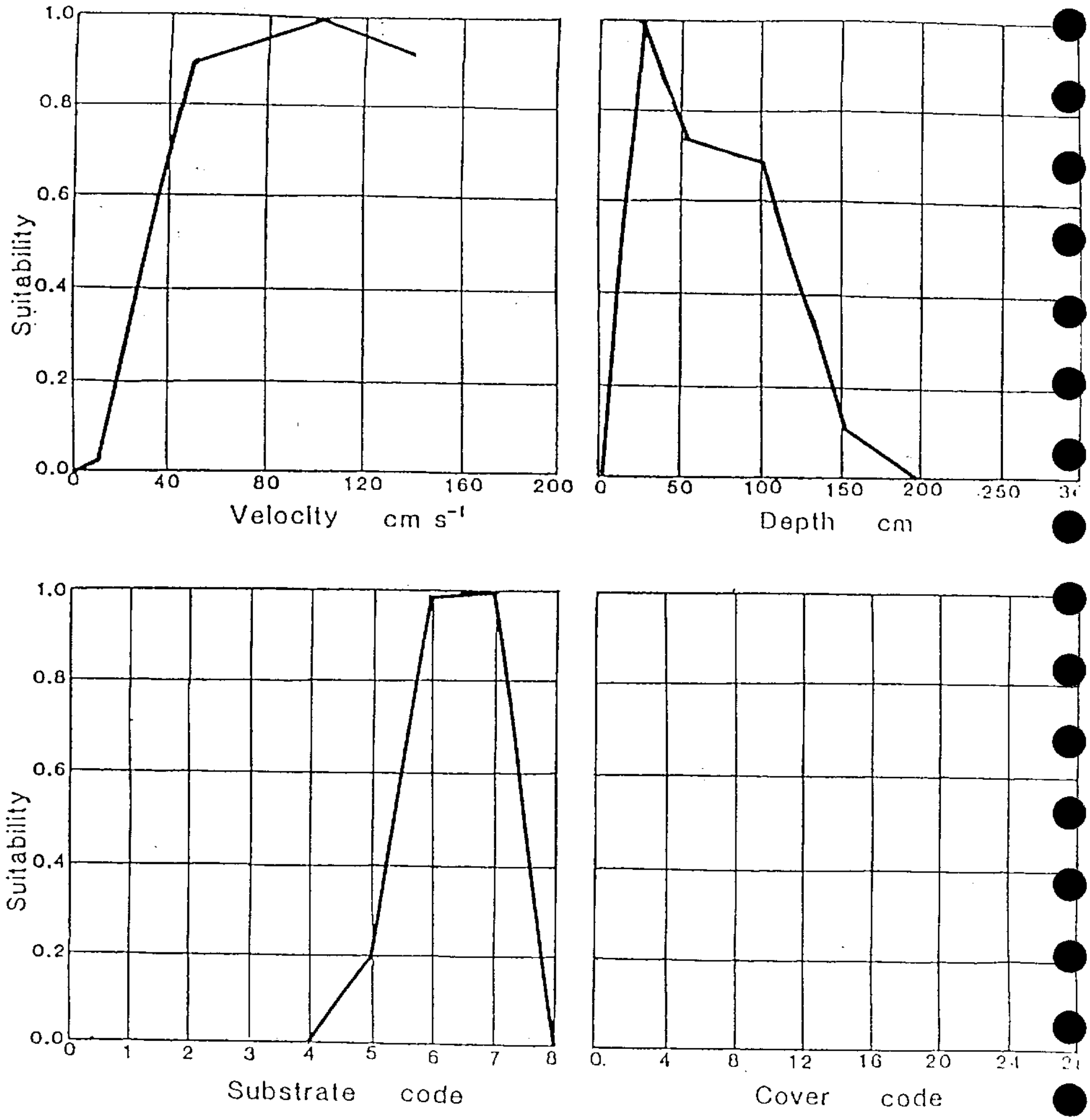


Figure 6.8: Habitat suitability curves: Leuctridae abundance

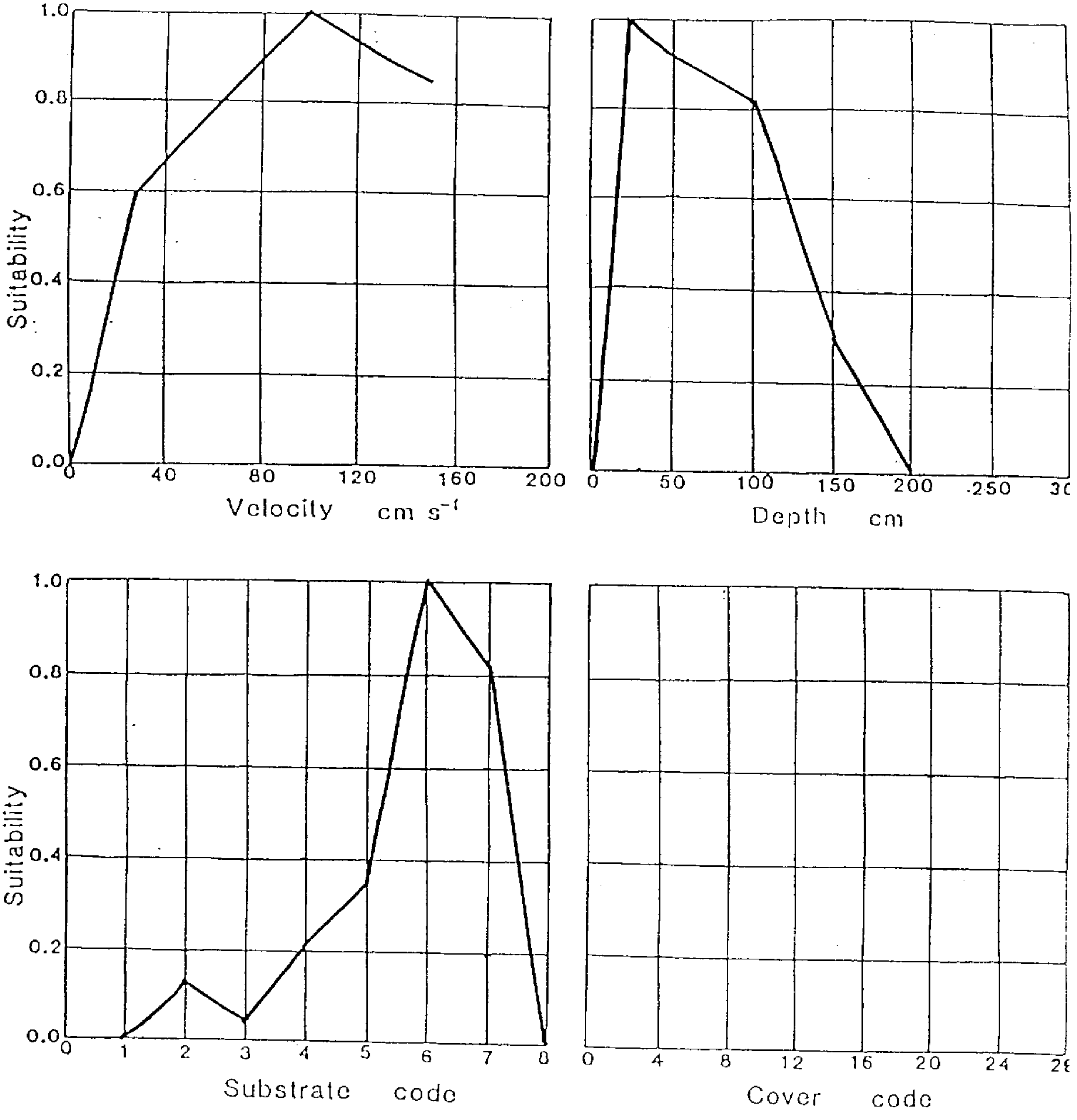


Figure 6.9: Habitat suitability curves: Chloroperlidae occurrence

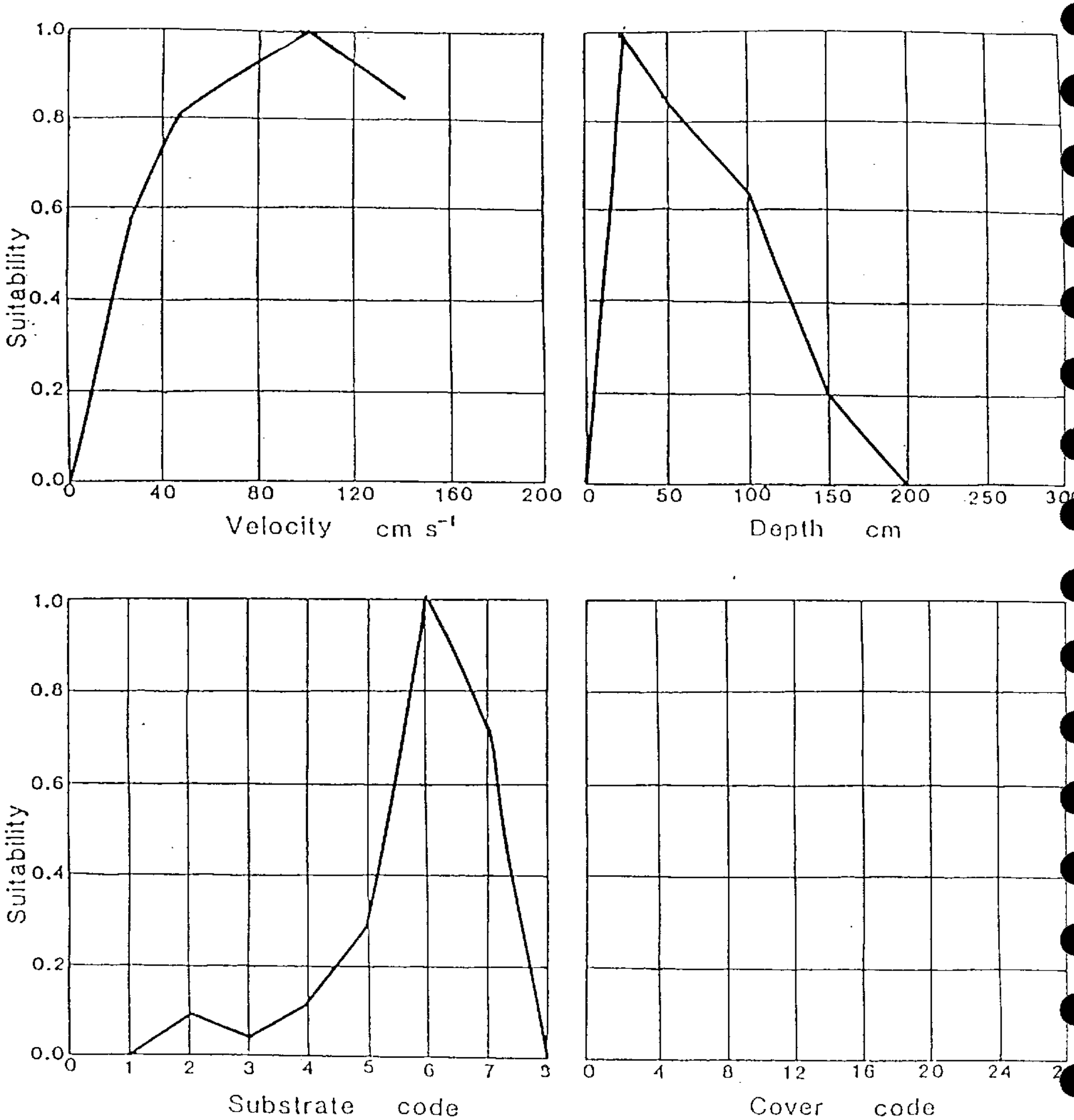


Figure 6.10: ***Habitat suitability curves: Chloroperlidae abundance***

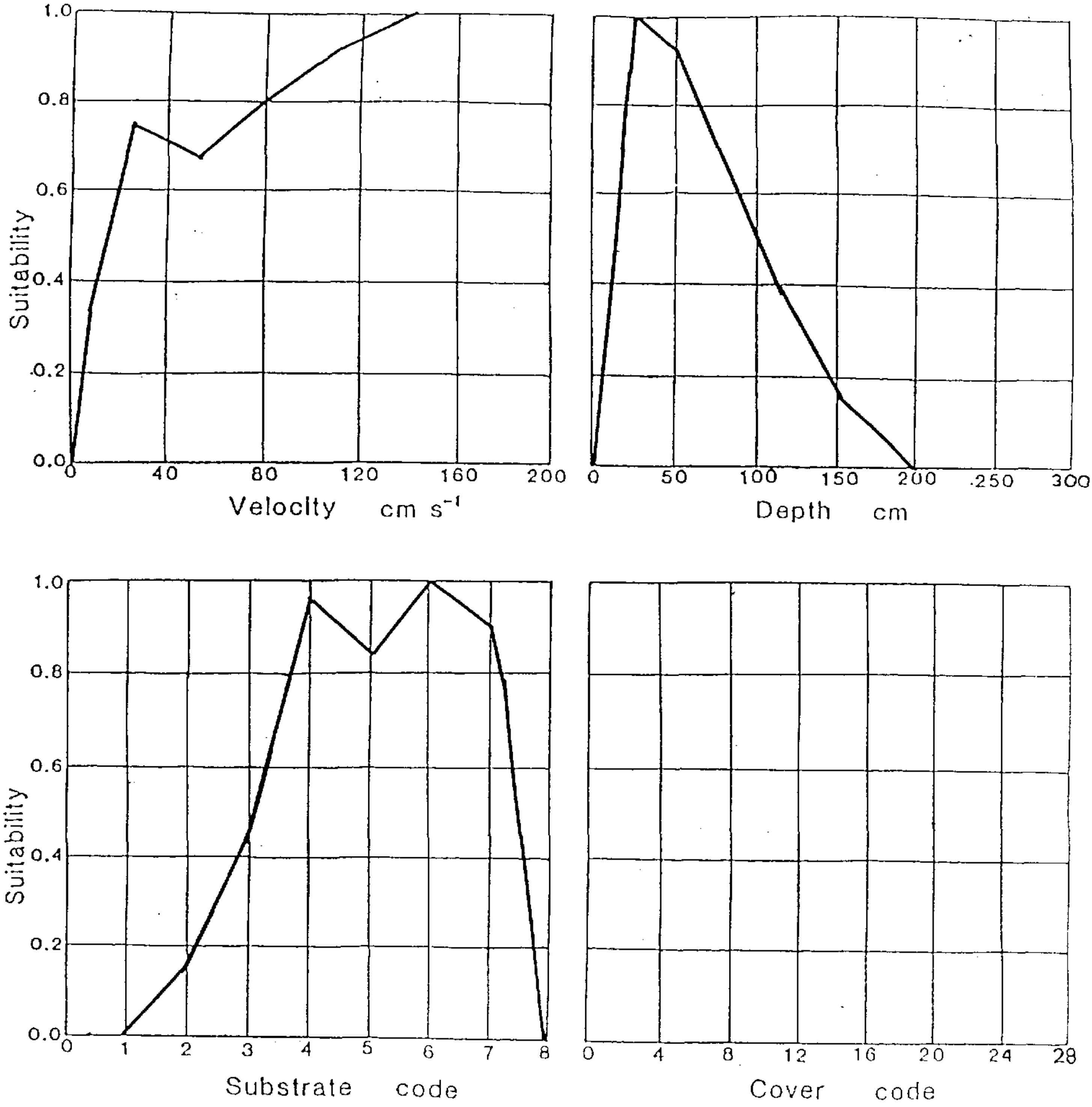


Figure 6.11: ***Habitat suitability curves: Sericostomatidae occurrence***

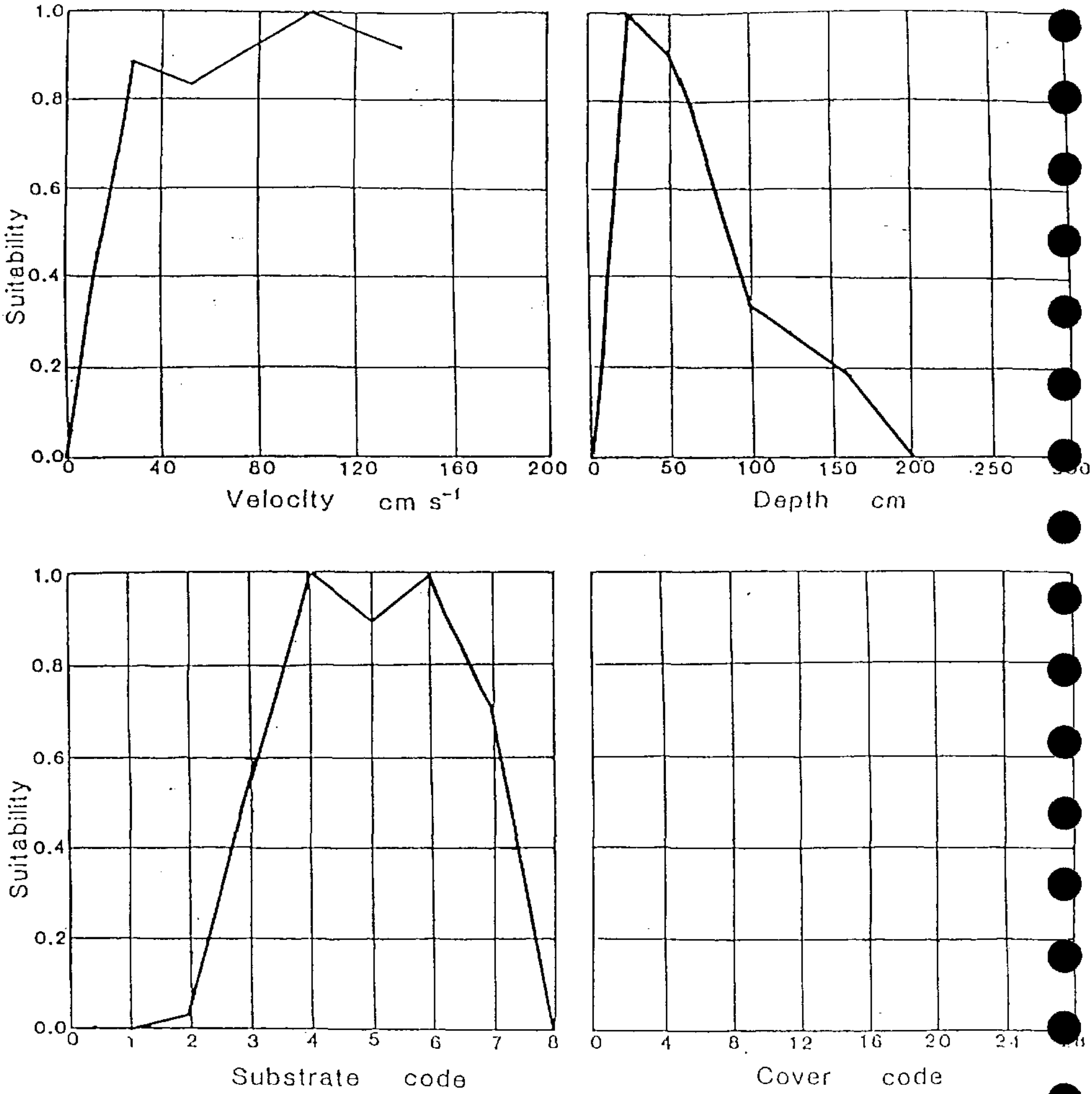


Figure 6.12: ***Habitat suitability curves: Sericostomatidae abundance***

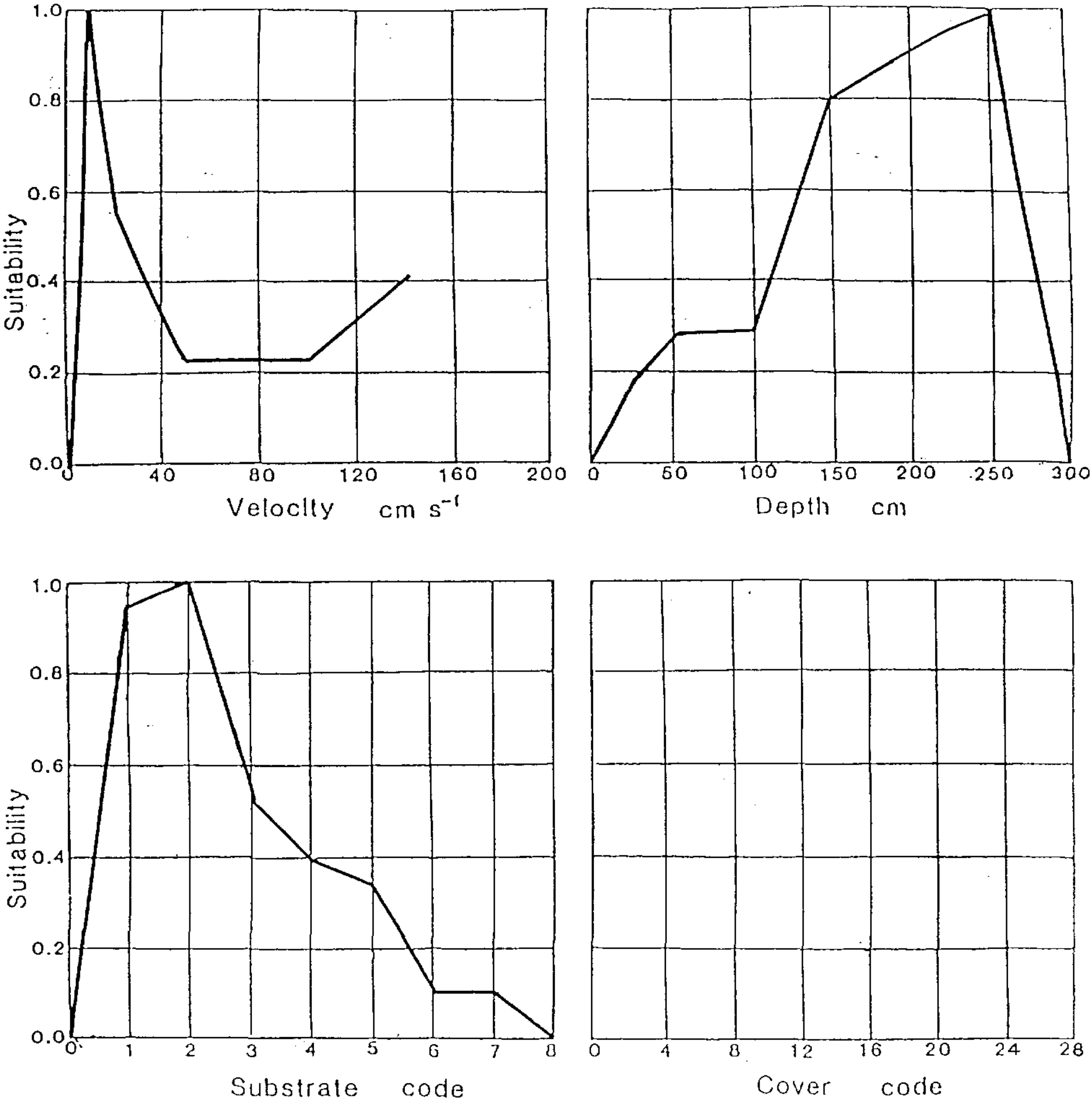


Figure 6.13: Habitat suitability curves: Crangonyx Pseudogracilis occurrence

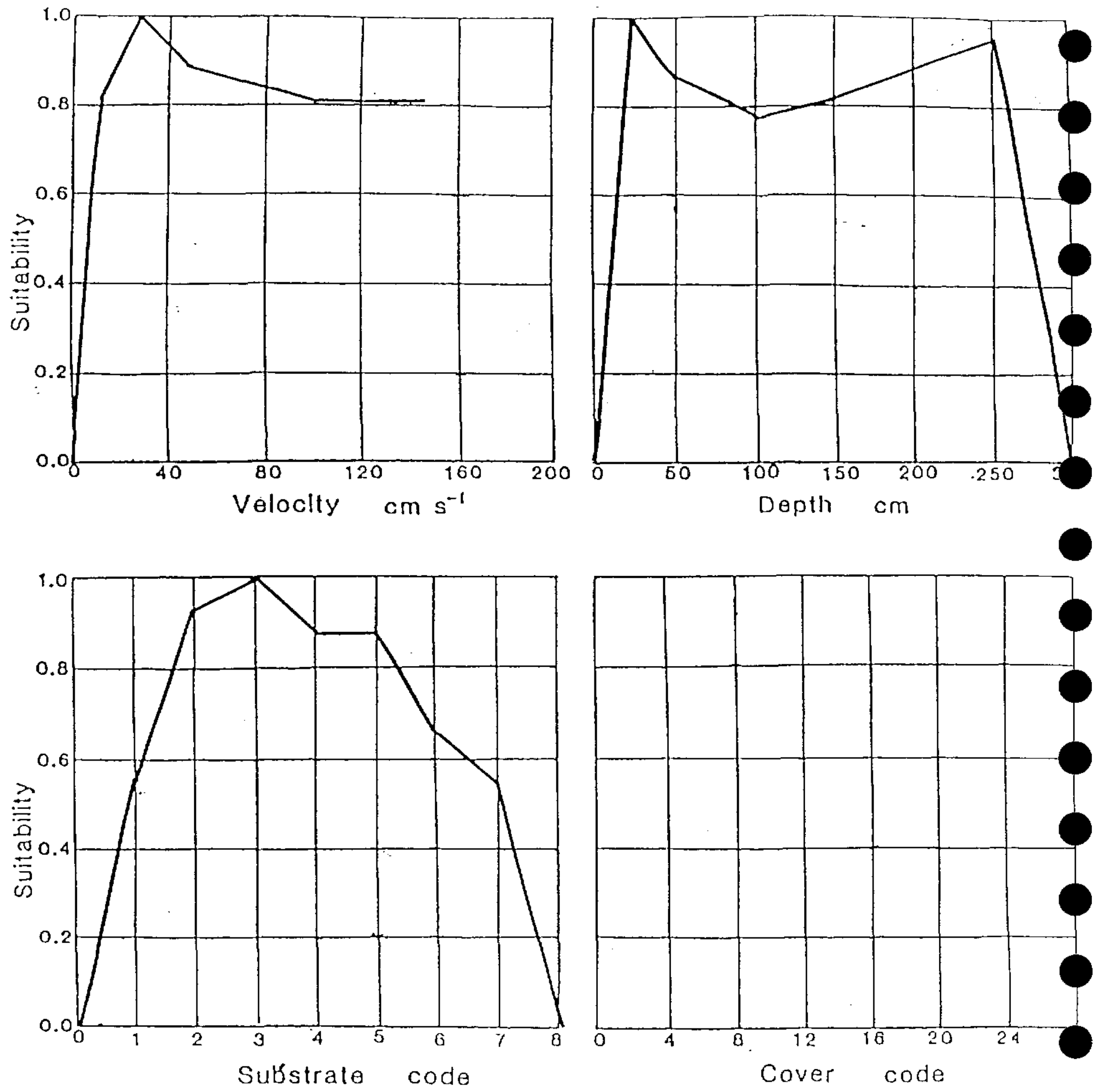


Figure 6.14: ***Habitat suitability curves: Gammarus pulex occurrence***

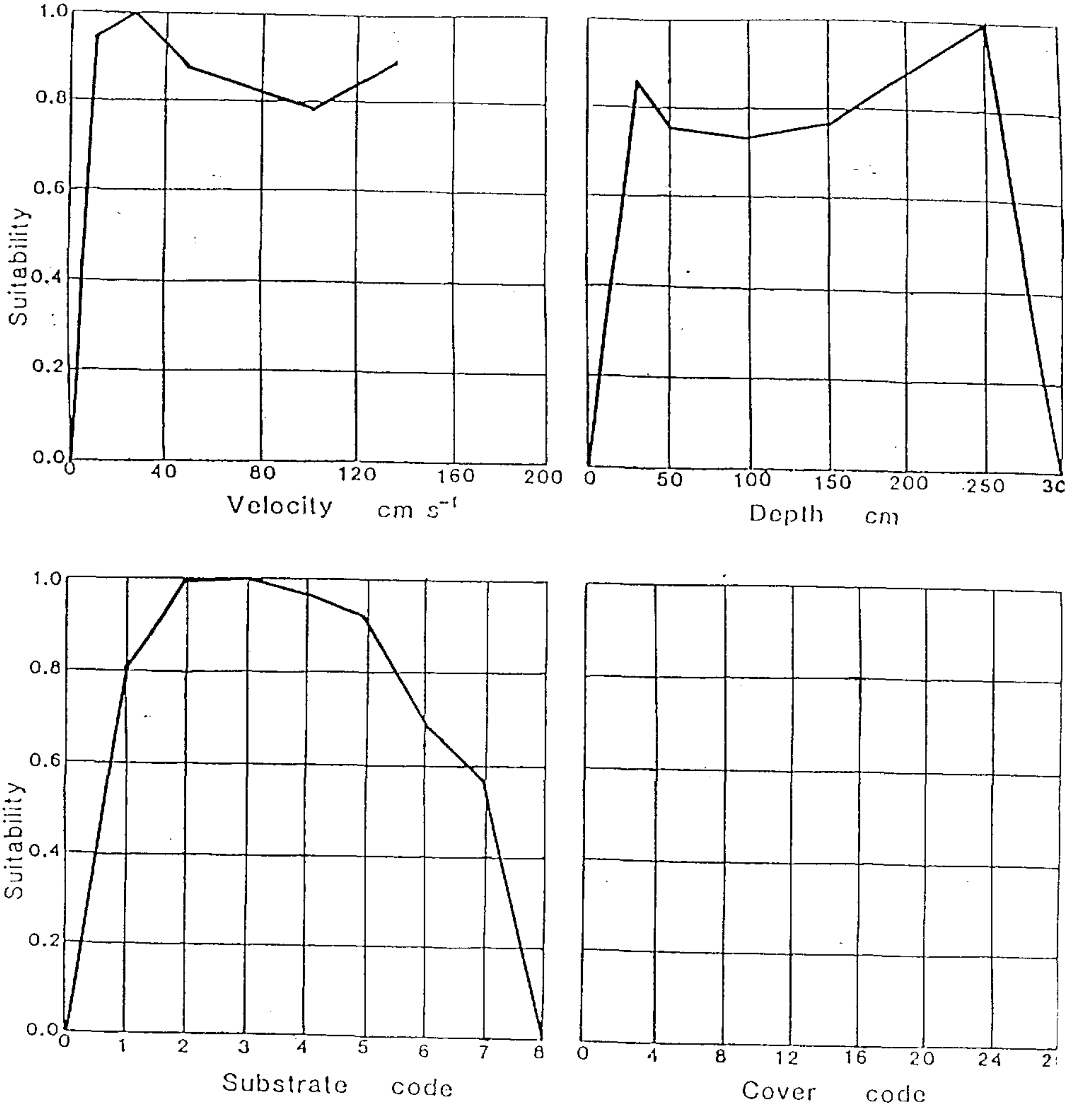


Figure 6.15: Habitat suitability curves: Gammaridae occurrence

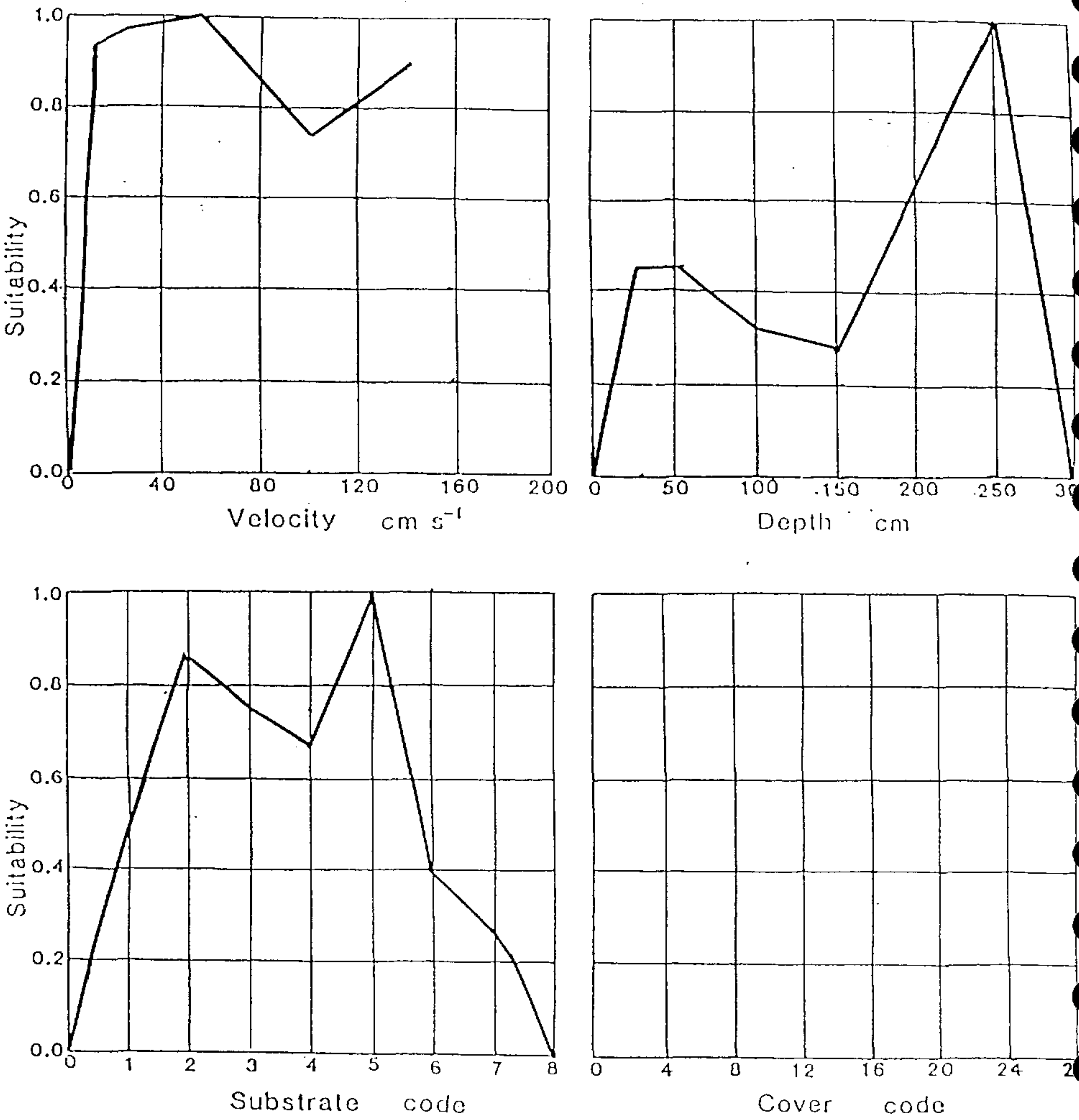


Figure 6.16: Habitat suitability curves: Gammaridae abundance

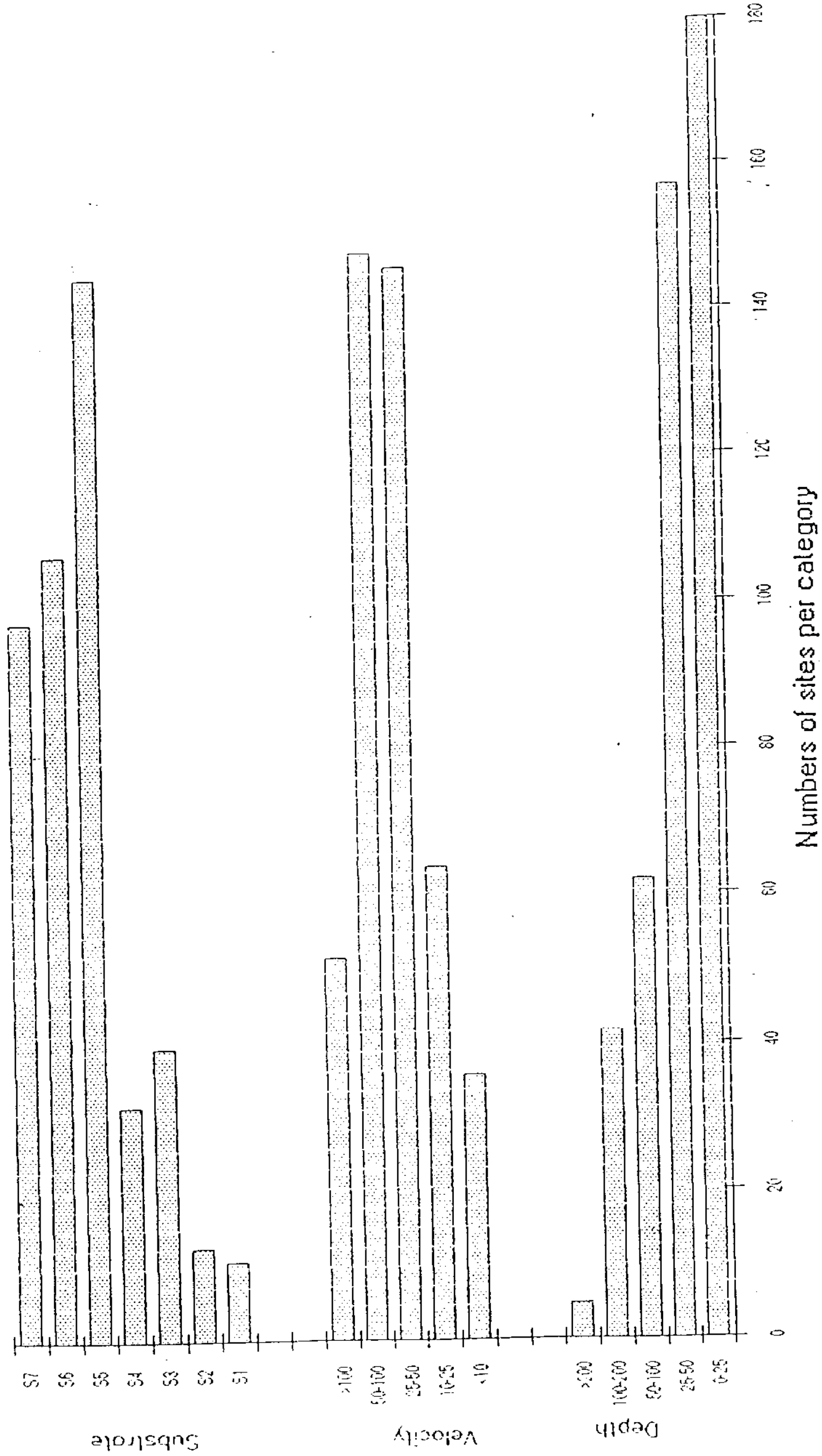


Figure 6.17: ***The distribution of the 446 sites in categories of velocity, depth, and substrate.***

b) Fish Habitat Preference Curves

Rationale

Selection of target fish species for preference curve construction presents a number of problems. In Britain there are three cyclostomes (lampreys) and more than thirty bony fishes which occur in fresh waters, of the latter only about twenty occur in running waters for substantial parts of their lives. Only the trout (which may be anadromous feeding in the sea and spawning in rivers), the eel (catadromous feeding in rivers and spawning in the sea), grayling, barbel, chub, dace, stone loach and bullhead are truly running water species. Pike, gudgeon, silver bream, bleak, bronze bream, minnow, roach, rudd, perch, ruffe, zander, and three spined stickleback occur in both still and running waters.

Stone loach, bullhead, gudgeon, bleak, minnow, ruffe and three spined stickleback are small and of little angling interest. Barbel, silver bream and zander are of fairly restricted distribution and, together with rudd are unlikely to occur in many of the PHABSIM test rivers. The remaining species are all worthy of consideration as target species.

Brown trout - Trout is probably the best documented river fish species and must really be included because of its territorial behaviour, wide distribution, high level of angling interest and strong data base. Having said this it is unfortunate that trout are widely and indiscriminately stocked so that distributions could in some instances be very misleading.***

Eel - Eel is possibly the most widespread and abundant species in the list. Because eels are catadromous in nature breeding and the first three years of larval life take place in salt water so that only the immature and early adult stages would provide information applicable to PHABSIM, probably not a satisfactory situation.*

Grayling - Grayling is a shoaling fish with much in its favour from the point of view of the present study. However, the distribution of the fish is patchy and it may be absent from many of the study sites. In addition grayling, like trout, is subject to management (usually intensive removal) and may thus be unsatisfactory.**

Chub - Chub is a river fish with a tendency to form shoals and has a wide distribution. Documentation of immature and adult stages is quite good but there may be little information about spawning and fry stages.**

Dace - Dace has much in common with chub, to which it is quite closely related. Dace is also a shoaling species and being smaller tends to be rather more numerous and possibly to penetrate into rather smaller watercourses. Documentation of the spawning requirements for dace is good. Probably a good choice of target species.***

Pike - Pike is a predator with a wide distribution and a good basis of knowledge regarding habits and habitat. The fish are relatively large and easy to catch by electro-fishing. Pike are heavily managed in many waters by intensive culling and removal, in others they are popular with coarse anglers and because of this it may not be the best choice for the present study.**

Bronze bream - Bronze bream is a fish strongly favoured by slow flows and is widespread in still waters. There is information regarding the various life stages of the fish because in Europe bream is farmed as food. Bream will certainly be present in some of the study rivers but may not be sufficiently widespread to be a useful target species.*

Roach - Roach is the most sought after angling species and is present in the majority of still and running waters. It is a shoaling species and is likely to provide a good contrast to trout and dace (which it resembles in some respects) with regard to its habitat preferences in some life stages. The various life stages of roach have been studied to differing degrees but there is likely to be adequate information for this study.***

Perch - Perch is a species which has been studied in great detail and in fact has provided the basis for major models of fish population dynamics, it is a popular angling fish and is widespread but, although perch live in many rivers they are most abundant in still waters and may be scarce in many running water situations. Probably not a suitable target species.**

On the basis of the above criteria together with the known and anticipated probabilities of occurrence of the species in the sites selected for the present study trout, dace and roach have been chosen as the target fish.

In addition to the factors outlined consideration has been given to the contrasting characteristics of the species in relation to their spatial and temporal requirements. For example, the brown trout differs from the others in being a salmonid which is territorial and frequently non-shoaling in its behaviour whereas both dace and roach are normally found in shoals of various sizes. The life stages will be considered in turn, with particular reference to features of the physical habitat which are known to influence behaviour or "ecological fitness" of life stages.

Spawning

It is probable that the spawning strategies of some fish species are flexible in terms of the relationship between egg numbers and egg size. This should be borne in mind when attempting to generalise about factors influencing survival of the early stages.

The eggs of the trout are relatively large, few in number and are deposited, in early winter, within shallow redds formed in gravel having an interstitial throughflow of water. The eggs develop slowly over a period of one to three months, this makes their development particularly susceptible to clogging of gravel interstices by fine sediment in the event of catchment erosion or reduced winter flows.

The dace also spawns on gravels in shallow water but the small eggs adhere to the surface of stones and are laid in springtime. The eggs develop quickly but may suffer heavy mortalities, during their development, in the event of redistribution of fine sediment (onto the spawning gravels) by spates. Presumably mortality would also occur if flash floods disturbed the spawning areas.

Roach spawn in late spring to early summer and the eggs are normally laid on macrophytes, including mosses and macrophytic algae. This species appears to be capable of successful spawning in either still water conditions or in very fast flowing water, the latter normally being selected in stream and river situations. The eggs adhere to plants and, as in the dace, develop over a few days (the period is, of course, strongly temperature dependent). It has been noted that sudden reductions in water level, such as may occur after weed cutting or flow diversion, can result in heavy mortality.

Fry

Trout fry live (at first) within the river bed in shallow, well aerated, flowing water. The behaviour patterns and colouration are cryptic and the young fish depend on supplies of yolk for two to three weeks. Subsequently the fish (2.5 - 3.0 cm in length) establish small territories in shallow, flowing water. In general faster growing fry show better survival. At this stage in the life cycle, in the absence of catastrophic events, survival is probably mainly density dependent.

Hatched dace fry probably migrate passively, with the flow, from the shallow spawning regions to slower flowing marginal areas. Large numbers of dace fry have been found to occur, in May, in deep marginal slacks with masses of floating weed present. In June fry still occur in marginal areas but in slightly faster flowing areas devoid of weed. In early summer the fry may be vulnerable to rapid changes in discharge conditions and in cool water growth will be relatively slow and susceptibility to physical damage and/or predation consequently prolonged.

Being later to hatch than dace, roach fry, which tend to occur in similar marginal conditions, are generally smaller than the dace. Although the fry will be susceptible to similar factors the timing of events may be critical in selectively influencing the different species.

In general it may be that inter- and intra-specific competition for resources is of importance to success of a species in a given situation. Similarly predation by fish may result in interactions which exclude one species in the presence of another. In any analysis of physical habitat conditions such possibilities should never be ignored.

Juveniles/mature fish

It can be quite difficult to define the cut off points between juvenile fish and fry or mature fish. In general it is easiest to regard 0+ specimens as fry, although it is probable that critical changes in form and behaviour take place before the "first birthday". At the other extreme, although the transition from juvenile to mature fish is relatively clearly defined in terms of physiology, the criterion of maturity being reached at a certain size, which is often applied, does not take account of differences between the sexes.

Brown trout grow rapidly and mature quite quickly. In practice the mature fish are extremely tolerant and various phenotypes use a range of habitats from marine coastal waters through lakes, reservoirs and small still waters to rivers and small stony streams. The behaviour of the fish differs in these situations from small active shoals in the sea to strictly territorial individuals in running waters where the feeding stations may be defined by flow patterns and topographic details of the stream bed (lies) and there is a requirement for overhead cover (which may be utilised by more than one fish) in times of disturbance. It may be that the presence of shear zones is more important than velocity sensu-stricto for the establishment of feeding territories. Summer droughts have been demonstrated to have severe effects on 1+ parr but other factors exerted no significant influence.

Dace form feeding shoals in shallow, relatively fast flowing water over stony or gravelly river beds. They are strictly river fish at all stages of their lives although the juveniles and adults may survive for long periods in still water. The larger mature fish probably make use of a wider range of depths, velocities and substrata than the immatures and expert opinion suggests that overhead cover may be relevant to their distribution. The fish migrate actively to suitable spawning localities in the early part of the year.

As mentioned previously roach are able to sustain large populations in both still and running waters. In the latter they tend to favour deep, slow flowing, weedy situations except during the spawning period. There appears to be little published information regarding the importance of overhead cover but personal observations suggest that object cover in the form of submerged branches, roots or aquatic vegetation may be significant.

COMPATIBILITY OF NRA DATA

If the NRA are to use the PHABSIM model and wish to collect compatible *IFIM* data the procedures applied by IH and IFE in the present study will be required. For territorial species, such as the brown trout, spot measurements of velocities, depths, substrata and cover characteristics of individual lies may provide useful supplementary information. However, it should be borne in mind that, as it stands, PHABSIM simply provides a measure of the weighted usable area of suitable habitat for a given species in a surveyed reach and is NOT a method for assessing the stock of a species present. For stock generation/support potential, models such as HABSCORE, which correlate stock with habitat features over a limited range of stream types, will be required.

In view of the above it would seem to be important that a longitudinal survey of any catchment under consideration should be carried out, with assessment of the occurrence of essential features for all life stages AT THE APPROPRIATE SEASONS. Also, since no account is taken of biotic characteristics (presence of competitors or predators) or of water quality information, these should be incorporated in any study together with the known or supposed tolerances of target species. It should also be appreciated that habitat preference curves are invariably constructed on inadequate data, notably in relation to the diel variations in species habitat requirements. Lastly there will always be a risk of an unforseen factor (e.g. an impassable obstruction preventing upstream access) which is not incorporated in the model influencing the suitability of the system.

PREFERENCE CURVES

Data

SPECIES		spawn	fry	juv	adult
Trout	Vel cm/s	28-38	0-73	0-40	0-50
	Depth cm	12-37	5-25	20-40	20-40
	subst	5	5	5-6	5-6
	cover	0	0	0-28	0-28
Dace	Vel cm/s	15-100	0.02-0.25	15-35	20-70
	Depth cm	20-80	10-30	30-70	50-70
	Subst	5	1-5	4-5	3-5
	Cover	0	weed cover night	see HPC	see HPC
Roach	Vel cm/s	10-120	0-34	0-40	0-40
	Depth cm	10-50	10-100	40-150	50-200
	Subst	1	1-4	1-4	1-4
	Cover	0-2	weed	see HPC	see HPC

COMPATABILITY OF NRA DATA WITH ULTIMATE PHABSIM MODEL

The present study is designed to test the feasibility of applying PHABSIM technology to British rivers. In order to do this the habitat preferences of selected target fish species will be described in the form of habitat suitability curves, the information required to construct these curves is derived mostly from published studies and reports (references appended). Understandably, the availability of data for curve construction is very limited. In many cases the details were collected as information which was incidental to the study in question and were published as background. Because of this it is quite rare to find adequate descriptions of velocity, depth or substrate. Correlations of the above factors with life stages are scarce and worthwhile information on the diverse, complex and controversial aspect of "cover" is virtually non existent.

It is clear that there are a number of problems which are general to all fish habitat studies in rivers. In general the total absence of suitable habitat with reference to any feature (depth, flow, sediment, cover) for any life stage should, in theory, eliminate that species but the following aspects must be taken into account.

Firstly, the distribution of species and of the different life stages of those species in rivers is rather poorly known and differs between river types and probably also in relation to interactions with other species. For example, fishes in chalk streams do not show the "classical" zonation of dominant species, (Minnows-trout-grayling-barbel-bream) (Mann, R., Pers. Com.). This lack of longitudinal partitioning is presumably related to blurring of habitat boundaries, intercalation of habitat features at any given site and biotic interactions.

Ultimately it will be necessary to group data into a number of river types. Within these groups different sub-models of PHABSIM or a derivative may be necessary to take account of varying levels of habitat factor predominance.

Secondly, fish are very mobile animals and may migrate large distances, often on a seasonal basis, in order to fulfil particular life history requirements. Mature brown trout, for example, shift upstream in late Autumn to locate suitable spawning areas. Because of such a shift it may well be that a section of river which, ostensibly, has no trout spawning gravels when surveyed supports a large population of juvenile and mature trout derived from breeding elsewhere in the catchment; possibly in some unsurveyed reaches.

A walk-over survey of the entire river system should therefore be a prerequisite. In considering the mobility of fish the presence of impassable barriers must be taken into account.

Thirdly, rivers, being dynamic systems, show strong seasonal variations in depth, velocity, substrate and cover characteristics. Again, taking the brown trout as an example, it is quite possible that a particular reach may only have extensive areas of spawning depth/velocity/substratum/cover in winter, when increases in discharge have flushed out the detritus, silt and plant growths accumulated over the summer.

Adequate seasonal coverage of study reaches is essential. It will usually be necessary to consider seasonal requirements in terms of the fish species which are known to be present or which are desired.

Fourthly, it is probable that strong interactions take place between (particularly) the young stages of larger fish and small species of fish (or even large invertebrates) such as minnow, bullhead, stone loach, sticklebacks and ruffe etc. (Winfield 1991).

Many of these latter species can not be sampled adequately by existing techniques but should be assessed by observation if possible. Four or five levels of abundance should be adequate for this purpose.

Fifthly, habitat characteristics interact strongly in such a manner that it may be impossible to dissociate the effects of factors considered as distinct. For example, Current velocity which is generally, and realistically, measured at some mean point on the depth/velocity profile, may have little relevance to fish which spend much of their time in positions of shelter behind large stones or other obstructions. Evidence is available which suggests that velocity shear zones may be the essential factors governing habitat suitability in some species: thus, in slow flows trout may choose the margins of faster flow in sections and in fast flows they may select lies peripheral to the slower flowing areas.

This particular constraint may, in some instances, reduce the value of spot measurements made in relation to the observed locations of individual fish (one of the cornerstones of traditional PHABSIM habitat preference curve development. It emphasises the fact that the "community approach" to preference assessment is essential and that the finer detail of habitat measurement could prove valuable.

Similar constraints to those outlined above are applicable to all species considered.

The Instream Flow Incremental Methodology required for the PHABSIM model operates on a relatively simple principle. Estimates of AVAILABLE USABLE AREA for discrete SPECIES LIFE STAGES under a range of DISCHARGE VALUES are established.

Currently, data is being collected from a selection of rivers in England and Wales, by IFE and IH, using the conventional PHABSIM approach developed in the USA with the objective of evaluating the technique. It would, of course, be possible for the NRA to simply increase the data set indiscriminately by precisely repeating the methodology presently in operation. However, a more efficient use of time and effort would seem to be to select those features which could be "guaranteed" to be useful. It may also be cost effective to record information on features which are not currently included in the model if this seems appropriate.

With regard to the "problems" mentioned above.

It will be necessary to group data into a number of river types. Within these groups different sub-models of PHABSIM or a derivative may be necessary to take account of varying levels of habitat factor predominance.

A walk-over survey of each entire river system should therefore be a prerequisite. In considering the mobility of fish the presence of impassable barriers must be taken into account.

Adequate seasonal coverage of study reaches is essential. It will usually be necessary to consider seasonal requirements in terms of the seasonal life history requirements of fish species which are known to be present or which it is desired to encourage/enhance.

Many of the small fish species can not be sampled adequately by existing techniques but should be assessed by observation if possible. Estimates at four or five arbitrary levels of abundance should be adequate for this purpose.

The constraint of habitat feature interaction may, in some instances, reduce the value of spot measurements made in relation to the observed locations of individual fish (one of the cornerstones of traditional PHABSIM habitat preference curve development). The "community approach" to assessment of "preference" is essential and determination of the finer detail of habitat measurement

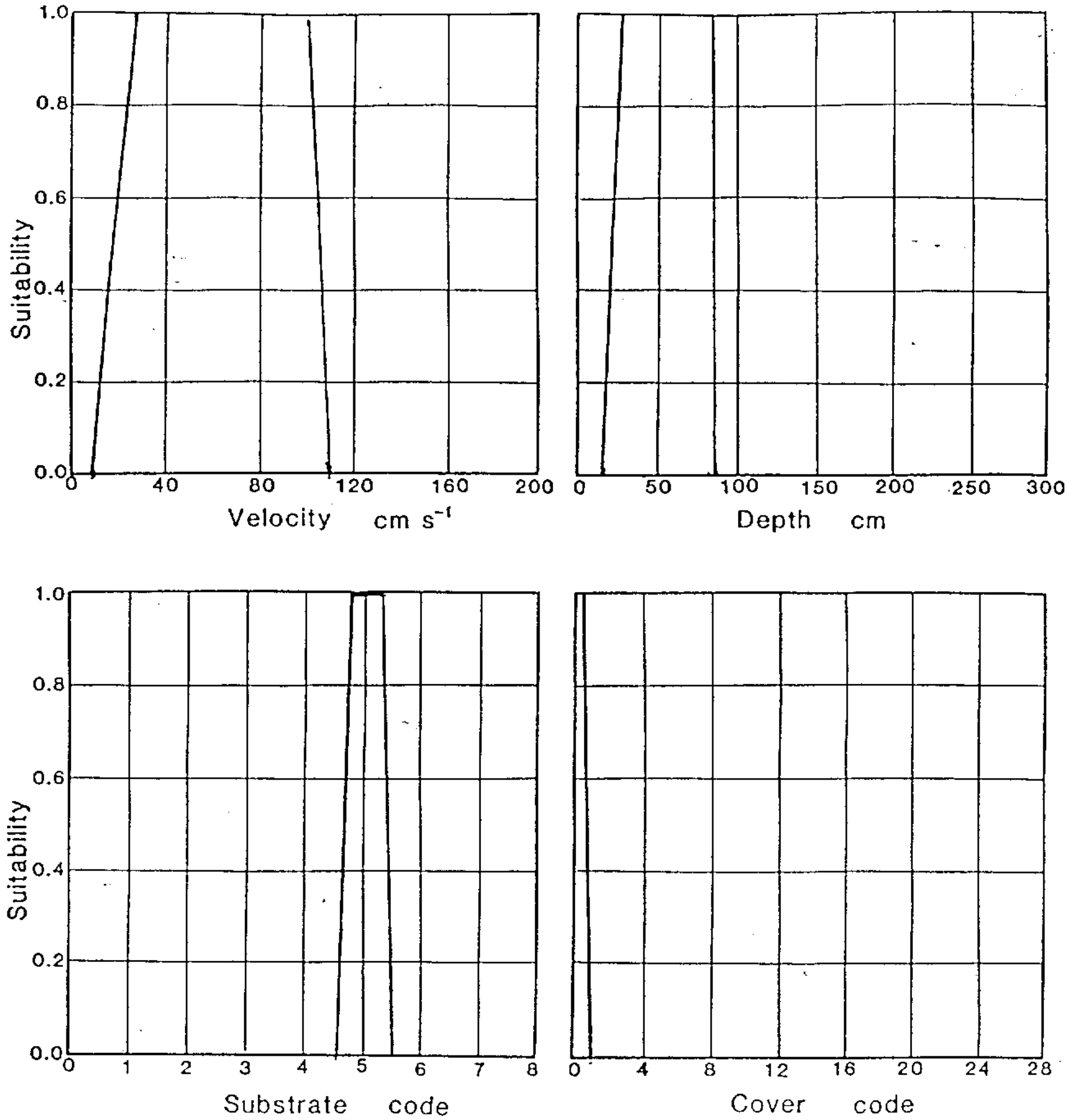


Figure 6.18: *Dace spawn*

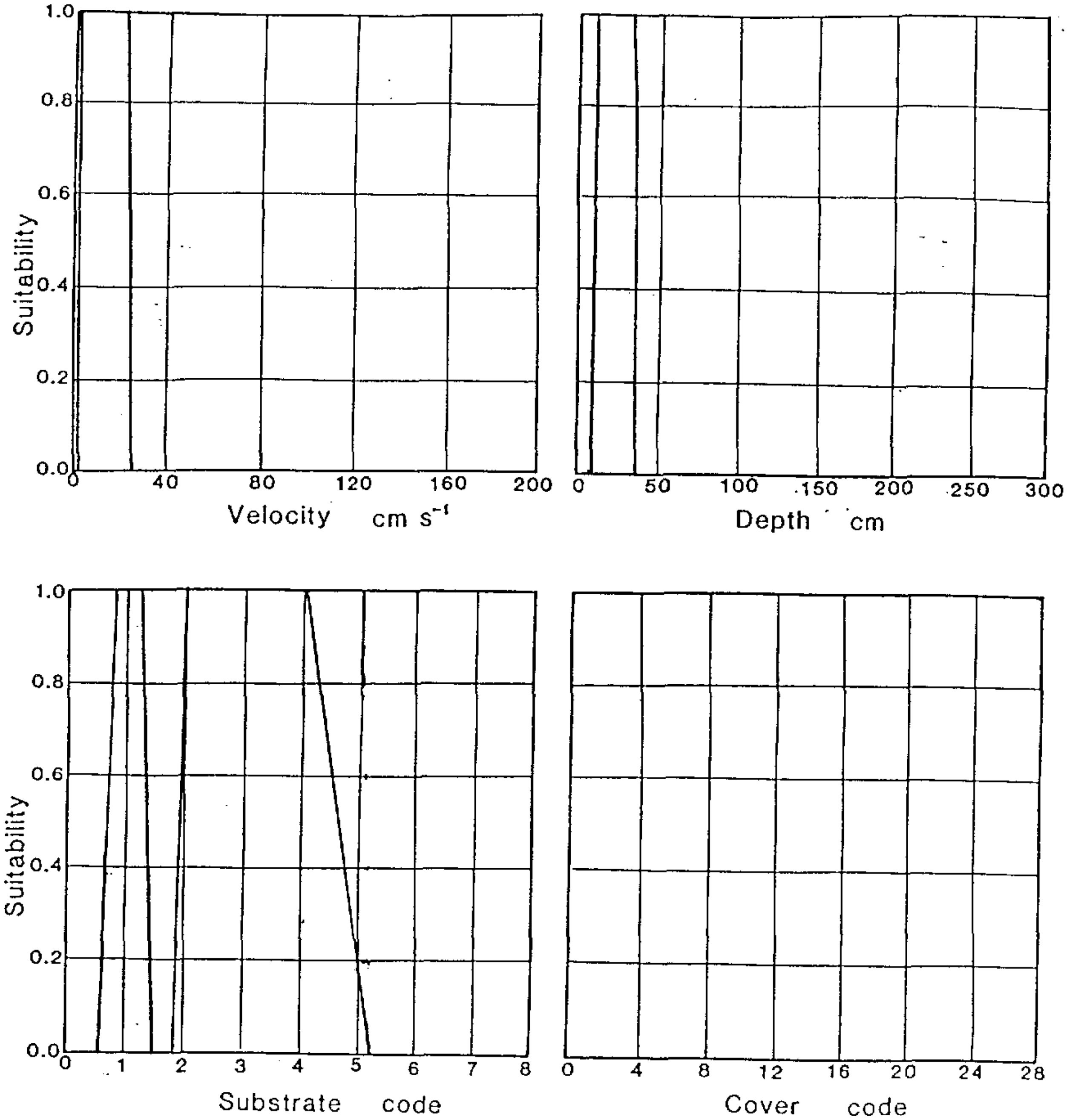


Figure 6.19: *Dace fry*

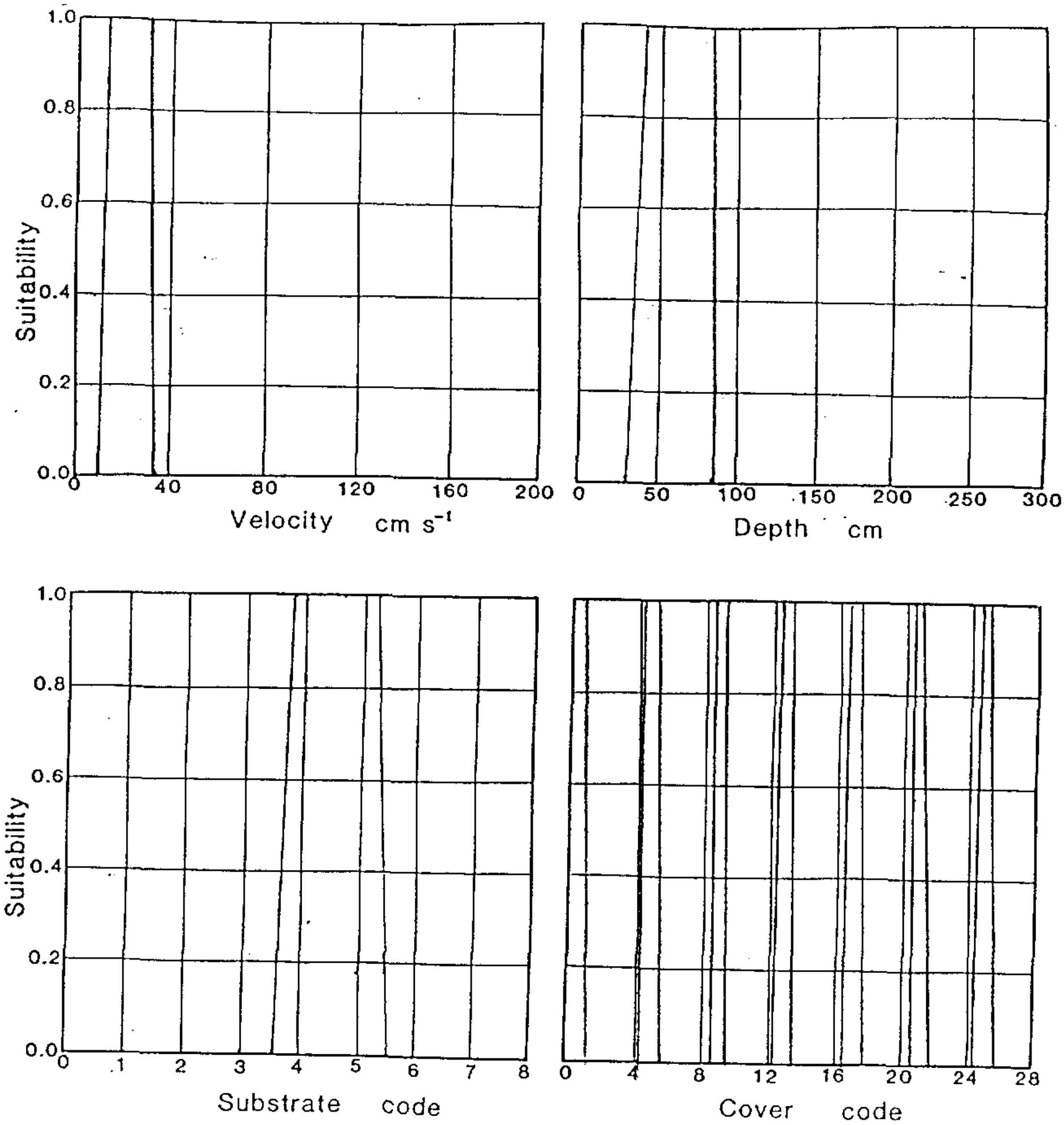


Figure 6.20: *Dace juvenile*

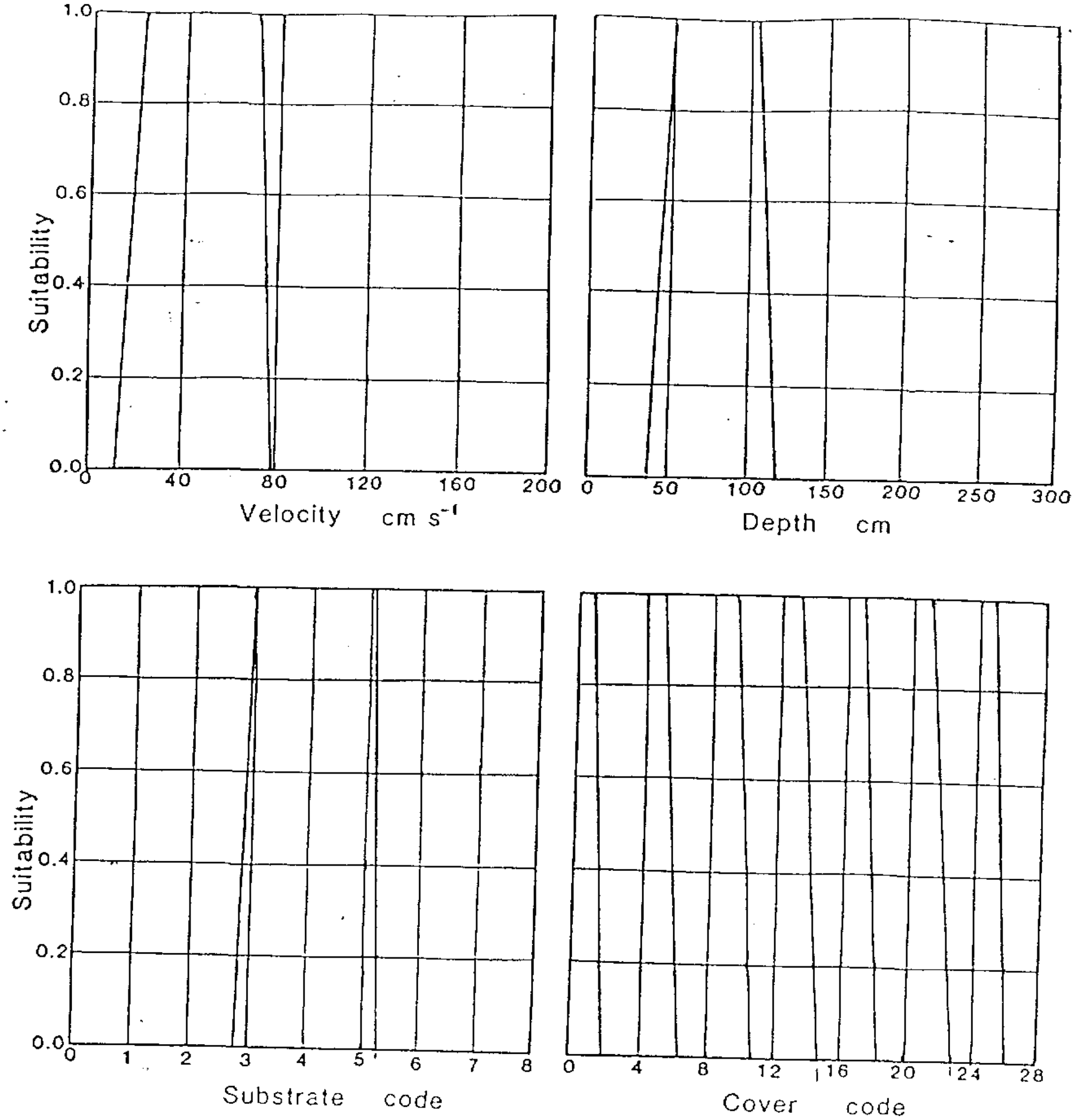


Figure 6.21: ***Dace adult***

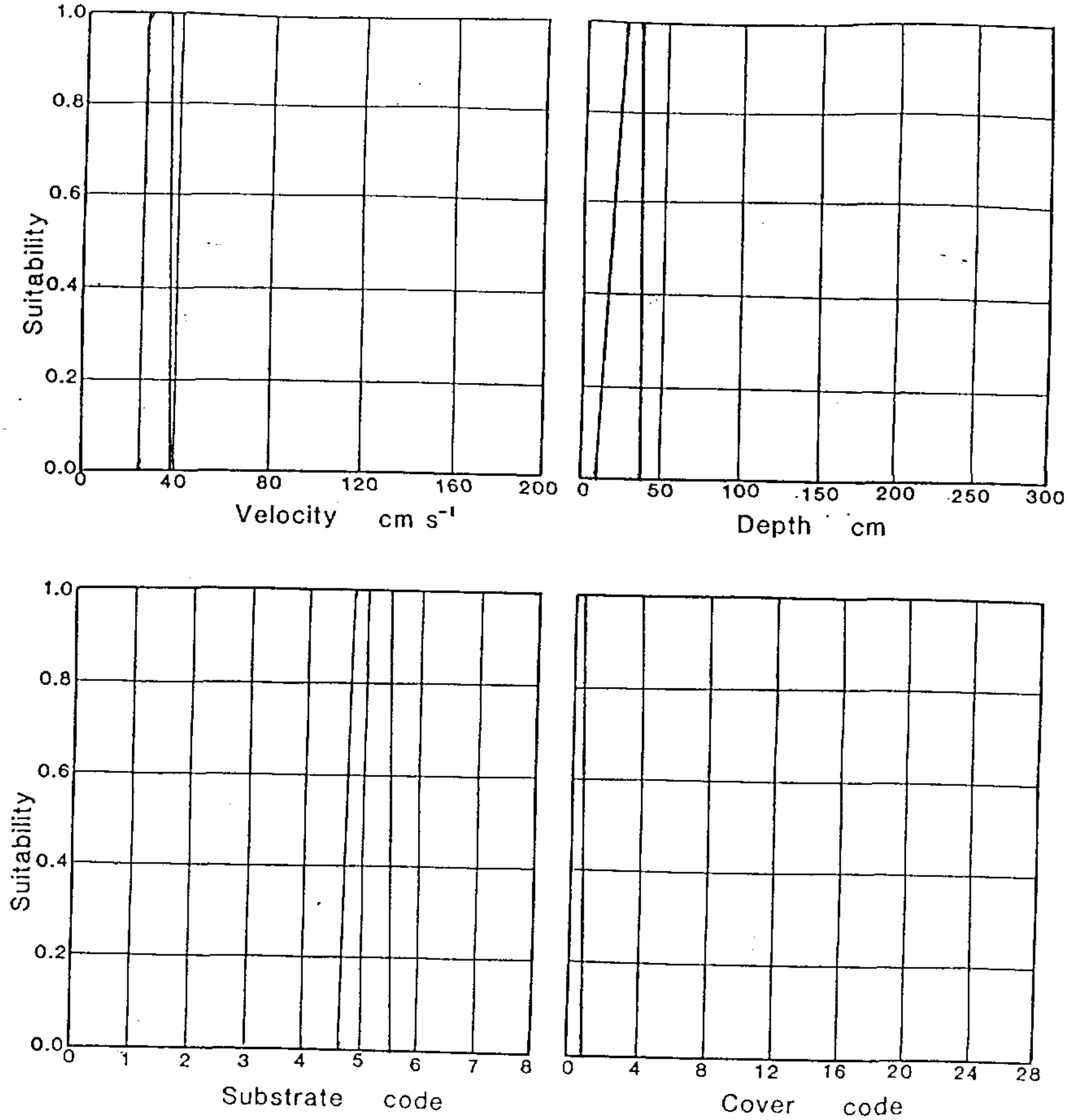


Figure 6.22: *Trout spawn*

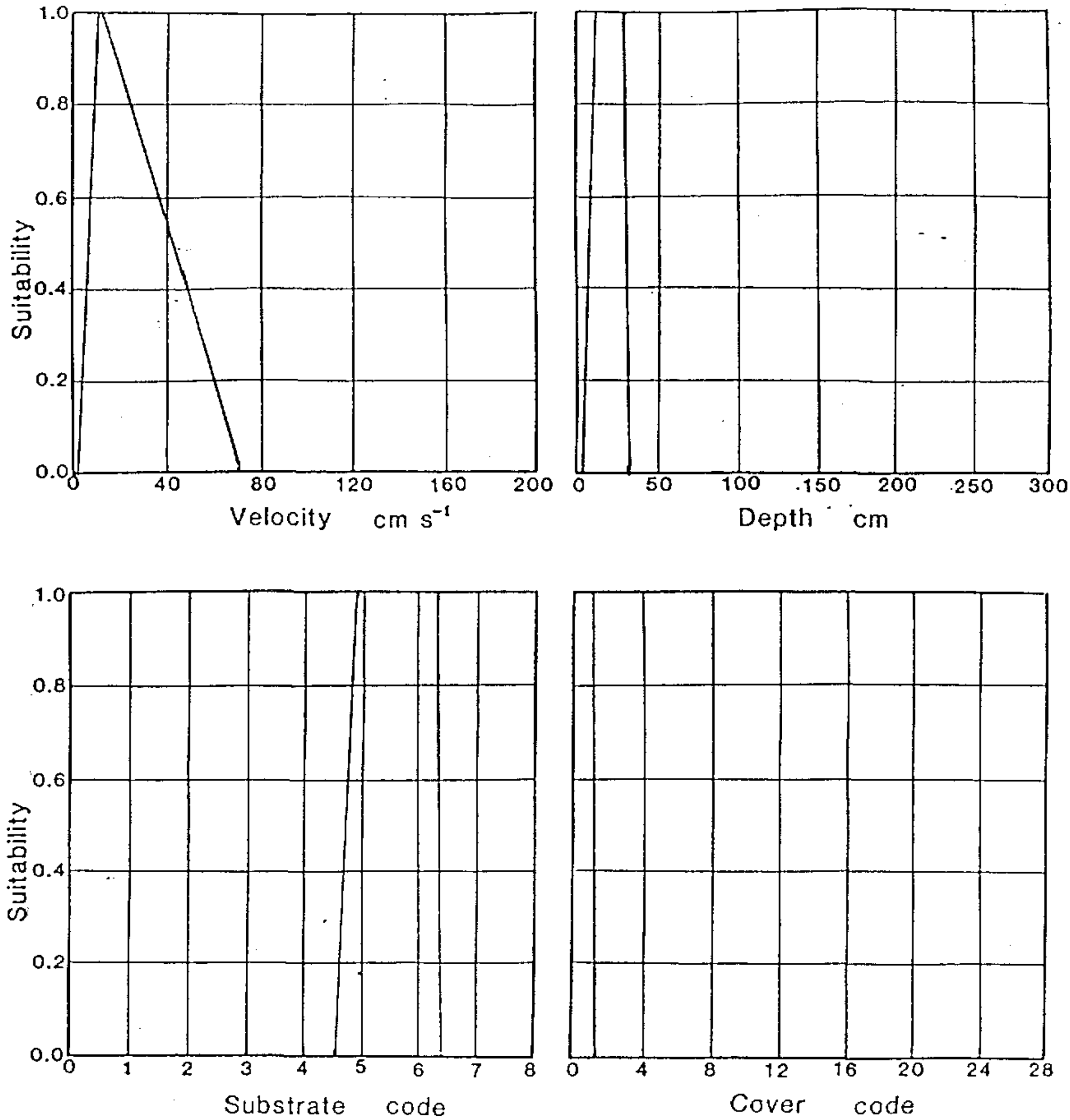


Figure 6.23: Trout fry

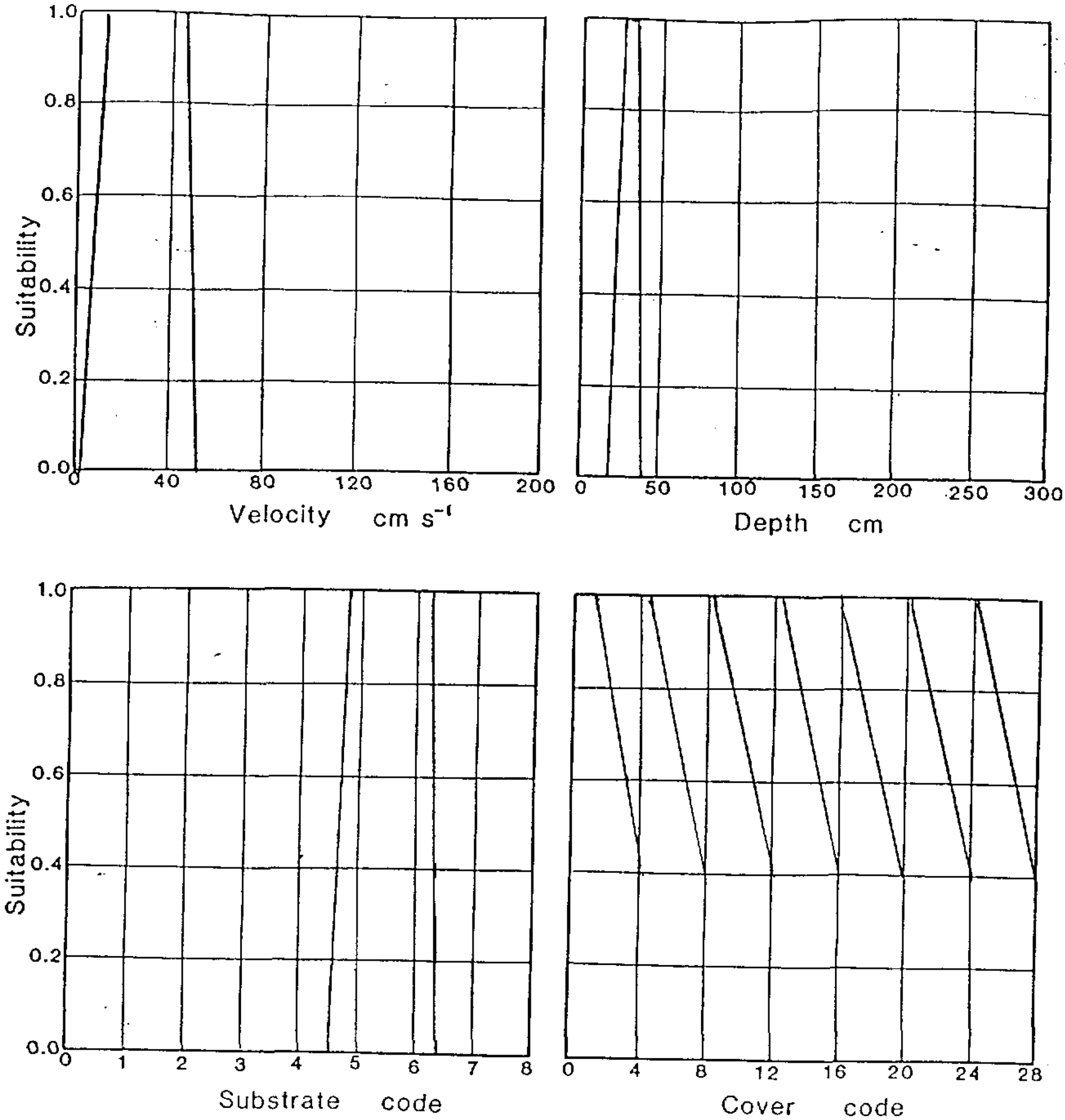


Figure 6.24: *Trout juvenile*

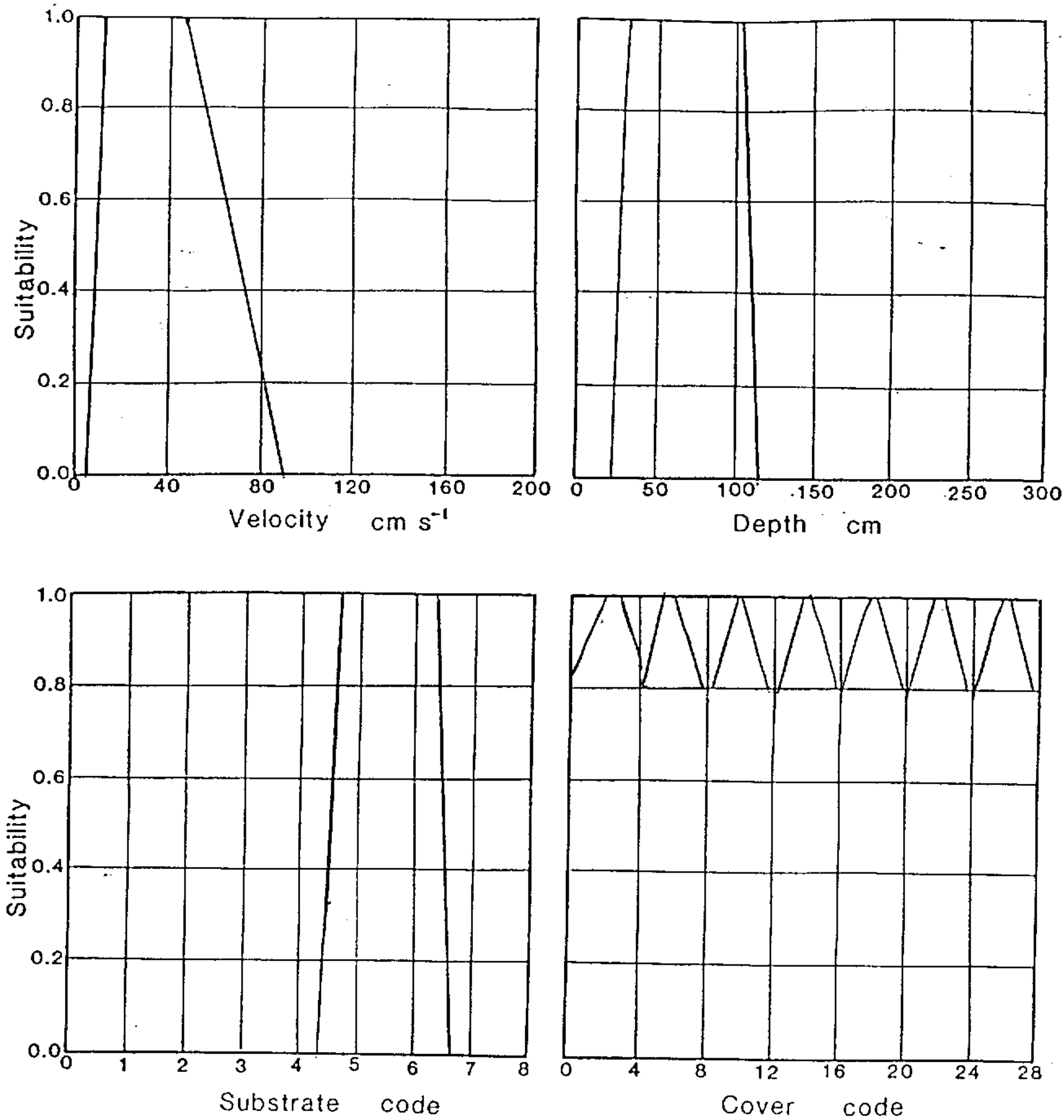


Figure 6.25: Trout adult

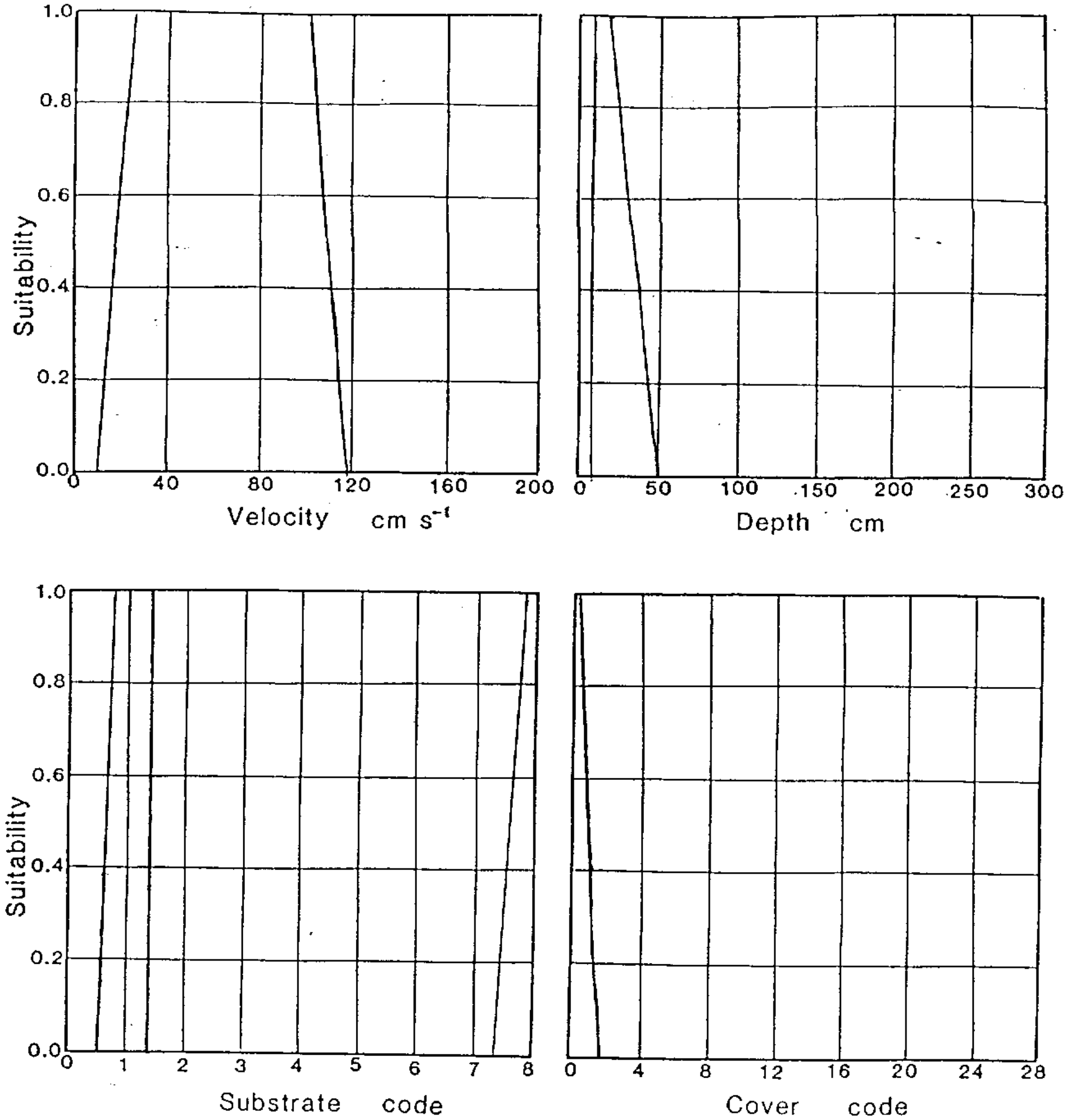


Figure 6.26: ***Roach spawn***

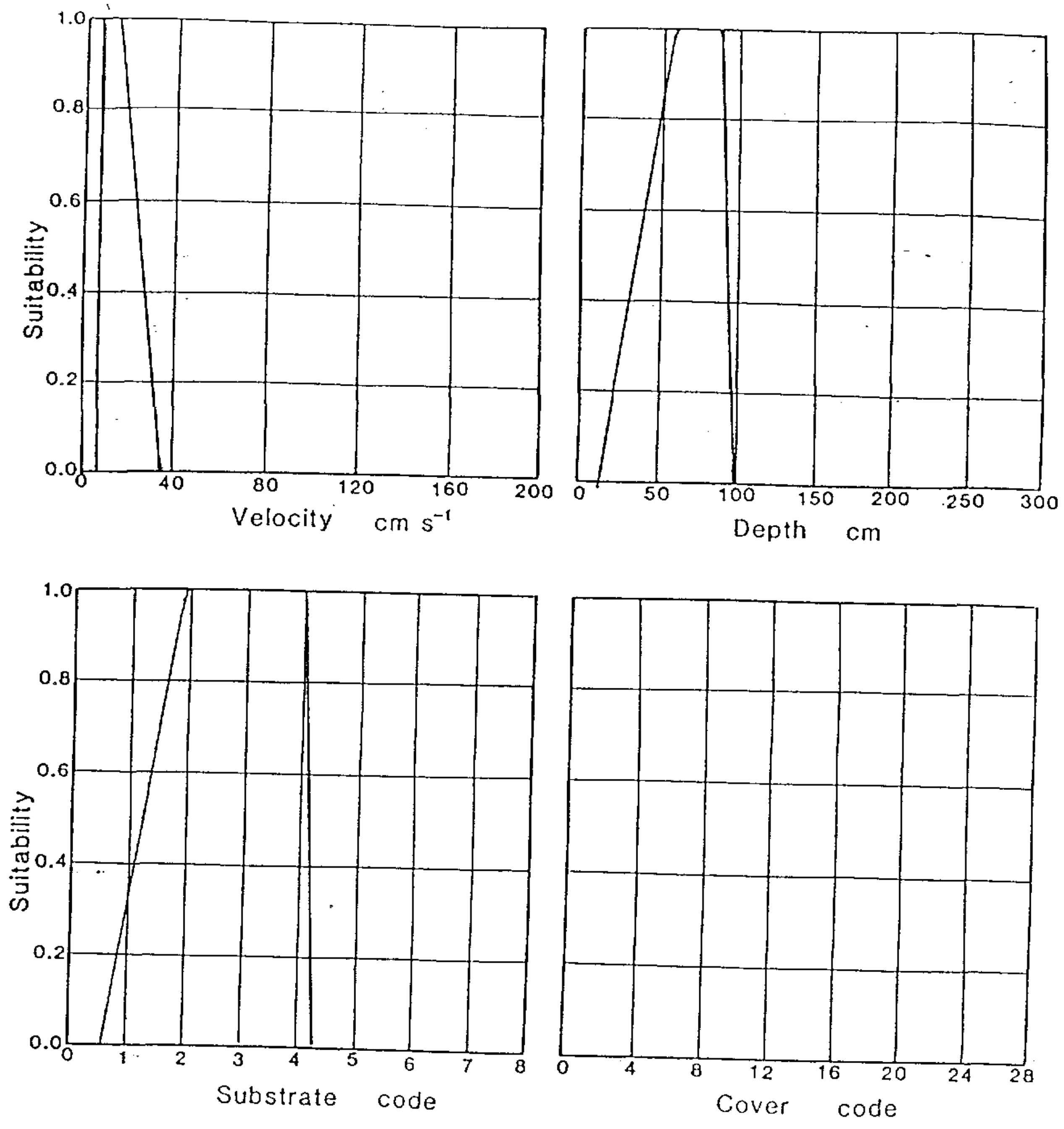


Figure 6.27: ***Roach fry***

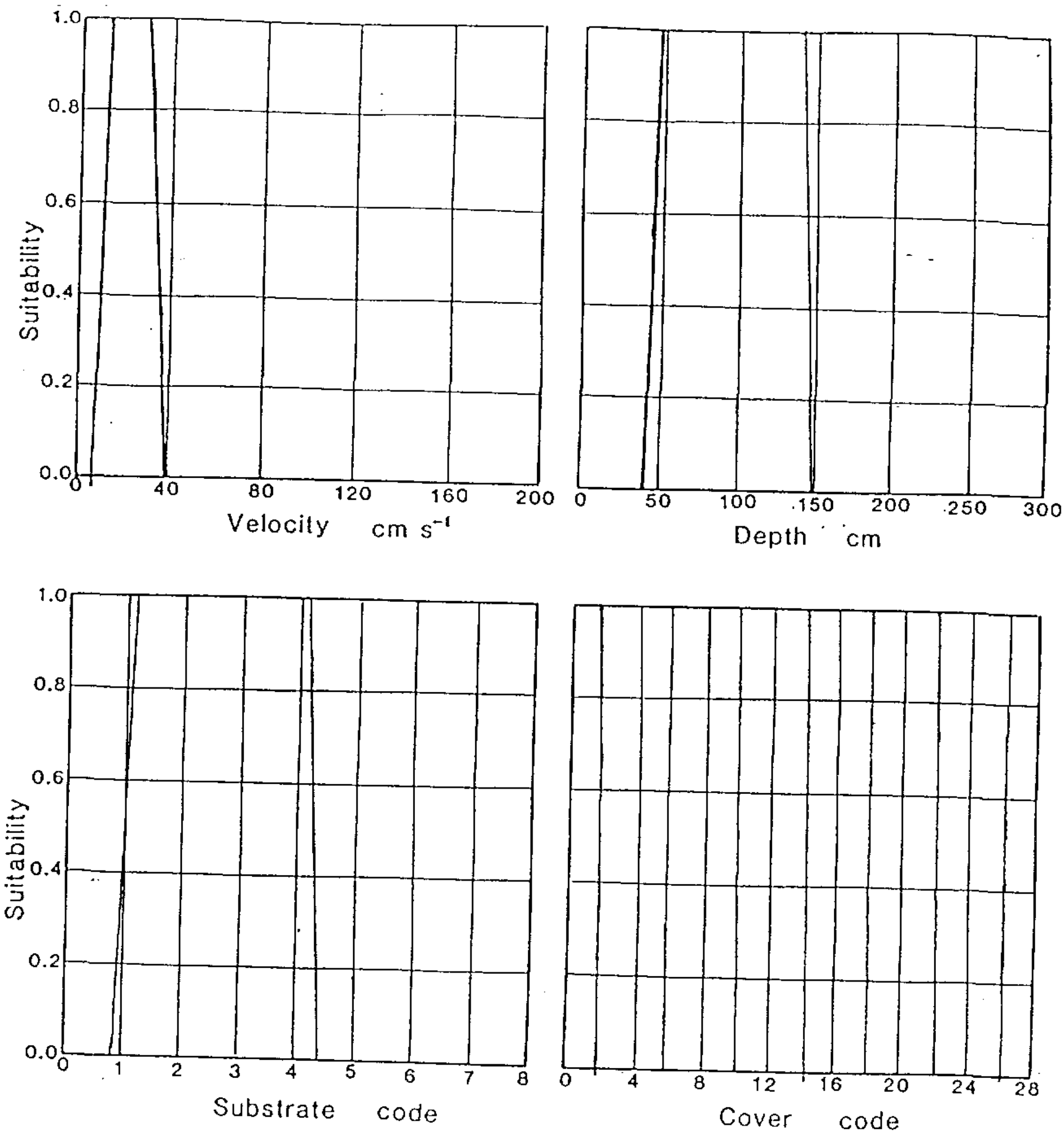


Figure 6.28: *Roach juvenile*

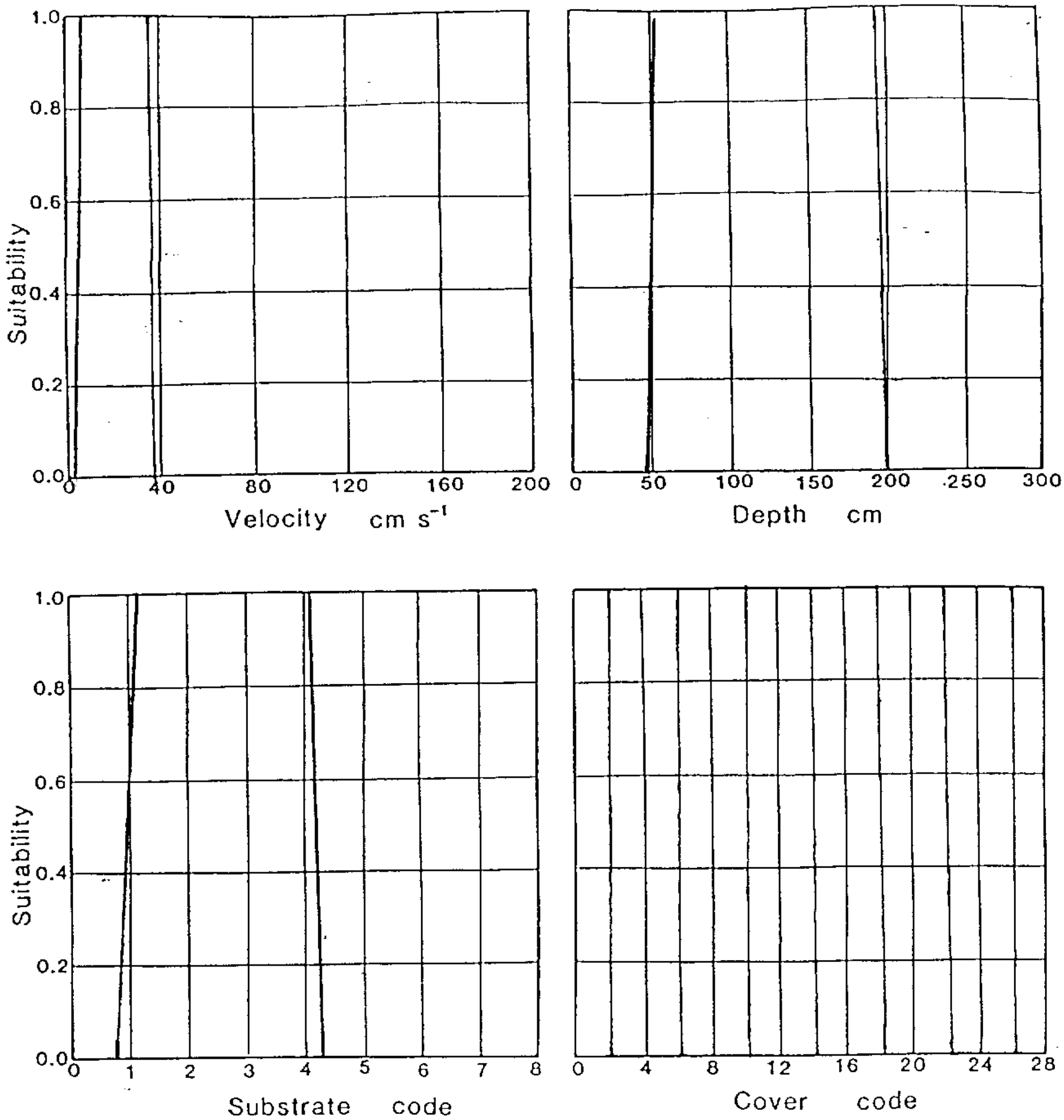


Figure 6.29: ***Roach adult***

could prove valuable. A similar aspect worthy of full consideration is the impact of variability in time and space, of habitat characteristics.

In conclusion it would seem that the best habitat model for each species will take into account the annual sequence of life stages and their habitat requirements. A river could be partitioned at the appropriate seasons to determine whether there is a proportion of usable area for all stages of the given species present at that time and a descriptive model generated to test the apparent suitability of the river in question. Preference curves are shown in Figures 6.18 to 6.29 below.

c) Macrophyte Preference Curve Construction

Background

There have been several attempts at choosing typical species and some attempts at defining their environmental range or requirements.
Such groups typically include:

Submerged - with bulk of plant in water but with access for fish

Ranunculus fluitans/penicillatus(/aquatilis)
Potamogeton pectinatus
Myriophyllum spicatum
Elodea spp
Callitriche spp
(stagnalis/obtusangula/platycarpe)
(large algae - filamentous)

Emergent - with plant divided between water and air & reduced or difficult habitat for fish:

Nasturtium/Apium/(Veronica)
Glyceria maxima
Phragmites australis
Scirpus lacustris
Sparganium spp

Floating: *Lemna spp*
Azolla spp

Surfacing - submerged attaching stems but with surfacing and shading leaves:

Nuphar spp
Potamogeton natans

Choice of aquatic plant genera to typify fish habitats

The selection of the typical aquatic plant species of most relevance to fish habitat is difficult although a recent assessment of weed control in flowing watercourses for WRc indicates that after emergent read-like species, *Potamogetons* and *Ranunculus* are the most abundant mainstream species followed by species of *Elodea* and of *Callitriche*. *Elodea* species develop later in the growing season and are considered to be a poor fish habitat apart from preferring to grow in slower non-salmonoid watercourses. *Callitriche spp* are slow in growth and are frequently managed on a cycle often exceeding a year. Thus the choice of *Ranunculus* as typifying submerged aquatic plants is particularly acceptable if the link between weed-cutting and fisheries is accepted in preference to the supposed basis in law of weed removal for land drainage purposes. The choice of emergent species, the *Nasturtium Apium Veronica* group, is less complex is a considerable knowledge base on *Ranunculus* and *Nasturtium* of the genera available for selection above.

Information on particular species of *Ranunculus* is complicated by the similarity in form, absence of confirmation in some distributional and taxonomic difficulties of several species. Thus is proposed to use a composite of three species as mentioned above; this will be called *Ranunculus afp* to emphasise the combination, the above complications but in additions the general quality or variation of result available even from clonal material under experimental conditions.

Data sources

Ranunculus afp

The basis data are derived from a intensive 4-year study of *Ranunculus penicillatus var calcareous* from the upper catchment of the River Piddle in Dorset together with plants from the adjacent River Frome. Other species were introduced to this experimental system for taxonomic studies and these results are also integrated. Overlying this data are a series of other data including:

1. A previous field study for this project on the river Gwash and Blithe (Mountford and Gomes, 1990);

2. Data from hydraulic, production and light studies on the Rivers Piddle and Frome. (see reference list);

3. Data from other IFE surveys particularly from EIA and Rivpacs.

Rorippa

Data on the habitat of this plant is derived from:

1. Detailed studies of sediment accumulation on section on the Rivers Piddle, Frome and Lambourne;

2. Detailed studies of the seasonal interaction of growth of *Ranunculus* and *Rorippa* on the R. Piddle.

Habitat suitability curves

The presence of absence of water plants is a fundamental problem to aquatic botanists. For example, Haslam considers that the presence of a plant is related to many factors whereas its absence may be caused by a single factor.

The extent to which a plant grows is determined by environmental factors but particularly light, carbon supply and nutrients. The biomass achieved must therefore be an assessment of the suitability of a habitat however this seems to contrast with that for fauna.

Plant growth in flowing water however modifies its environment particularly water flow, thus water velocity may decrease progressively during the growing season resulting in significantly raised water levels up to 0.5 m at the time of maximum biomass. Water velocity during these periods is both difficult to measure and to interpret the results. Experimental data shows that whilst the mean velocity of a cross section falls the velocity range is extended considerable. Thus the water velocity within the plant stand may be <0.1 m s^{-1}, the flow between stands may be 1 m s^{-1} but the mean may be 0.25 m s^{-1}. (habitat preferance curves to be included in final version of interim report).

Growth habit

Ranunculus afp

Normally found growing rooted in stable gravels in streams and river not subjected to large extremes of flow ie where the maximum to minimum is less than 1:10-20, or in areas of such where the effects of winter flows are moderated locally by the effects of barrages etc. Suitable gravels are likely to be cemented together by sand or silt grains to form a hard pavement and not worked over during winter flows.

Nasturtium

This emergent plant is normally found growing as an annual in shallow water to 0.7 m or in late summer in the margins of larger rivers. Although seedling development is important, backwaters and marginal areas protected from scouring or direct effects of winter flows act as refugia and as seasonal growth starts in the late spring many fragments or propagules are continually broken off to pass downstream to colonies suitable areas. Frost may however limit overwintering and thus this select for presence of this plant in warmer water streams ie. those fed from springs.

Velocity

Preference curves were made from mean velocity data for the cross sectional area of the watercourse either at a discrete sample site as a mean of a 100 m section. (Winter or maximum velocities are indicated by a dashed line.)

Depth

A wide range of water depths were incorporated. Mean depth of the section of stream was used although it is often likely with Nasturtium in depths over approx. 1 m that growth will be from the margins. (Growth above the surface is indicated by a line to the right of zero depth.

Substrate

Data collection for sites with high plant cover of the stream bed differs from that of low cover sites in that the progressive seasonal growth yielding high biomasses enhance sediment accumulation of that type of material available upstream for deposition, within the plant stands but leaves substrates of larger size exposed between plant stands for easy observations. If excessively large plant stands develop because of slightly lower flow than sedimentation over the entire stream bed may occur and the base bed may only be visible following the winter washout period should this occur. In the case of *Ranunculus*, although rooting may occur within such soft sediments only those plants or parts of rooted in the firmer base substrate will survive winter flooding.

Cover

Cover was equated to shade and preference curves were made from data from both large-scale experiments and detailed continuously-recorded observations from several river sites in Britain and Denmark. A model derived from data obtained light measurements from artificial vertical shade was also included.

Other Factors

Nutrient level

The minimum and maximum levels of nitrate-nitrogen, phosphate-phosphorus and potassium were in milligrams per litre respectively:

	Nitrate-N	Phosphat-P	Potassium
Ranunculus	0.28-5.1	n.d.-0.37	0.36-6.1
Nasturtium	0.25-4.7	n.d.-0.46	0.60-5.8
Apium	1.10-9.5	n.d.-0.55	n.d.-1.6
Veronica spp.	0.05-1.8	n.d.-0.34	0.26-6.3

These were all within the normal limits expected for acceptable level of plant growth and would not be expected to limit plant growth.

Water temperature

The water temperature range is considered to be range from 5^0C at which net photosynthesis is at a maximum to 25-30^0C at which the temperature related metabolism is at a maximum tending to reduce the net gain in biomass not withstanding any temperature adaption effects.

Discussion

Water velocity effects are the most significant effect for both *Ranunculus afp* and *Nasturtium officinal.* In the former, for example, where the seasonal range of flow is small eg 3:1 there is little winter washout and often a high overwinter biomass with a high maximum biomass in the successive season whereas in rivers with a seasonal flow range of 10-20:1, a similar seasonal maximum biomass may not be achieved. This reduction in biomass may be further reduced by the effect of deeper water such that at mean depths of 2-3 m only a small biomass may be achieved; this leaves the plants susceptible to overgrowth by algae at relatively low nutrient levels and their elimination from this part of the system.

The seasonality effects of plant growth and the consequential effects on water flow have been discussed with R.T Milhous. Habitats have not been satisfactorily coded from Cover groups and their combinations.

6.2 Fish field data

Introduction

Habitat preference curves of selected target species will be developed mainly from information in published papers and unpublished reports. These curves will be applied in the PHABSIM program to examine the effects of habitat loss at reduced discharges on the selected target species. In order to test whether the results from the PHABSIM program are accurate it is necessary to have information about the fish population in the river.

The planned fishing programme will show how fish in differing river types are distributed with respect to habitat. (River and site selection procedure are outlined in chapter 5). In addition, repeat fishings and scale analysis and length/weight relationships will provide data on the age structure and density of the population.

These data can be used to assess the accuracy of the PHABSIM predictions and in addition will supplement information on habitat requirements of particular fish species.

During the electrofishing it is possible for an operator to record the position of fish caught and to relate this to reference markers on the bank and instream. The procedure carried out in the millstream involved preparing a sketch map of each reach and relating this to reference points such as trees and bushes and the IH markers. When the fishing team catch a fish its identity is communicated to the operator on the bank who records the capture locus on the sketch map. The location of fish can then be directly linked to the physical characteristics of the reach as determined by the IH transects. This procedure is described and illustrated in more detail in chapter and an example of the possible output is shown in Fig. 6.30 for Dace on the River Blithe.

The consensus view of several fish workers suggests that the proposed methodology will provide useful information on the association of fish species with particular habitat characteristics. More detailed field assessment of habitat requirements of fish would require a considerable amount of effort and may need to consider seasonal aspects, longitudinal movements (out of the reach or tributary) and life-history data. Such effort is beyond the scope of this project and it is hoped that the proposed methodology offers a compromise whereby a good deal of information is obtained with an economy of effort.

PROGRESS

The methodology used to sample each site is described in Chapter 5. However this was modified slightly to accommodate the range of river type and topography. Ideally the whole site would have been isolated with stop nets, fished three times and a triple catch depletion estimate made of the population number. This has only been possible on two of the five sites fished to date. The length of the sites on the other three rivers has necessitated the division of the sites into two or more reaches. With the exception of the River Hodder each of these reaches were then fished three times to obtain an estimate for each reach. The reach population estimates and standard error estimates were added according to the formula:

$$Var(T) = (SE(N_i)^2$$

This process probably increased the number of invalid population estimates because one invalid reach estimate would invalidate the site estimate. On the River Hodder time constraints arising from the size of the site meant that only two fishings of each of the two reaches could be carried out.

Estimates of both total population and population density have been made for all the rivers fished to date (Table 6.9 overleaf). Where an asterisk (*) is shown in Table 6.9 population estimates were not possible for that species at that site; either because of low numbers of fish caught, or a variable catch efficiency rendering the population estimate invalid. Where possible in these cases a minimum population estimate based on actual catch is shown. A cross (X) in table 1 indicates that the species was not present at that site.

The distribution of Dace in upstream and downstream sections of the site on the River Blithe is shown in Fig.6.30 at the end of this sub-section.

The completion of site selection and hydrological mapping of the remaining sites will allow the outstanding fishery surveys to be carried out within the next three months (January-March). The completion of these surveys on schedule will be dependent upon weather and river conditions. When fish data are available for all sites they will be further stratified into juveniles and adults and density estimates will be made.

PHABSIM FISH DENSITIES (100 m^2)   * = min density   † = combined sea trout and brown trout

	Trout	Salmon	Dace	Gudgeon	Roach	Chub	Minnow	Tench
R. Exe	10.0 ± 0.9	17.2 ± 0.8	x	x	x	x	x	x
R. Wye	3.6 ± 1.2	8.9 ± 6.0	x	x	x	x	* 7.4	x
R. Blithe	* 0.2	x	9.8 ± 0.1	* 6.0	* 2.0	2.8 ± 0.3	*	* 0.1
R. Hodder	* 0.2 †	* 9.8	x	x	x	x	*	x
ESMS I	* 0.5	* 0.1	12.4 ± 0.9	* 15.3	* 0.7	x	* 15.6	x
ESMS II	* 0.4	* 1.0	13.6 ± 3.9	* 3.8	* 0.7	x	* 12.8	x

	Bleak	Perch	Pike	Flounder	Grayling	Bullhead	Loach	Eel
R. Exe	x	x	x	x	x	x	x	*
R. Wye	x	x	x	x	x	x	x	1.0 ± 0.0
R. Blithe	* 0.1	1.8 ± 0.2	x	x	x	*	*	*
R. Hodder	x	x	x	x	x	*	*	x
ESMS I	x	x	x	4.1 ± 0.3	x	*	*	* 26.0
ESMS II	x	x	* 0.2	* 1.0	* 1.7	* 1.7	* 1.6	* 3.7

Table 6.9. The densities (numbers per 100m²) of fish species taken in five rivers. [ESMSI and ESMSII = May and June fishings of the East Stoke Mill stream]

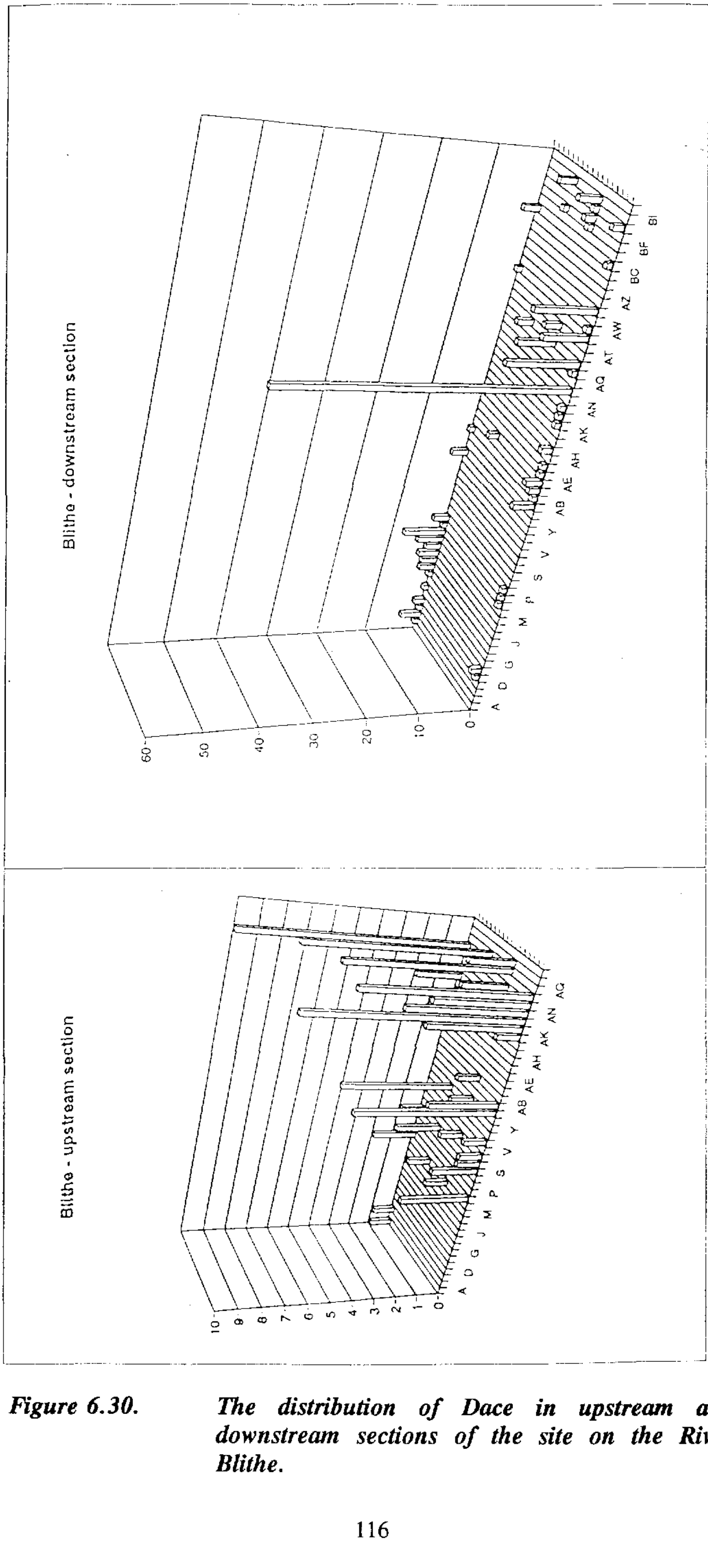


Figure 6.30. ***The distribution of Dace in upstream and downstream sections of the site on the River Blithe.***

6.3 Supplementary studies

Modelling faunal and floral response to reduced flows and habitat loss in a river. An experimental approach. [The Mill stream project - biological studies]

Introduction

Modifications of the environment are frequently accompanied by changes in the composition, distribution, and abundance of the resident flora and fauna. In rivers, resident biological communities are adapted to basic river characteristics with flow (discharge-velocity) a major controlling factor.

Basic information on the distribution and movements of fish and invertebrates in response to flow changes is needed to increase our understanding of how such modifications affect the resident populations. The East Stoke Mill stream, with its controllable flow, provides an ideal opportunity to carry out a series of large-scale experiments designed to elucidate the responses of biological components of the ecosystem to reduced flows.

This project is science budgeted by NERC to support biological (Institute of Freshwater Ecology) and hydrological (Institute of Hydrology) studies. The NRA, for the 'Ecologically acceptable flows project', contributed funds for the first two months.

Objectives

1. To describe habitat availability at 'normal' flows for fish, invertebrates and plants.

2. To determine the effects of reduced flows on habitat availability for the biota above.

3. To examine the response of fish and invertebrate populations, in terms of composition, distribution, and abundance, to loss of habitat.

4. To measure physical and chemical changes resulting from low flows.

5. To use data obtained in 1-4 to determine the overall responses of component parts of the ecosystem to reduced flows.

6. To repeat flow reductions to provide replicate data and to examine seasonal effects.

7. Using the PHABSIM model (Physical Habitat Simulation System) evaluate the relationship between observed and predicted response of physical habitat

to modified flows.

8. Using the PHABSIM model evaluate the relationship between predicted change and observed change in faunal and floral response. This will be carried out by relating weighted habitat area to changes in species and abundance of invertebrates, fish and macrophytes.

9. Objectives 1-4 will provide basic information on the distribution, community composition, population structure and food preferences of fish in different habitat types in relation to flow changes. Ultimately studies on diel and seasonal changes of fish distribution related to spawning, life-stage and feeding will provide the information necessary to model detailed habitat requirements of fish species and associated invertebrate and macrophyte communities.

The objectives above can only be achieved with full staffing and resources. Contractual obligations have resulted in a shortage of staff such that certain aspects of the project have not been started in this first year of study. This situation has resulted in a reduced effort and invertebrate work has not been instigated because of lack of staff availability. Most effort in this first year has been placed on investigating the response of fish populations to flow changes and developing a method for recording the distribution of fish. Macrophyte populations were mapped and the distribution of plant stands was followed throughout the period May to September. Chemical data has been collected from six sites from May to the present.

Study area

The Mill stream is a branch of the River Frome which flows for about 1.2 km before rejoining the main river. The channel morphometry comprises an upstream section about 500 m in length which is divided from the lower section by the 'Fluvarium' which can be used to control the flow downstream by closing hatches. The upstream section is characteristically deeper and slower flowing than the downstream section. The experimental reach is located in the downstream stretch and comprises three sub-sections (Upper, Middle and Lower).

A sketch map of the Mill Stream showing the location of the experimental reach and chemical sampling points is given in Figure 6.31 overleaf.

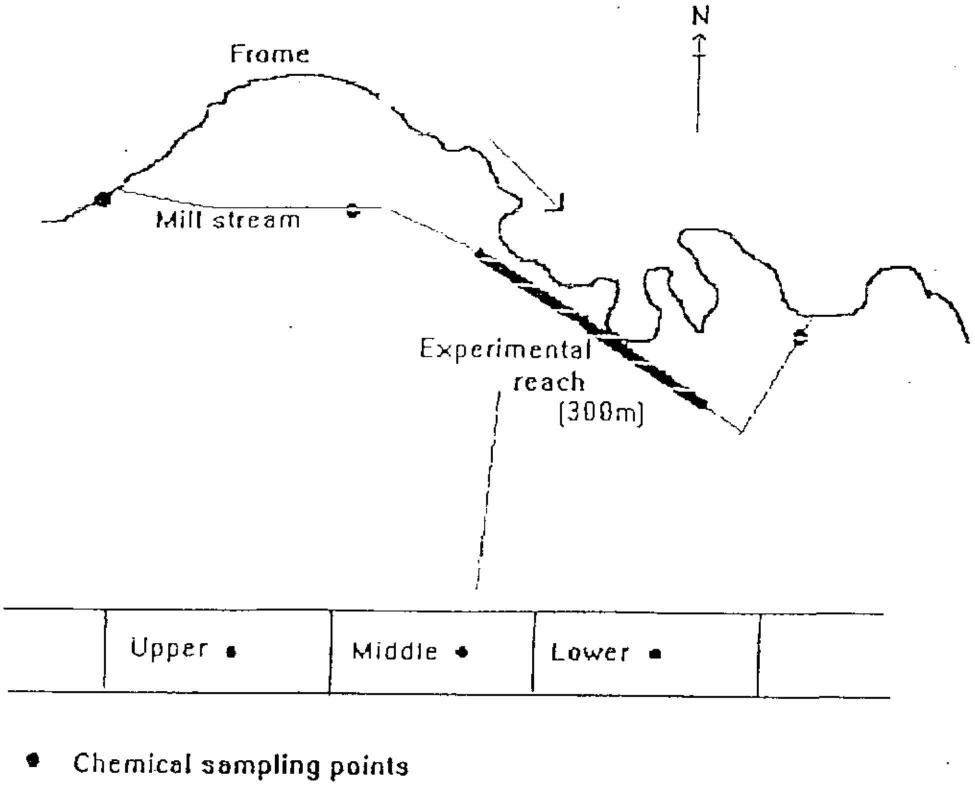


Figure 6.31 A sketch map of the Mill Stream showing the location of the experimental reach and chemical sampling points.

The three experimental sections were selected prior to detailed hydrological analysis to reflect the range of available habitat.

The upper reach is 120m long, unshaded and moderately deep, the middle reach is 80 m long, shaded, and deep, and the lower reach is 110 m long, largely unshaded, and is the shallowest and fastest flowing of the three sections.

Discharge data will be collated for both Frome and Mill stream but detailed information was not available for inclusion in this interim report. The observed range of discharge throughout the period May to November was 0.25-2.1cumecs.

Methods

The effort to date has been put into a study of fish responses to changes in flow. At 'normal' flow the three experimental zones were demarcated with nets across the stream. The flow was reduced by closing hatches in the fluvarium to facilitate electrofishing. Each zone was then fished (see Section 5.9 for details) to determine distribution, composition and population structure. The nets were then removed and the flow maintained at a 'lower than normal' level' for a period of forty-five days. After this time the nets were replaced, the flow reduced and the whole experimental reach was electrofished. This procedure was repeated every month to date. However the maintained flows were not necessarily much lower than the normal unregulated flow. Details of conditions are presented below. All mean discharge measurements are given in stage board heights together with maximum and minimum values and the standard deviation of the mean. The values pre- and post are those discharges recorded just prior to fishing and one day after.

Date	15/05	27/06	24/07	08/08	13/09	24/10	27/11
Stage pre-	2.70	1.55	1.80	1.20	1.40	1.7	2.8
Stage post-	1.75	1.40	1.75	1.10	1.60	1.65	2.6
Mean	-	1.60	1.63	1.38	1.21	2.15	2.89
Max	-	1.80	2.60	1.80	1.45	3.50	4.40
Min	-	1.55	1.00	1.18	0.80	1.60	1.60
SD	-	0.178	0.388	0.210	0.229	0.579	0.763
Days	0	43	27	15	36	41	34

A technique was developed to record the position of fish at the time of capture. This provides data on the preferred distribution of stressed fish and may help to show the relative importance and variation in cover requirements for different species of fish. In addition it probably accurately reflects distribution of species along the reach for all but shoaling species, but this latter requires testing. Details of the method are described in Chapter 5 and some examples of the results are also included.

Hydrological data were collected at a range of flows.

Macrophyte vegetation was mapped throughout the experimental reach on 20th July and again on the 7th of August.

Results

For Tables 6.10 to 6.11 and Figures 6.32 to 6.46 see end of sub-section.

Chemistry

Major anions and cations have been analyzed every week since the start of May 1991. The objectives of this monitoring work are to establish the within reach variability and determine whether the selected experimental discharges result in changes in concentration of the major ions. For each date there are six points which correspond to locations on the Frome/Mill stream system. Data on nitrate, phosphate and pH levels are presented in Fig. 6.32 for the first two months.

The results in general agree with those reported by Casey & Clarke (1979) for nitrate and Casey & Clarke (1986) for phosphate, and their were no distinct and consistent longitudinal trends in concentrations along the Mill stream. The values of pH did however show a tendency to increase with distance down the Mill stream. These results must be considered in relation to the full set and await further analysis.

Fish

The fish community in the millstream comprised a total of 10 species on the first fish survey and 12 on the second, the additional two species being pike and grayling. Densities together with 2* standard error values (fish / 100m^2) for all fish caught are given in Table 6.10. Where possible, estimates of population density have been made for all species. Where an * is shown in Table 6.10 population estimates were not possible for that species, either because of low numbers or a variable catch efficiency which renders the population estimate invalid. Where possible in these cases a minimum population density based upon actual catch is shown. A cross (X) in the table indicates that species was not present in that reach. Histograms of the densities (100m2) for trout, salmon, dace and gudgeon are shown in Figs 6.33 and 6.34. The distribution of Dace in May and June throughout the experimental reach is shown in Figs 6.35 and 6.36.

Trout densities showed the same pattern for each of the sampling dates, with the highest density being found in reach 1 (the lower section). Smaller densities or no fish were recorded in reach 2 (middle) and reach 3 (upper).

Salmon were found only in reach 1 on both fishing dates but densities were markedly higher on the June fishing.

Dace densities showed a similar pattern of density for each reach at each date and no differences between dates can be seen when looking at the results from the whole of each reach. However the distribution of captured fish was more even in the June fishing compared with the situation in May, see Figs 6.35 and 6.36.

Gudgeon densities show a marked difference between both reaches and dates. Densities on the first fishing increased from reach 1 (lower), 9.5 fish / 100m2, to reach 3 (upper), 23 fish / 100m2. Densities for the second fishing were much lower and whilst the highest density was again found in reach 3 it was at the much lower value of 5.8 fish / 100m2.

Data on fish distribution and abundance continues to be collated from the millstream fishings.

Macrophyte and habitat changes - June-November 1991

The relation between botanical map zone and the position of survey pegs is illustrated in Fig. 6.37.

A significant increase in the cover of many riparian plants was noted between June and August, including *Phragmites australis* (Cav.) *Trin. ex Steudel* (Common Reed), *Carex L. spp.* (Sedges), *Solanum dulcamara L.* (Woody Nightshade or Bittersweet), *Glyceria maxima* (Hartm.) *Holmberg* (Reed Sweet-grass) and *Sparganium erectum L.* (Branched Bur-reed). The most significant growth observed, however, were the stands of *Nasturtium officinale R. Br.* (Water-cress), which grew mostly in zone 5.

The growth of many of these plants altered the range of aquatic habitats by increasing areas of shading and affecting flow rates. The density of the *Phragmites australis* stand in zone 5, for example, reduced the velocity of the water on the south side of the stream, which was presumably compensated for by an increase in the velocity along the north side.

One of the most dominant aquatic plants observed during the surveys in June was *Ranunculus penicillatus* (Dumort.) *Bab. var. calcareus* (R.W. Butcher) C.D.K. Cook (Water crowfoot). This species was almost absent in the November surveys, however, with only remnants of the large stands formerly observed in zone 6. This loss of water crowfoot was apparently due to damage incurred by swans.

Consonant with this reduction was the loss of a large expanse of *Lemna minor L.* (Common Duckweed) that was trapped in a stand of *R. penicillatus* mid-stream in zone 6. This loss was also possibly due to the water spates that occurred periodically between June and August following heavy rain. In many other stretches of the river, however, *L. minor* was observed to have increased in extent.

Most of the riparian plants have died back since the surveys were conducted in August; this has resulted in greater habitat uniformity along the river bank. Although the stands of *Phragmites australis* (most notably in zone 5) have died back, they have further reduced water flow by collapsing into the water. The large *Nasturtium officinale* stand (zone 5) has not died back.

Invertebrates

Work was confined to sampling 'microhabitats' as part of a general invertebrate sampling programme in rivers nationwide. These results are described separately under the section 'supplementary invertebrate studies'.

Discussion

It is too early to review the findings from this study in detail. However it is clear that the experimental facility is providing much data on the distribution of fish and seasonal changes in macrophytes. The chemical data are also showing the relative small effects of discharge (within the range available). Most chemical changes are associated with high rainfall/flood events and in general there does not seem to be a difference between reaches. However this may simply be because the discharges were not maintained at a low enough level for a long period.

Perhaps the most significant feature to emerge from this work to date has been the role of macrophytes in controlling flows. Despite low discharges in the Frome in the summer weed growth caused the main river to overtop its banks and riffles in the experimental reach were 'drowned-out' by the rise in water level. The implications for the application of the PHABSIM model, which was developed in generally weed-free rivers, are important and data from the Millstream work will provide information which can be used to modify the model to take account of this feature of British lowland rivers.

It is hoped that a start will be made on other aspects of the project in the coming year. Most particularly invertebrate communities will be investigated in more detail, if staff are available. In addition more work will be carried out on the effect of weed growth on flow retention and habitat availability.

Distribution of Invertebrates Along River Reaches - The Rivers Gwash and Blithe.

Introduction

In a previous study which examined the feasibility of using the PHABSIM model in the UK, invertebrate samples were collected from three reaches on the River Blithe and from one reach on the Gwash (Armitage & Ladle 1989). These samples were collected at the same time as physical and hydraulic variables were measured along transects for input into the model. There were insufficient funds available for processing the samples at that time and the entire collection was stored by the Institute of Freshwater Ecology until such time and funds became available for further examination.

This current project allows for these data to be processed in order to examine in more detail the distribution of invertebrate groups across and along a broad area of river.

Most invertebrate surveys are confined to a single sample within a given reach. This sample may include all microhabitats within the site area (usually rather loosely defined) which may consist of a section 5-10m along the stream. In this type of sample the catches from different microhabitats within the area are usually bulked together and no microhabitat-specific distributional data can be extracted. Other techniques involve sampling a single habitat usually a riffle and again no picture of distribution patterns for the reach can be obtained from the results.

It is important to know whether invertebrates have a patchy distribution and this has been the subject of much investigation by theoretical ecologists (see Pringle et al. 1988, JNABS 7,503-524). However to date there has been little attempt to obtain such data for studies of applied problems. Detailed distributional data has practical application particularly in the field of flow changes. Such changes are accompanied by shifts in the proportions and absolute amounts of habitat types which in turn can have major effects on the benthic community. It is the object of this investigation to determine the distribution of benthic invertebrates along river reaches and relate them initially to substrate features with the ultimate aim of defining zones/reaches which would be particularly sensitive to flow changes and their associated hydraulic characteristics.

Methods

Six samples were collected along every other transect (see Fig. 6.38 for details of the grid system). Each sample consisted of one 60s kick within a defined area in a cell. Such a sample can provide quantitative data (Armitage et al. 1974). Water flow carries the fauna from the disturbed area of river bottom into a net held downstream. Where flow is too slow the net is moved to and fro over the area of disturbance.

Each sample was preserved in formalin solution, and sorted into alcohol. The cost both in time and money precluded the identification of the fauna to species level in all reaches, and analysis is confined to family level. Data are available on the substrate characteristics at each sample point and velocity and depth data were collected along each transect. In this study substrate type is considered to be the consequence of velocity and depth variations over a period of time. Seven categories of substrate were recognized and coded as follows:- silt=1, silty sand=4, sand=9, sandy gravel=16, gravel=25, pebbly gravel=36, and cobbles=49. This allowed substrate type to be plotted for the whole reach.

Results and Discussion

The results are presented as a series of three-dimensional plots which show the distribution and abundance of selected families across and along the whole of each experimental reach.

Substrate

Substrate variation in the three reaches on the river Blithe are indicated in Fig 6.39. Gravel is the dominant particle size in every reach but there are variations between Blithe 1-3. Silt and silty sand is largely confined to the downstream end of Blithe 1. Blithe 2 has a relatively homogenous gravel substrate but heavily overlain with silt. Blithe 3 shows more variability than the other two sites with a higher proportion of larger particle sizes.

In Gwash 3 the substrate is heterogeneous with silty margins, slightly coarser gravel in the middle of the reach with most of the largest particles at the downstream end (see Fig 6.40).

These categorisations of substrate conditions are oversimplified but present an overall picture of conditions in each reach. Data which are not included in the plots concern information on the occurrence of vegetation (algae or macrophytes) or coarse organic detritus. The River Blithe was relatively free of vegetation with only isolated patches of vegetation in contrast to the Gwash reach in which most samples contained either macrophyte or algal material.

Fauna

Faunal analyses are not complete for all reaches. Data for this interim report are presented only for Gwash 3 and Blithe 3. The distribution of total numbers per sample per reach is illustrated in Fig 6.41 for Blithe 3. There is considerable variation in numbers per sample in the reach as a whole. The most obvious trend is the generally higher numbers in the midstream section compared with the stream margins. Major trends in distribution are more clearly seen when individual families are plotted. Fig 6.42 presents distributions of 9 commonly occurring families. The patchiness of the distributions is clear but association with particular substrate conditions is not marked. This may be a consequence of the relatively heterogeneous substrate which offers a wide range of niches for the benthic fauna.

In the Gwash (see Fig 6.43) total numbers are more evenly spread over the reach than at Blithe 3 despite a substrate distribution which is much patchier. Coarse particles are almost restricted to the downstream end of the reach and silt is common at the top and along most of the margins. This substrate patchiness is reflected in the distribution of certain invertebrate families. For example, Hydropsychidae and Rhyacophilidae are restricted to the downstream end of the reach where the substrate is coarser. Simuliidae are more abundant towards the upstream weedier section as are Baetidae. Gammaridae although widespread are more common in the downstream section as are the riffle beetles Elmidae (see Fig 6.44).

The observed distributions point up the need for site specific rulings for water abstractions. Invertebrates clearly require specific conditions to flourish. Any changes in flow will alter hydraulic conditions and available habitat which will have repercussions on the distribution of the faunal community. The impact on the benthos will vary according to the river type.

SUPPLEMENTARY INVERTEBRATE STUDIES

Introduction

Habitat preference curves for this study are based largely on information held on the IFE data base which has been used to develop the predictive model RIVPACS. However these data do not include information from specific microhabitats. In order to investigate the distribution of invertebrates within these areas a series of samples were taken in microhabitats within the reaches selected for the fishing programme which includes a wide range of river types from chalk streams to upland spatey rivers.

The objectives were to determine a) whether 'microhabitats' selected from the bankside would contain different communities of invertebrates; b) whether these communities were stable across a range of river types and c) to use any appropriate data to supplement the habitat preference information obtained from the RIVPACS data base.

Study Area and Methods

Details of the river selection programme are given in Chapter 3 and need not be repeated here. At each river five microhabitats were identified which fitted as closely as possible into the following categories:-

A - SLACK, an area with no flow, often immediately downstream of an obstacle such as a submerged log or large boulder.

B - MARGINAL, an area of low or minimal flow in marginal vegetation or its roots.

C - RIFFLE, shallower part of study reach where the water flows with broken or rippling surface.

D - WEED, submerged aquatic vegetation. In the absence of macrophytic vegetation algae was sampled. In all cases sampling was confined to the vegetation, not the underlying substrate.

E - DEEPER, a deeper and more slowly flowing part of the reach where the substrate is usually finer due to increased deposition of particulate material.

Each sample consisted of a 15 second kick sample, taken in either the weed or substrate with a standard pond net. The area of disturbance was approximately one tenth of a square metre (Armitage et al. 1974). The fauna in each sample was sorted counted and identified to family level.

Results

Although the biological data have been processed the collation and analytical phases are not complete. The exception is habitat preference data which have been worked up to supplement the RIVPACS based preferences.

The preferences for depth, substrate and velocity were calculated for seven families of invertebrate for which data are available from the RIVPACS data base. The results are presented in Table 6.11 and Figs 6.45 and 6.46. In general despite the relatively low numbers of samples (40) on which the curves are based there is a good agreement between the findings from the microhabitat study and those based on the RIVPACS data. These results await further analyses.

Discussion

Analysis of the complete set of results is likely to suggest modification to the invertebrate sampling programme. Preliminary indications are that microhabitats as identified in this project are not sufficiently discrete to obtain the fine focusing needed to identify precise conditions required by the benthos.

ESMS I = 15.5.91 ESMS II = 27.6.91

Fish density /100 m²

	Trout	Salmon	Dace	Gudgeon	Roach	Minnow	Pike	Flounder	Grayling	Eel
ESMS I										
R1	0.8±0.0	0.3±0.0	14.2±0.0	9.5±1.9	x	24.1±7.0	x	2.2±0.0	x	* 20.6
R2	* 0.2	x	15.5±1.4	* 13.4	* 2.1	* 6.6	x	4.7±0.6	x	* 19.5
R3	* 0.6	x	7.6±2.3	23.0±11.0	x	16.0±3.6	x	5.5±0.5	x	37.8±7.6
ΣR	* 0.5	* 0.1	12.4±0.9	* 15.3	* 0.7	* 15.6	x	4.1±0.3	x	* 26.0
ESMS II										
R1	0.8±0.0	3.0±0.8	14.7±2.2	* 4.0	x	* 17.1	x	* 2.5	x	5.8±3.1
R2	x	x	16.9±11.6	1.6±0.0	2.1±0.7	8.9±1.3	* 0.5	x	x	5.2±1.0
R3	* 0.4	x	9.2±0.7	5.8±0.8	x	* 12.5	* 0.2	* 0.6	5.1±0.8	x
ΣR	* 0.4	* 1.0	13.6±3.9	* 3.8	* 0.7	* 12.8	* 0.2	* 1.0	* 1.7	* 3.7

***Table 6.10** Fish density estimates for the East Stoke Mill stream ESMS in May and June 1991. See text for details.*

Gammaridae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	1	0.11	4.71	13.89	1	0.11	0.31
pg	19	14	0.74	31.22	92.11	428	22.53	62.82
sa	7	5	0.71	30.27	89.29	251	35.86	100.00
si	5	4	0.80	33.90	100.00	36	7.20	20.08
	40	24	2.36			716	65.69	
Heptageniidae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	4	0.44	74.07	100.00	69	7.67	100.00
pg	19	3	0.16	26.32	35.53	45	2.37	30.89
sa	7	0	0.00	0.00	0.00	0	0.00	0.00
si	5	0	0.00	0.00	0.00	0	0.00	0.00
	40	7	0.60			114	10.04	
Leptophlebiidae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	1	0.11	17.09	38.89	1	0.11	6.94
pg	19	1	0.05	8.10	18.42	4	0.21	13.16
sa	7	2	0.29	43.96	100.00	10	1.43	89.29
si	5	1	0.20	30.77	70.00	8	1.60	100.00
	40	5	0.65			23	3.35	
Ephemeridae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	2	0.22	38.31	100.00	10	1.11	100.00
pg	19	4	0.21	36.30	94.74	13	0.68	61.58
sa	7	1	0.14	24.63	64.29	4	0.57	51.43
si	5	0	0.00	0.00	0.00	0	0.00	0.00
	40	7	0.58			27	2.37	
Chloroperlidae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	2	0.22	58.48	100.00	5	0.56	100.00
pg	19	3	0.16	41.55	71.05	9	0.47	85.26
sa	7	0	0.00	0.00	0.00	0	0.00	0.00
si	5	0	0.00	0.00	0.00	0	0.00	0.00
	40	5	0.38			14	1.03	
Leuctridae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	6	0.67	38.76	100.00	70	7.78	100.00
pg	19	8	0.42	24.48	63.16	110	5.79	74.44
sa	7	3	0.43	24.92	64.29	18	2.57	33.06
si	5	1	0.20	11.63	30.00	2	0.40	5.14
	40	18	1.72			200	16.54	
Sericostomatidae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	1	0.11	10.48	25.93	1	0.11	4.86
pg	19	6	0.32	29.79	73.68	11	0.58	25.33
sa	7	3	0.43	40.43	100.00	16	2.29	100.00
si	5	1	0.20	18.87	46.67	3	0.60	26.25
	40	11	1.06			31	3.58	

***Table 6.11** Frequency of occurrence and abundance of selected families together with weighted % and habitat suitability (suit) for substrate (bc, boulders/cobbles, pg, pebbles/gravel, sa, sand, si, silt); depth (categories as indicated based on depths in cm); and velocity (categories as indicated (cm per second) in a data set of 40 samples obtained from 5 'microhabitats' on each of 8 rivers (Blithe, Exe, Gwash, Hodder, Lambourn, Lymington, Millstream, and Wye).*

Gammaridae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	11	0.55	31.25	77.00	207	10.35	33.16
2 (>25-50)	14	10	0.71	40.58	100.00	437	31.21	100.00
3 (>50-100)	6	3	0.50	28.41	70.00	72	12.00	38.44
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	24	1.76			716	53.56	
Heptageniidae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	6	0.30	81.08	100.00	112	5.60	100.00
2 (>25-50)	14	1	0.07	19.31	23.81	2	0.14	2.55
3 (>50-100)	6	0	0.00	0.00	0.00	0	0.00	0.00
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	7	0.37			114	5.74	
Leptophlebiidae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	3	0.15	51.72	100.00	13	0.65	91.00
2 (>25-50)	14	2	0.14	49.26	95.24	10	0.71	100.00
3 (>50-100)	6	0	0.00	0.00	0.00	0	0.00	0.00
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	5	0.29			23	1.36	
Ephemeridae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	4	0.20	39.22	100.00	15	0.75	75.00
2 (>25-50)	14	2	0.14	28.01	71.43	6	0.43	42.86
3 (>50-100)	6	1	0.17	32.68	83.33	6	1.00	100.00
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	7	0.51			27	2.18	
Chloroperlidae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	4	0.20	54.05	100.00	11	0.55	100.00
2 (>25-50)	14	0	0.00	0.00	0.00	0	0.00	0.00
3 (>50-100)	6	1	0.17	45.05	83.33	3	0.50	90.91
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	5	0.37			14	1.05	
Leuctridae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	13	0.65	50.39	100.00	180	9.00	100.00
2 (>25-50)	14	2	0.14	11.07	21.98	15	1.07	11.90
3 (>50-100)	6	3	0.50	38.76	76.92	5	0.83	9.26
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	18	1.29			200	10.90	
Sericostomatidae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	7	0.35	42.17	100.00	12	0.60	56.00
2 (>25-50)	14	2	0.14	17.21	40.82	15	1.07	100.00
3 (>50-100)	6	2	0.33	40.16	95.24	4	0.67	62.22
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	11	0.83			31	2.34	

Table 6.11 contd.

Gammaridae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	10	0.77	27.47	100.00	234	18.00	41.47
1-25 1	5	2	0.4	14.29	52.00	217	43.40	100.00
>25-50 2	10	5	0.5	17.86	65.00	38	3.80	8.76
>50-100 3	4	2	0.5	17.86	65.00	90	22.50	51.84
>100 4	8	5	0.63	22.32	81.25	137	17.13	39.46
	40	24	2.79			716	105	
Heptageniidae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	3	0.23	28.85	92.31	51	3.92	64.05
1-25 1	5	1	0.2	25.00	80.00	12	2.40	39.18
>25-50 2	10	1	0.1	12.50	40.00	2	0.20	3.27
>50-100 3	4	0	0	0.00	0.00	0	0.00	0.00
>100 4	8	2	0.25	31.25	100.00	49	6.13	100.00
	40	7	0.78			114	12.6	
Leptophlebiidae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	4	0.31	61.54	100.00	15	1.15	100.00
1-25 1	5	0	0	0.00	0.00	0	0.00	0.00
>25-50 2	10	2	0.2	40.00	65.00	8	0.80	69.33
>50-100 3	4	0	0	0.00	0.00	0	0.00	0.00
>100 4	8	0	0	0.00	0.00	0	0.00	0.00
	40	6	0.51			23	1.95	
Ephemeridae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	4	0.31	34.19	100.00	14	1.08	71.79
1-25 1	5	1	0.2	22.22	65.00	6	1.20	80.00
>25-50 2	10	0	0	0.00	0.00	0	0.00	0.00
>50-100 3	4	1	0.25	27.78	81.25	6	1.50	100.00
>100 4	8	1	0.13	13.89	40.63	1	0.13	8.33
	40	7	0.88			27	3.9	
Chloroperlidae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	0	0	0.00	0.00	0	0.00	0.00
1-25 1	5	1	0.2	25.00	80.00	2	0.40	57.14
>25-50 2	10	2	0.2	25.00	80.00	7	0.70	100.00
>50-100 3	4	1	0.25	31.25	100.00	1	0.25	35.71
>100 4	8	1	0.13	15.63	50.00	4	0.50	71.43
	40	5	0.78			14	1.85	
Leuctridae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	5	0.38	16.72	61.54	93	7.15	86.71
1-25 1	5	3	0.6	26.09	96.00	16	3.20	38.79
>25-50 2	10	4	0.4	17.39	64.00	15	1.50	18.18
>50-100 3	4	1	0.25	10.87	40.00	10	2.50	30.30
>100 4	8	5	0.63	27.17	100.00	66	8.25	100.00
	40	18	2.26			200	22.6	
Sericostomatidae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	4	0.31	23.67	82.05	5	0.38	13.74
1-25 1	5	1	0.2	15.38	53.33	14	2.80	100.00
>25-50 2	10	2	0.2	15.38	53.33	4	0.40	14.29
>50-100 3	4	1	0.25	19.23	66.67	4	1.00	35.71
>100 4	8	3	0.38	28.85	100.00	4	0.50	17.86
	27	7	1.33			26	5.08	

Table 6.11 contd.

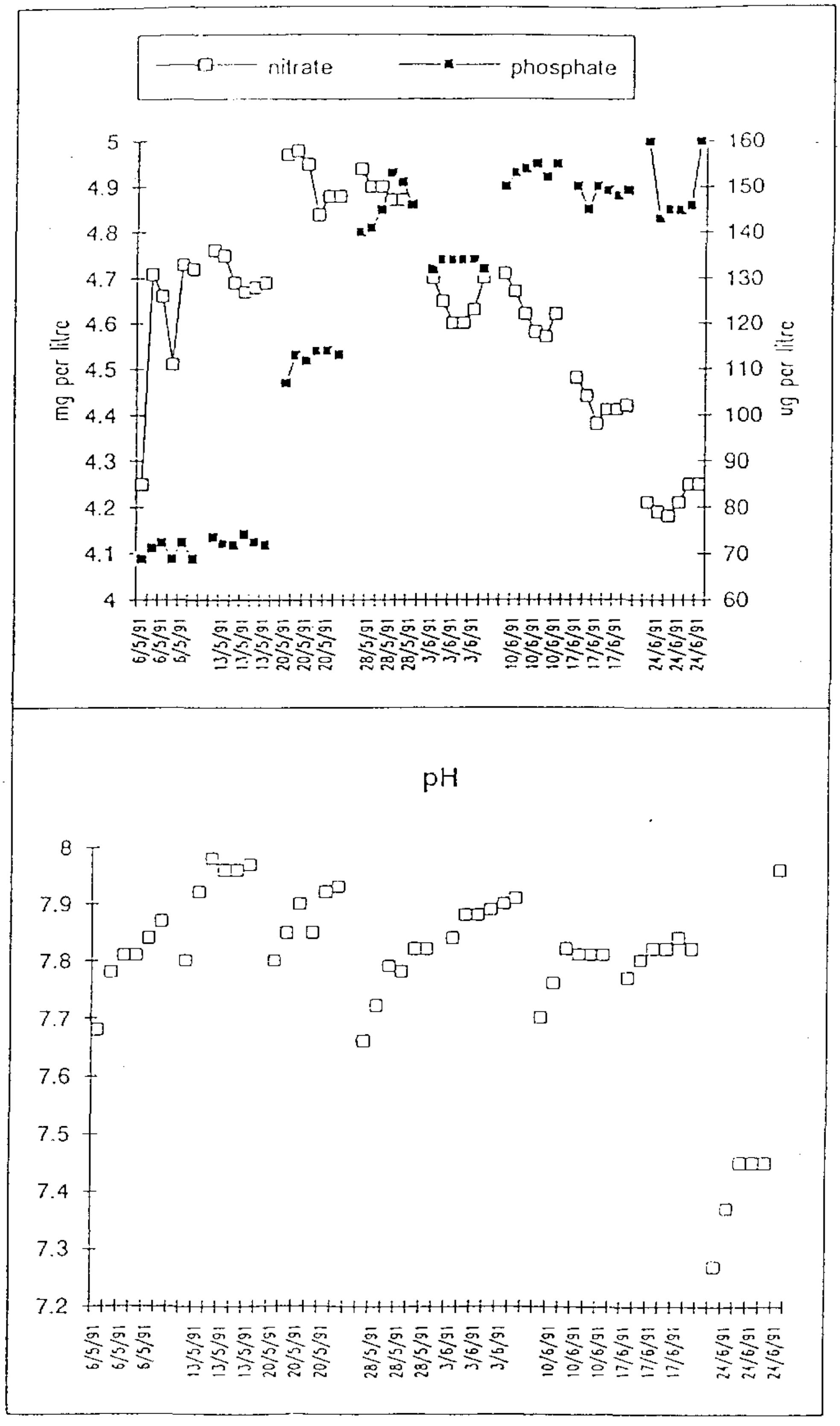


Figure 6.32 The variation in values of nitrate and phosphate, and pH in the first two months of the study. Each grouping of six points per date represent the sample locations noted in Fig. A -working from left to right Frome, upstream of fluvarium, upper reach, middle reach, lower reach and 50m downstream from confluence with Frome.

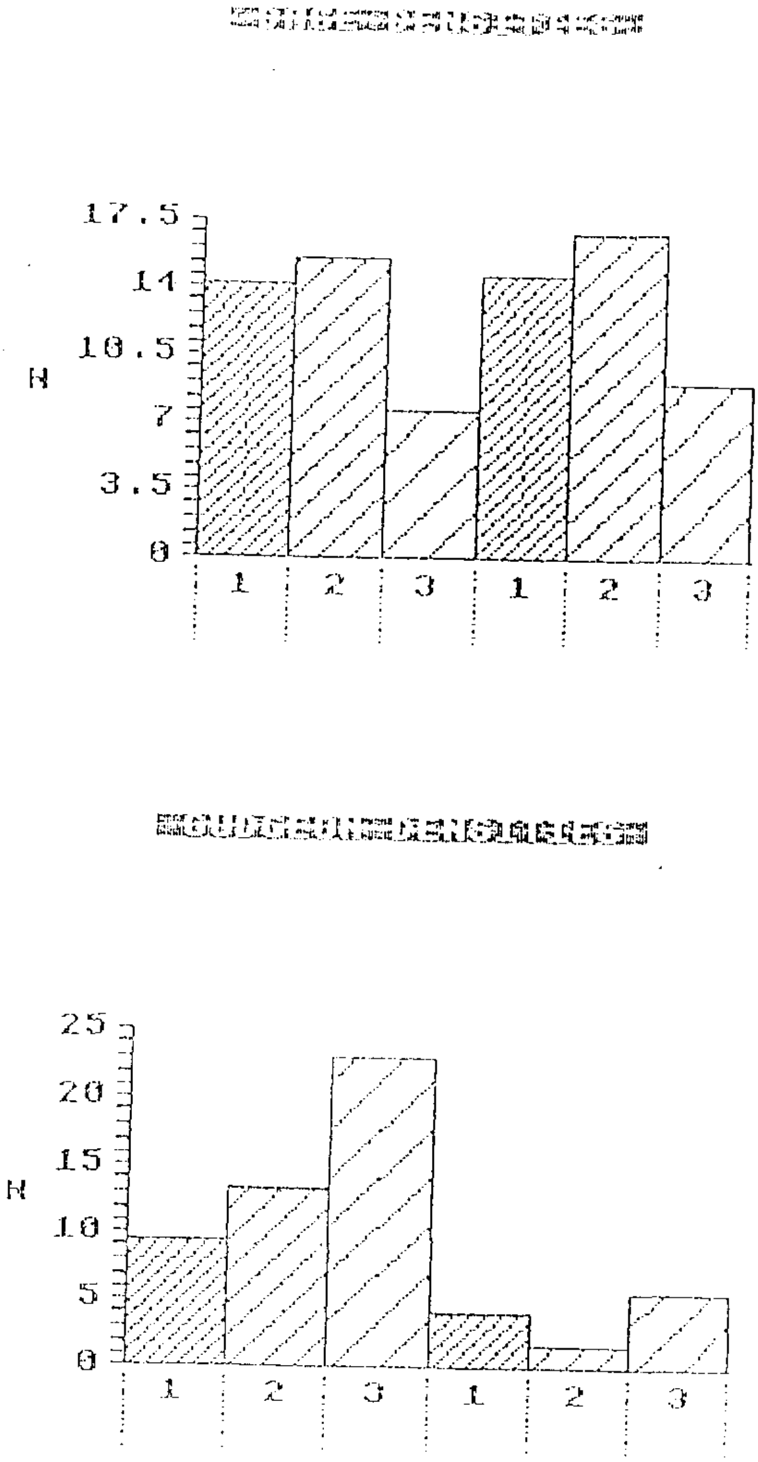
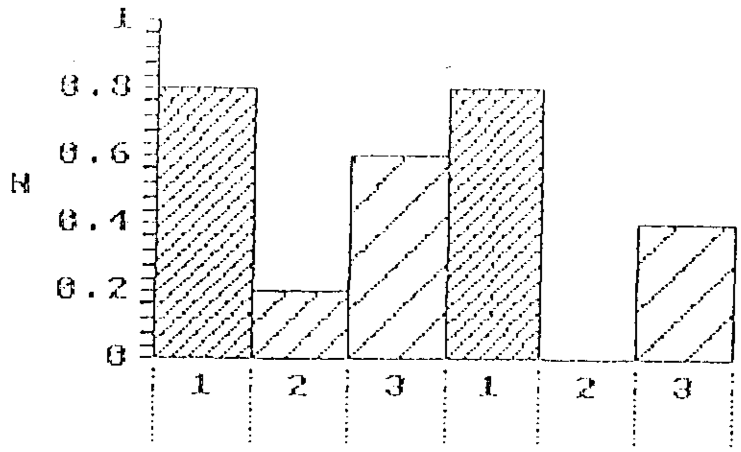


***Figure 6.33** The densities (N= number per 100m2) of dace and gudgeon in lower (1), middle (2) and upper (1) reaches of the experimental section of the Mill stream for May (left) and June (right).*



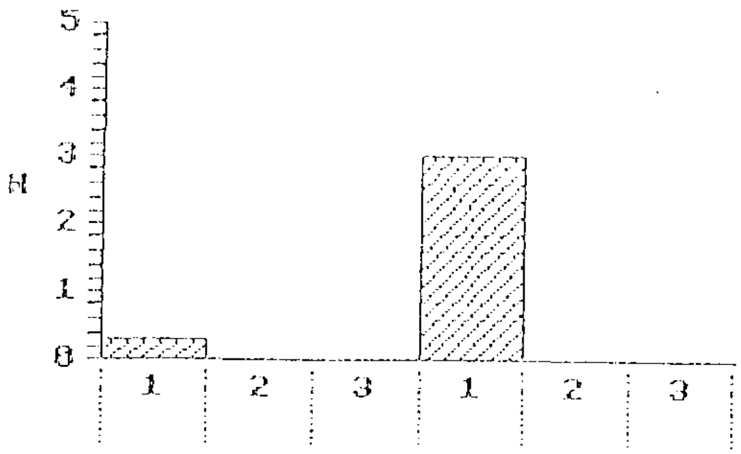


***Figure 6.34** The densities (N= number per 100m²) of trout and salmon in lower (1), middle (2) and upper (1) reaches of the experimental section of the Mill stream for May (left) and June (right).*

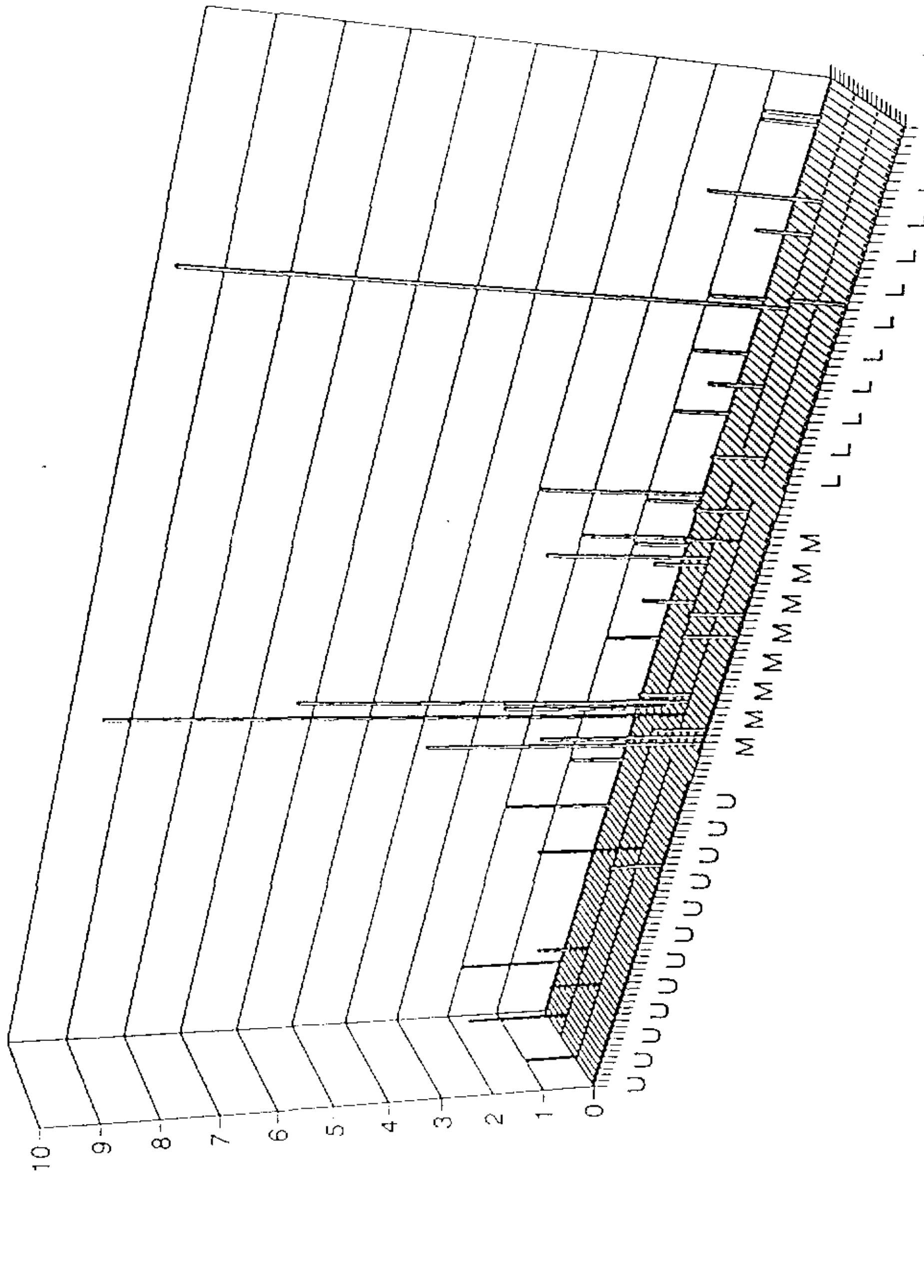


Figure 6.35 The distribution of Dace in the experimental section of the Mill stream, May 1991. (U upper, M middle, L lower).

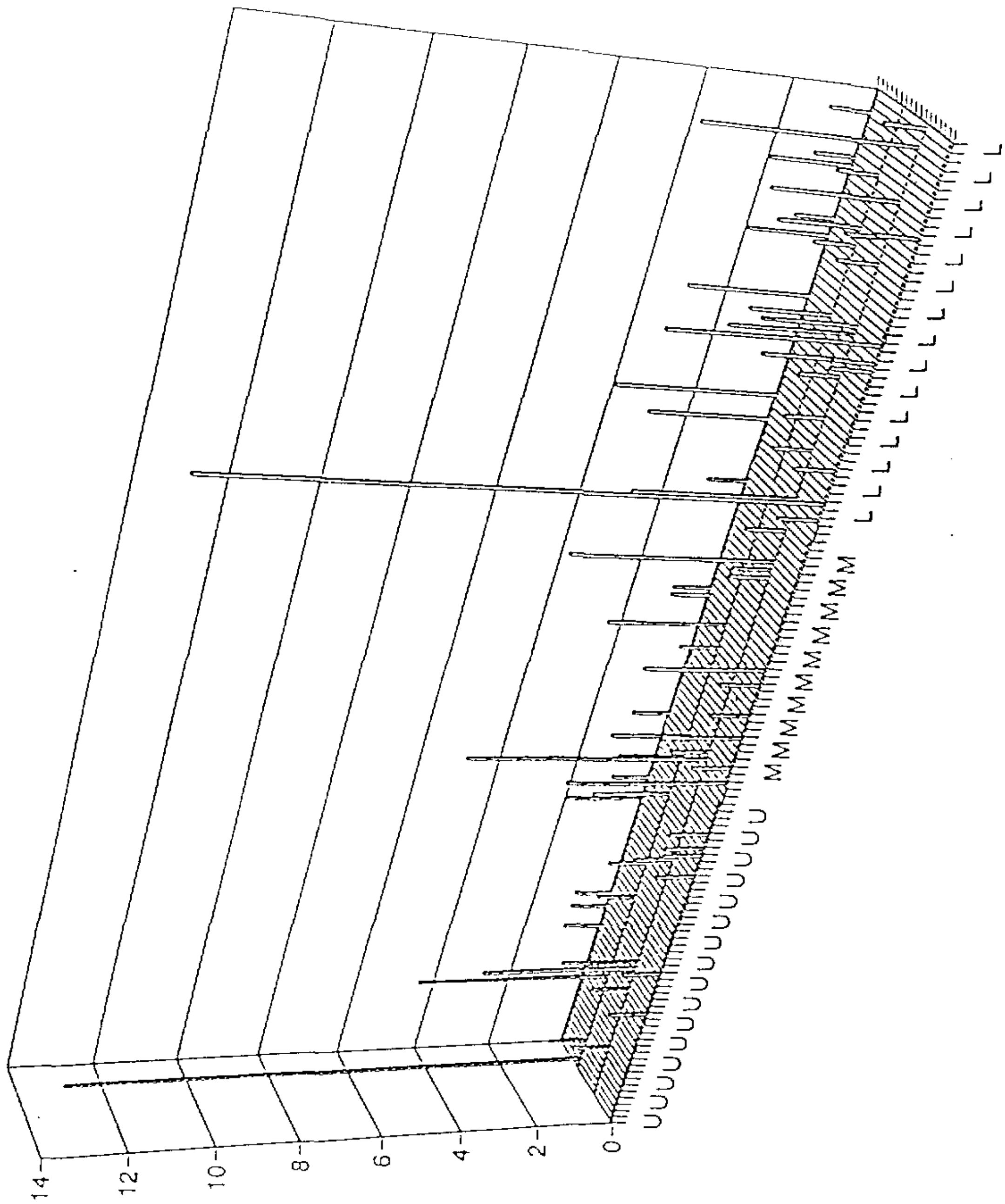


***Figure 6.36** The distribution of Dace in the experimental section of the Mill stream, June 1991. (U upper, M middle, L lower).*

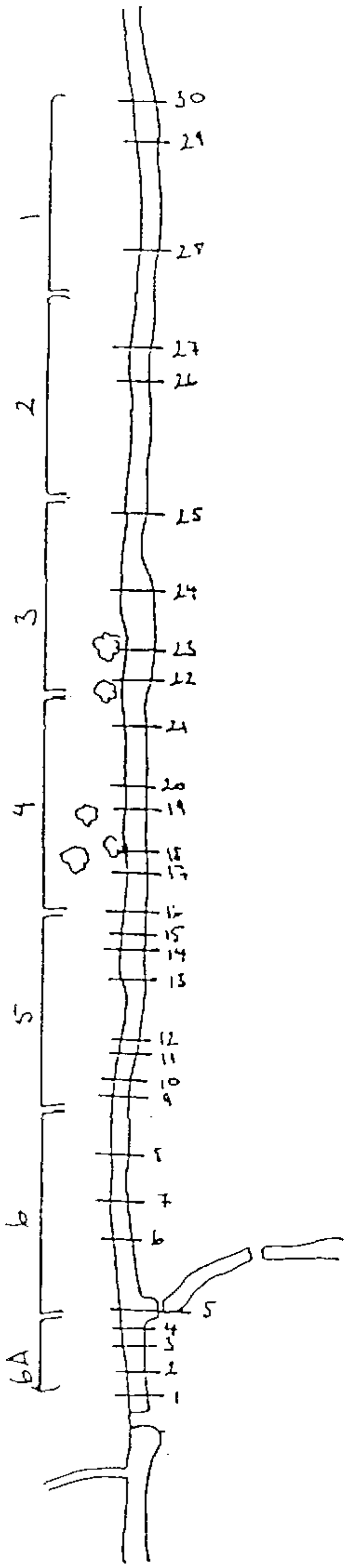


***Figure 6.37** Sketch of Mill stream experimental zone showing the relationship between hydrological survey pegs and botanical zones.*

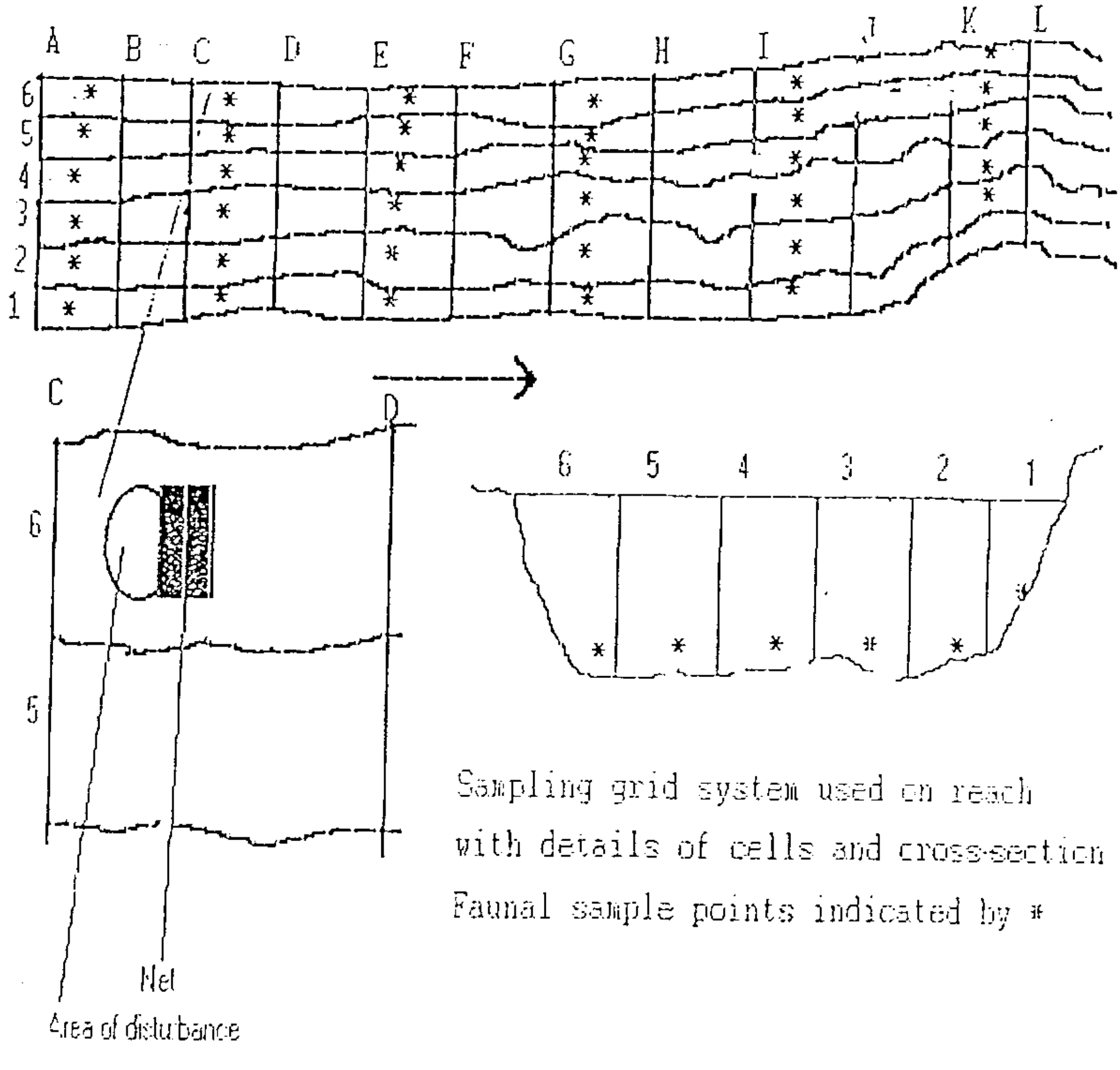


Figure 6.38 The sampling grid system employed in the Rivers Gwash and Blithe.

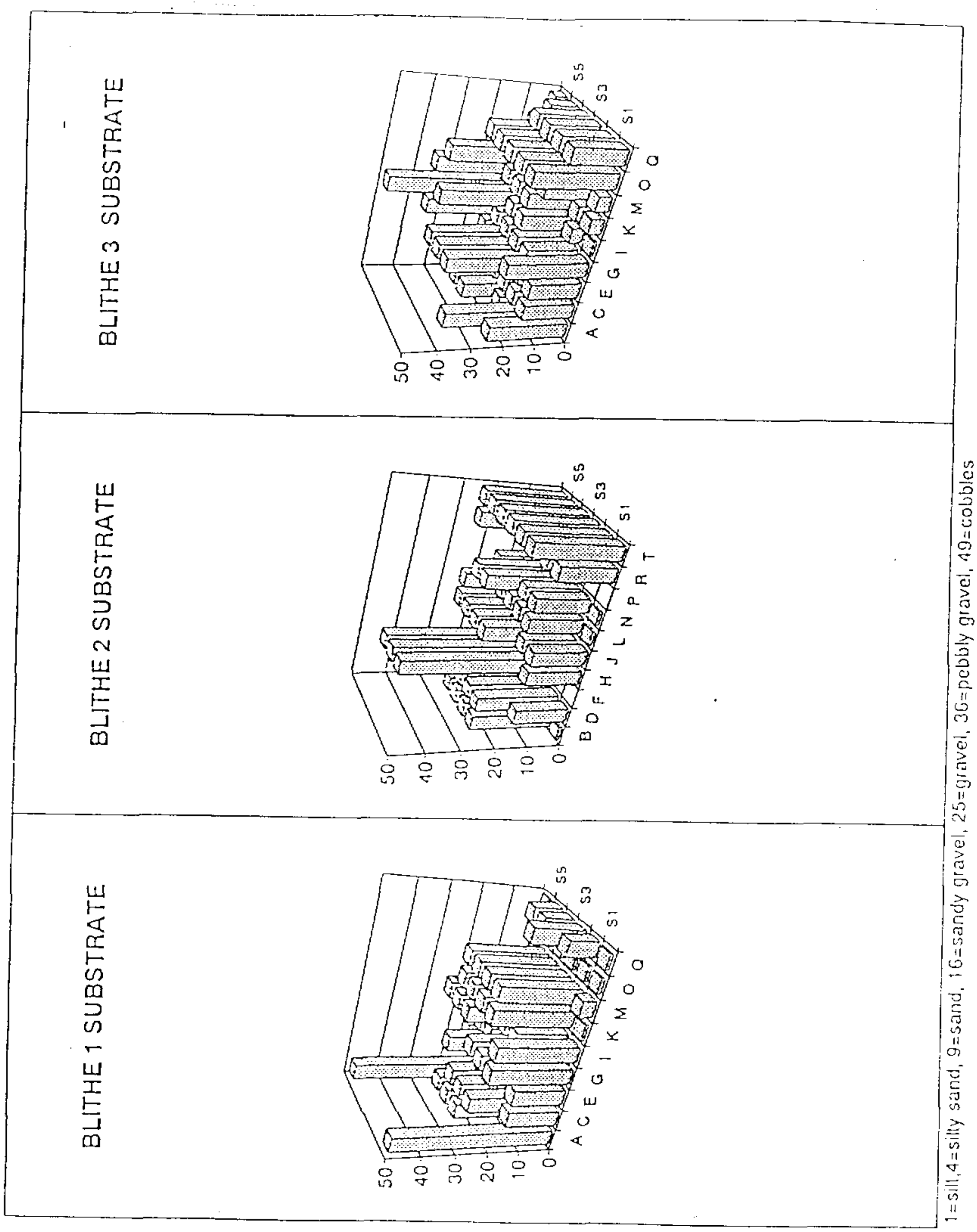


Figure 6.39 The distribution of dominant substrate particle size in each of the three reaches sampled on the River Blithe.

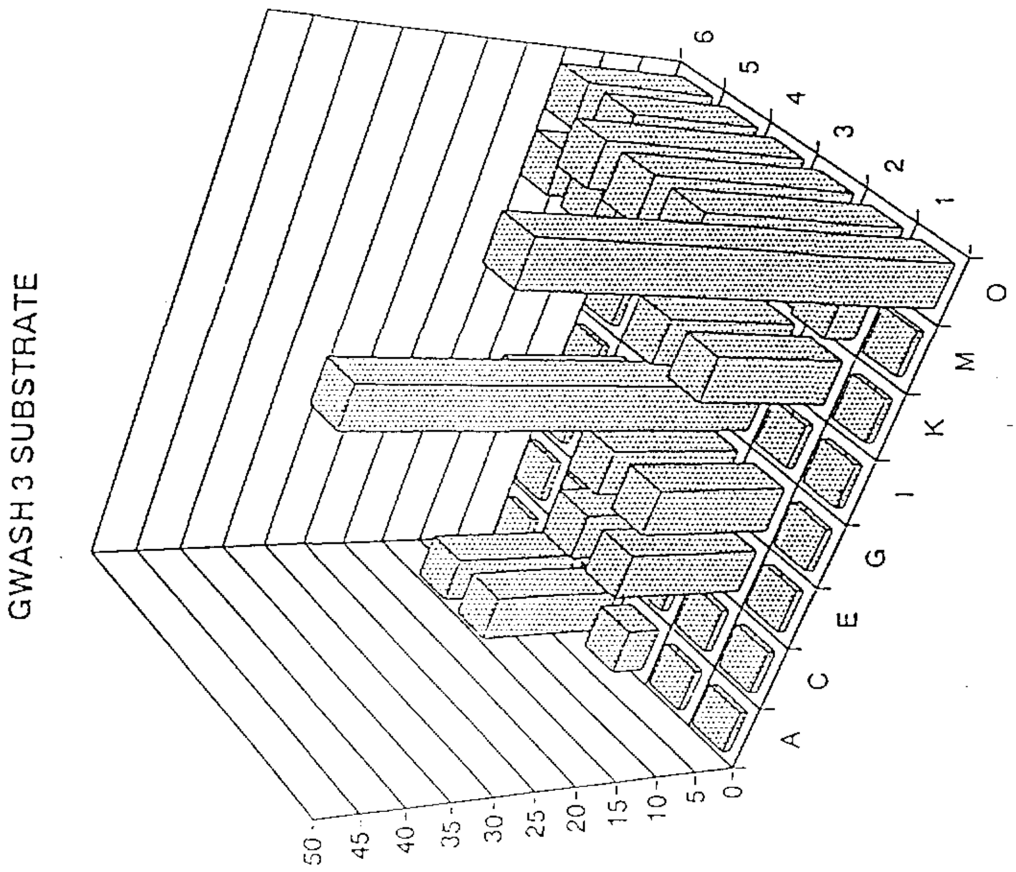


***Figure 6.40** The distribution of dominant substrate particle size at site 3 on the River Gwash.*

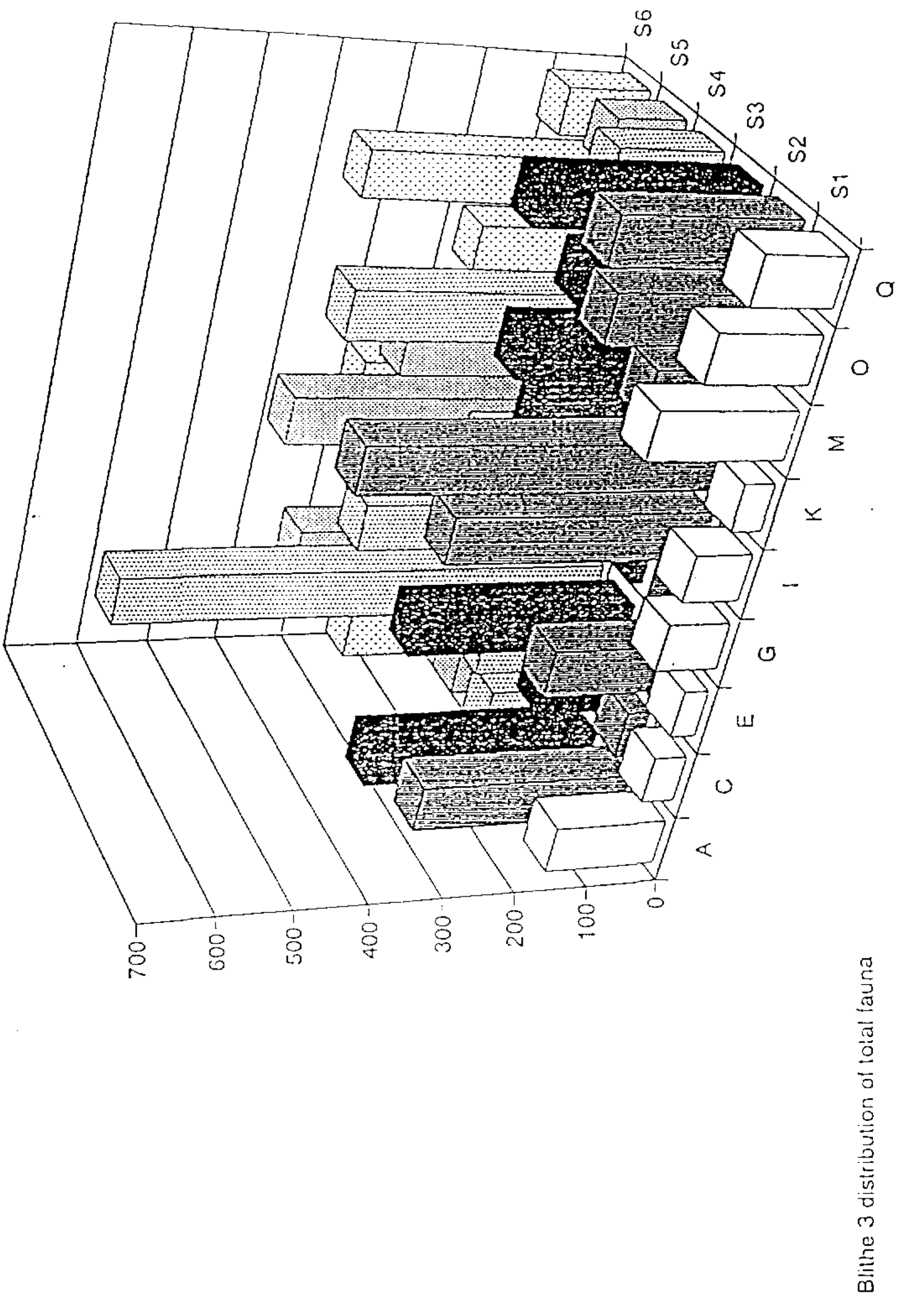


Figure 6.41 The distribution of total fauna (numbers per sample) at site 3 on the River Blithe.

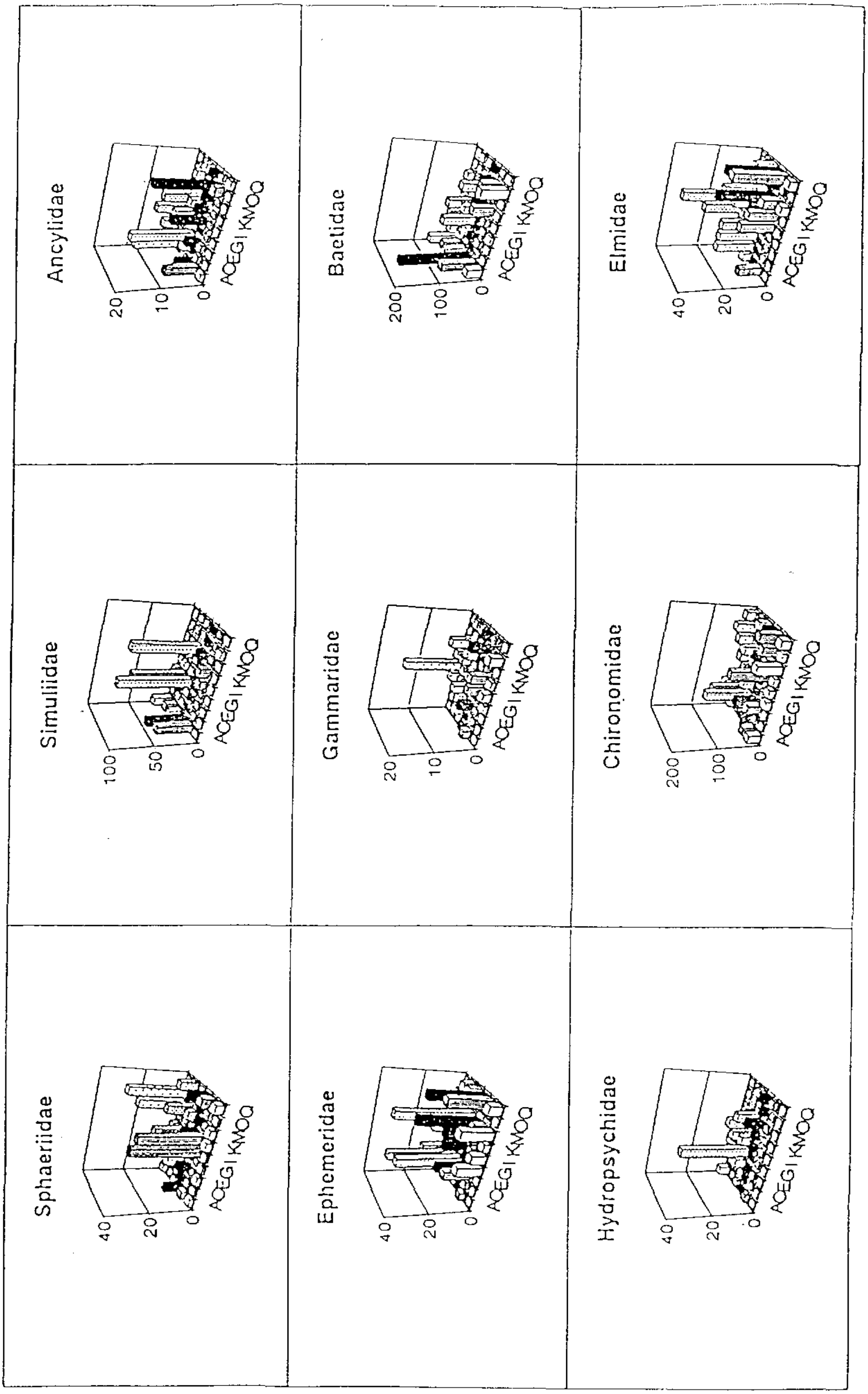


Figure 6.42 The distribution of selected families (numbers per sample) at Blithe 3.

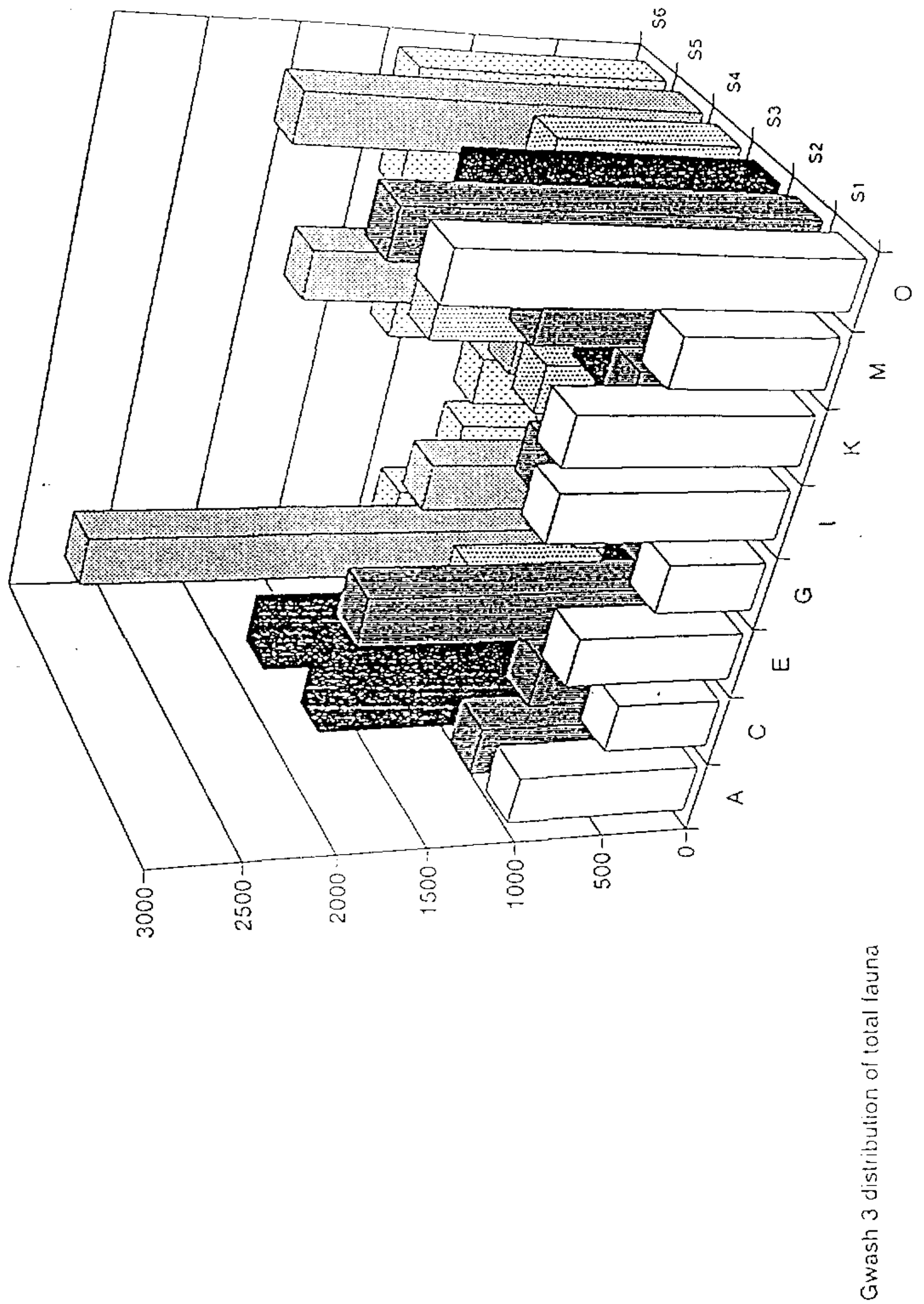


Figure 6.43 The distribution of total fauna (numbers per sample) at site 3 on the River Gwash.

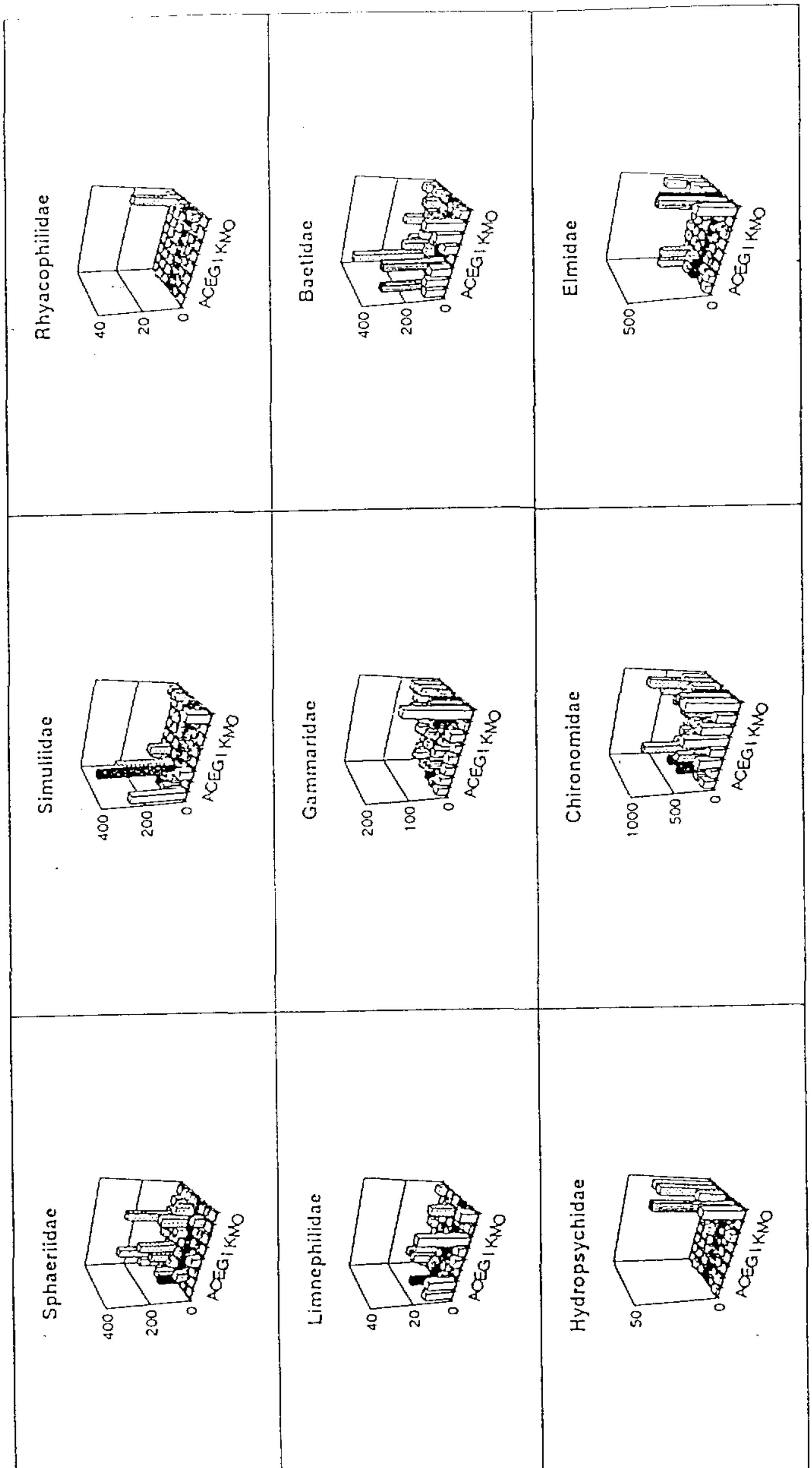


***Figure 6.44** The distribution of selected families (numbers per sample) at site 3 on the River Gwash.*

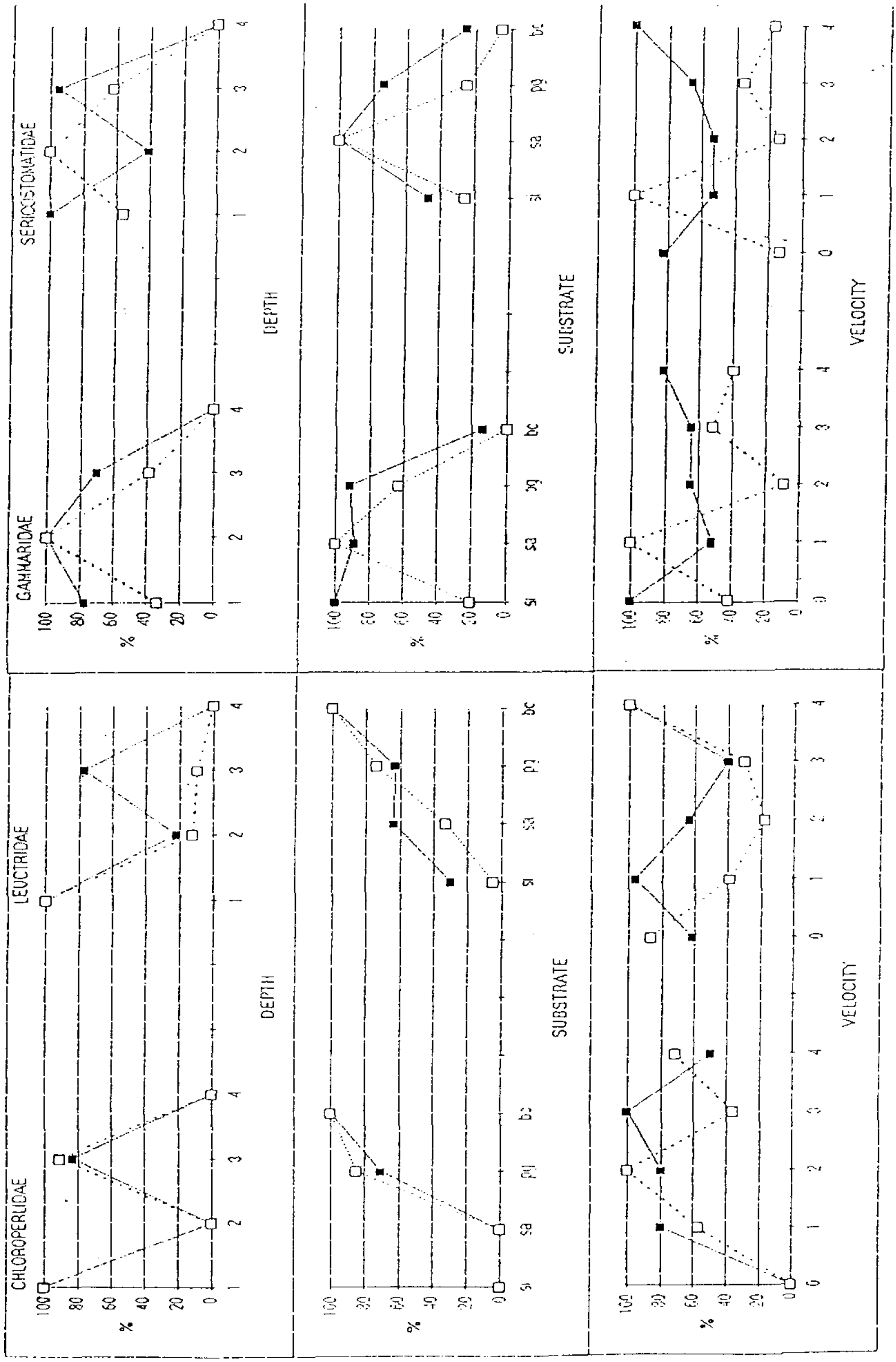


Figure 6.45 Habitat suitability curves for Chloroperlidae, Leuctridae, Gammaridae, and Sericostomatidae based on data in Table 6.11.

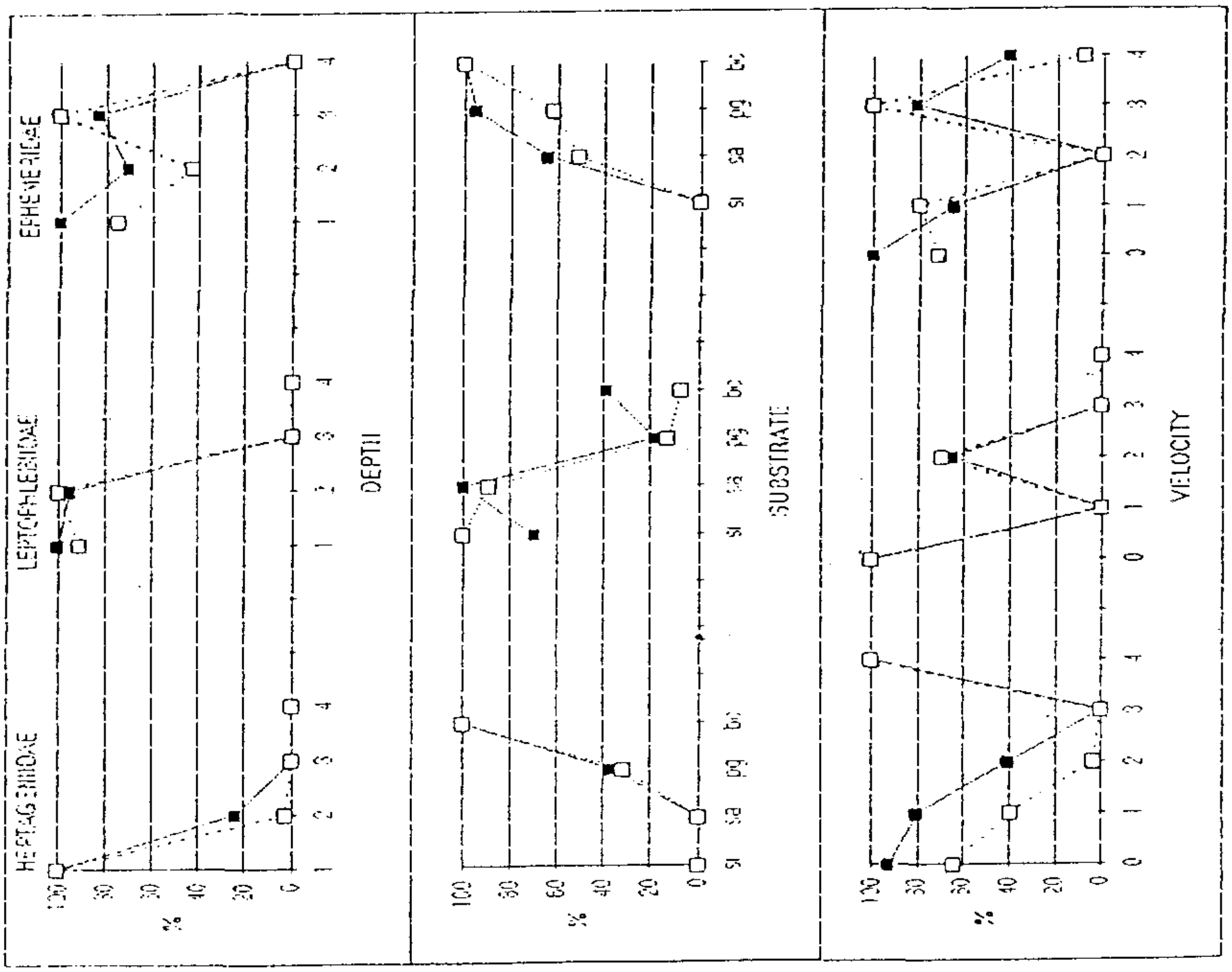


Figure 6.46 Habitat suitability curves for Heptageniidae, Leptophlebiidae and Ephemeridae based on data in Table 6.11.

7 Calibration

In this section we discuss calibration procedures for the hydraulic and habitat models used in PHABSIM simulations. Many of the recommendations made here result from experiences of users in the U.S.A. and were made as part of the IF310 "Using the PHABSIM System" given by Dr Thomas Hardy of the U.S. Fish & Wildlife Service at Utah State University, September 1991

7.1 HYDRAULIC MODELS : THEORY AND CALIBRATION IFG4

Water Surface Profiles

IFG4 predicts water surface profiles using a standard stage-discharge approach at each transect independently:

$$S\text{-}SZF = aQ^b$$

where S is the stage at discharge Q and SZF is the stage of zero flow. For any transect not controlled by a downstream transect SZF is the lowest point on the transect. For a transect controlled by a downstream transect SZF is the lowest point on the downstream control.

Measurement of water surface elevations are made at a minimum of three calibration discharges. The coefficients a and b are then derived from a linear regression of log(Q) vs log(S-SZF) for the calibration data. Water surface elevations can then be predicted for the simulation discharges using these values of a and b.

A common effect observed in practice is that the stage-discharge relationship may exhibit a hysteresis as flows rise and then fall, as shown in Fig 7.1 below.

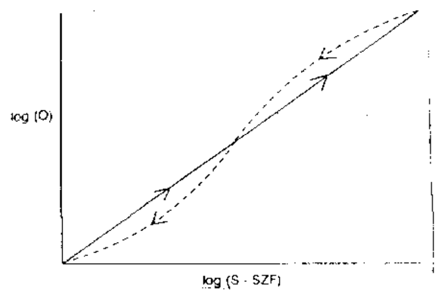


Fig 7.1 Hysteresis effect in stage-discharge relationship

In order to minimise errors in the presence of such possible effects it is recommended that calibration flows be measured in strictly increasing or decreasing order (on the increasing or falling limb of the stage-discharge curve).

Another effect which may perturb a log-linear stage-discharge relationship is the scouring of sediment from the bed in sand bed rivers; water surface levels may remain constant with increasing discharge as sediment is scoured away. The IFG4 model assumes a completely rigid boundary of the bed. Since such effects are more pronounced at higher discharges we may expect the model to perform best at low discharges.

If a non-linear log(Q) vs log(s) is observed when the IFG4 model is run on data for a given transect it may also be due to any of the following:

(i) Survey error.
(ii) A truly non-linear relationship due to a missed control downstream.
(iii) This transect may be a control at low discharges but nay cease to be a control at higher discharges.

In the calibration of IFG4 to predict water surface profiles we must define which discharge is to be associated with the measured stage at each transect for the calibration data sets. By changing the IOC *input/output control options* we can choose either Q1, the measured discharge at the transect or Q2, the "best estimate" of discharge for the reach. The best estimate may be an average of measured discharges at all cross sections, the discharge at a transect thought likely to yield a good estimate or from gauged flow data if available.

It is recommended that in the case of multiple calibration sets a consistent choice of either Q1 or Q2 be made throughout calibration. The recommendation from the IF310 course is to use Q1 to develop the stage-discharge relationship. Using Q1 generally gives a more realistic velocity distribution, with the associated VAFs (velocity adjustment factors) closer to unity.

Velocity Prediction

For multiple velocity sets IFG4 uses the relationship

$$V_i = C_i Q^{D_i}$$

at each data point. In practice this relationship has frequently been seen to fail and its use is not recommended. An alternative approach is to build up the WUA vs Q relationship in a piece-wise manner using velocity data from each calibration flow independently over different ranges of discharge, ie for high flows run the model using velocity data from the highest velocity calibration set only etc. Some post-processing will be required to give a continuous WUA vs Q relationship.

For the prediction of velocities within PHABSIM we have a choice of using either the IFG4 or the WSP model only,since MANSQ predicts water surface elevations only. The IF310 course recommends the use of the IFG4 model in all cases. Calibration of the WSP model to predict velocities by point-by-point adjustment of Manning's n can be very time consuming owing to the dependence of values at neighbouring transects in the computations.

An outline step-by-step guide to the method of velocity calibration using IFG4 recommended on the IF310 course is as follows:

(i) Predict velocities at one calibration flow with IFG4 and compare predicted and observed values of point velocities across each transect.

(ii) Alter point values of Manning's n to adjust any unacceptable velocities.

(iii) Run the model at a number of simulation discharges over the range that predicted water surface profiles (possibly those from WSP or MANSQ) are thought to be reliable.

(iv) Repeat steps (ii) and (iii) ,paying particular attention to the likelihood of unacceptably high velocities at the edge cells as the discharge increases.

This process should be repeated at each of the measured calibration sets available. After inspection of the predicted velocities over the full range of simulation discharges the range to be best associated with each calibration set may be identified.

As mentioned above seperate PHABSIM simulations can be performed, running the IFG4 model to predict velocities using different single sets of calibration data over distinct portions of the flow regime. The resulting expressions of WUA for each distinct portion of the flow regime must be post-processed in some manner if a continuous representation of WUA vs Q.

In the prediction of velocities the same adjustment to the value of Manning's n is applied to each point across a given transect as the discharge varies, despite the variation in channel shape. Clearly for a channel shaped as in Fig 7.2 below this would seem inappropriate.

Fig 7.2 Example of non U-shaped channel cross section

As a result large errors in velocity predictions for the simulation discharges may occur, particularly for cells at the edge of the stream. For this reason the velocity profile predicted for each transect should be inspected. If velocities are seen to be unrealistically high the value of Manning's n can be manually adjusted at the offending points and the simulation repeated.

Mansq

Water surface profiles

MANSQ may be used to predict water surface profiles when IFG4 fails to give sensible stage-discharge relationships. As an alternative to the stage-discharge relationship used in IFG4, MANSQ uses an approach based on Manning's equation. The model assumes a constant value for Manning's n to predict water surface profiles at the simulation discharges. In the process of calibration we must choose a value for beta coefficient which acts as a roughness modifier, effectively altering Manning's n as the discharge varies. In order to estimate Beta we choose a starting value given by the output from a simulation with one calibration data set only. We then run the model using this Beta coefficient for the remaining calibration discharges. By altering the value of Beta iteratively we try to match the predicted values of the water surface at the remaining calibration flows as closely as possible to the observed values. Essentially, altering Beta alters the slope of the regression of log(Q) vs log(S) as shown in Fig 7.3 below.

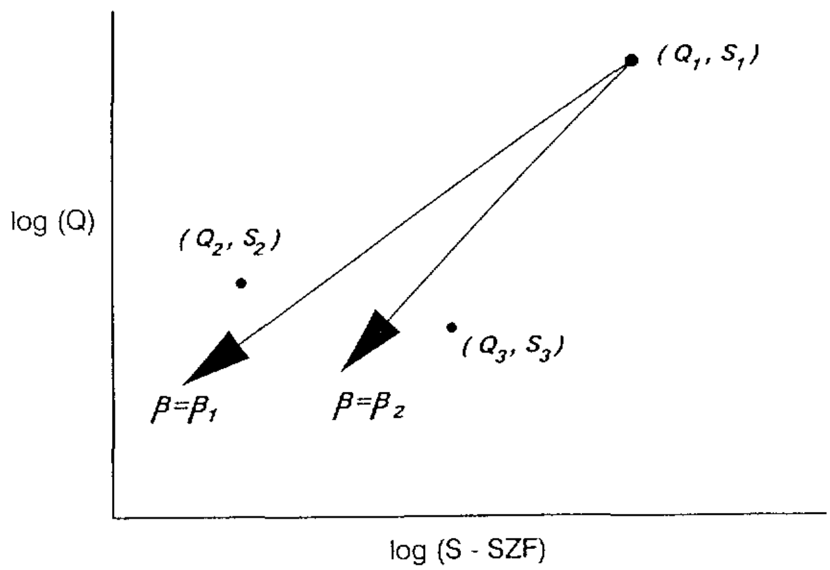


Fig 7.3 Effect of altering Beta coefficient in MANSQ calibration

The use of the beta coefficient in MANSQ can mimic theoretical hydraulic behaviour at higher discharges in riffles and runs better than IFG4,but it is known to perform badly in pools.

Wsp

Water Surface Profiles

WSP is a standard step-backwater method. It is the only hydraulic model within PHABSIM which conserves mass and energy. The value of Manning's n used in the model can be varied as a function of discharge. In general a constant n value is used across each transect.

The model requires values of the water surface profile at the most downstream transect to be given for each of the simulation discharges. These may be provided by using IFG4 or MANSQ at this transect prior to calibrating WSP.

The basic steps in the calibration of the WSP model are as follows:

a) Single calibration data set

(i) Estimate a value for Manning's n for each transect (n=0.065 throughout is recommended as a reasonable starting point).

(ii) Run the WSP model using data from one calibration flow only and compare predicted and observed water surface profiles at each transect as in Fig 7.4 below.

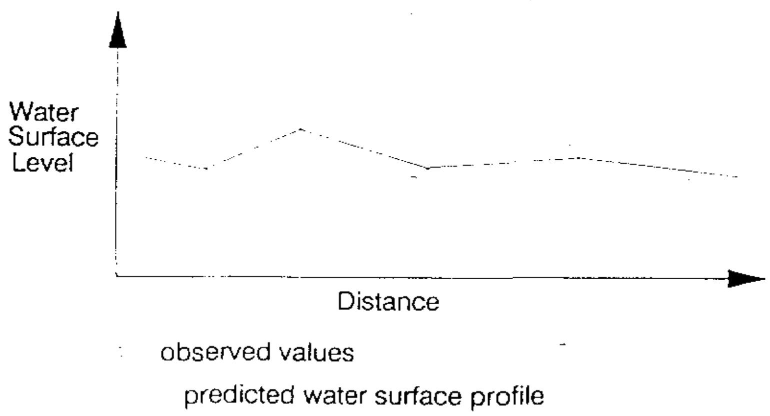


Fig 7.4 Observed and simulated water surface profile in WSP calibration

(iii) Alter n values for each transect accordingly: If the predicted water surface is too high then n is too high. Since transects are modelled in a dependent manner altering Manning's n at one transect will affect the predicted water surface level at neighbouring transects both up and downstream.

(iv) Repeat steps (ii) and (iii) until a satisfactory match between predicted and observed water surfaces is achieved.

(V) Set the overbank and main channel roughness modifiers equal to unity (since we have only one set of calibration data we have no basis on which to vary roughness with discharge)

If there is a problem matching observed and measured water surface levels in this manner due to predicted values being either consistently too high or too low a possible source of error is in the measurement of inter-transect distance. The WSP model, in its energy balance computation computes the inter-transect distance as the thalweg distance. By changing the appropriate IOC option this may be substituted by the right bank distance,left bank distance or average of left and right bank distances. One of these alternative choices may yield better agreement between predicted and observed values.

b) Multiple Calibration Data Sets

If we have more than one calibration data set available the procedure for calibrating the WSP model is as follows:

(i) Using one of the calibration data sets only follow steps (i) to (iv) above.

(ii) Enter the remaining calibration data sets on the QARD lines, setting the roughness modifiers equal to unity, and run the model to predict water surfaces at each calibration discharge.

(iii) For the calibration sets not used in step (i) compare observed and predicted water surface levels at each transect. Adjust the roughness modifiers accordingly: this has the effect of multiplying the n values at each transect predicted by calibration of the single data set by the same constant. Thus applying different roughness modifiers for the different calibration discharges effectively alters n as the discharge varies.

(iv) Repeat steps (ii) and (iii) iteratively until the best fit between observed and predicted water surface levels is found for each additional calibration discharge.

(v) Before proceeding with a production run at the simulation discharges of interest we must supply appropriate values of the roughness modifiers for each discharge. These may be provided by plotting a regression of log(roughness modifier) vs log(Q) using data from step (iv) and picking off values of the roughness modifiers for the simulation discharges.

(vi) Having entered roughness modifiers at all simulation discharges we must supply a starting water surface level at the most downstream transect for each simulation discharge (using IFG4 or MANSQ) before the final production run.

7.2 HYDRAULIC MODELS: RECOMMENDED DATA REQUIREMENTS

The following minimum data requirements are recommended for applying the PHABSIM model:

1 set of velocities
3 stage-discharge relationships

For UK applications where stream gradients are much lower than those frequently encountered in U.S. studies it is envisaged that use of the WSP model will be necessary, since this is the only model which accounts for backwater effects. In order that variable roughness be adequately modelled it is preferable that at least three stage-discharge relationships are available at each transect.. The recommended modelling procedure is as follows:

(i) Calibrate WSP to water surface elevations
(ii) Run WSP at simulation discharges
(ii) Calibrate IFG4 to velocities
(iii) Load predicted water surface elevations from (ii) into calibrated IFG4 file
(iv) Make production runs with modified IFG4 file.

In general velocities predicted by the model will be most accurate for simulation discharges close to the velocity calibration discharge. In order that a whole flow regime be adequately modelled the collection of multiple velocity calibration data sets (at least three) is strongly advised. Seperate simulations can be performed using different velocity calibration data for different ranges of the simulation discharge.

Constraints of time and expenditure may limit the amount of field data available. If insufficient data is available to perform simulations in the manner recommended above other combinations of models can be used. Models available for use with different types of data sets are as follows:

		Models available
1)	Multiple stage-discharge measurement, WSP,MANSQ,IFG4 transects dependent	WSP, MANSQ, IFG4

2)	Multiple stage-discharge measurement, transects independent	IFG4, MANSQ
3)	Single stage-discharge measurement, transects dependent	WSP (*), MANSQ
4)	Single stage-discharge measurement, transects independent	MANSQ

(*) Starting values of water surface elevation must be provided at the most downstream section (by using MANSQ for example)

7.3 HABITAT MODELS

Habitat models within PHABSIM require very little calibration in comparison with hydraulic models. Given suitability indices and a set of predicted values of microhabitat variables from the output of hydraulic simulations the user has little control in the computation of the Weighted Usable Area using one of the habitat models in PHABSIM. This is essentially limited to the assignment of weights (upstream weighting factors) ,based on field observations and in the choice of Composite Suitability Index. The assignment of weights has already been covered in some detail in section 4.8.

Suitability Indices and Choice of Composite Suitability Index

The Weighted Usable Area (WUA) predicted by the habitat models available within PHABSIM is based on the calculation

$$WUA = A_i \times CSI_i \qquad (1)$$

Where A_i is the cell area associated with point i and CSI_i is the value of the Composite Suitability Index, a function of the predicted depth,velocity and substrate/cover value at the same point.

For each of the microhabitat variables depth,cover and substrate/cover we must supply, as input data to the habitat model functions known as Suitability Indices. One such index must be supplied for each target species of interest.

Suitability indices take values between zero and unity. Their function is to describe the relative suitability to the target species of different values of each of the microhabitat variables used in PHABSIM. Different indices are also required for each target species life-stage. Clearly the suitability indices must be well-defined for the full range of microhabitat variables predicted in the simulations.

The CSI above is a function of the suitability indices for velocity, depth and substrate/cover,ie

$$CSI_i = f(SIV(V_i), SID(D_i), SISC(SC_i))$$

where SIV,SID,SISC are the suitability indices for each of the microhabitat variables velocity, depth and substrate/cover.

The habitat models used in PHABSIM give the user a choice of three different options for the functional form f of the CSI ; a multiplicative index :

$$CSI_i = SIV(V_i) \times SID(D_i) \times SISC(SC_i)$$

a geometric mean index:

$$CSI_i = (SIV(V_i) \times SID(S_i) \times SISC(SC_i))$$

and a minimum index:

$$CSI_i = MIN(SIV(V_i), SID(D_i), SISC(SC_i))$$

Clearly the exact form of the WUA vs Q relationship given by equation (1) will depend upon the choice of CSI. In general the three different indices will tend to give WUA vs Q relationships which have the same shape but are slightly shifted in absolute terms as shown in Fig 7.5 below:

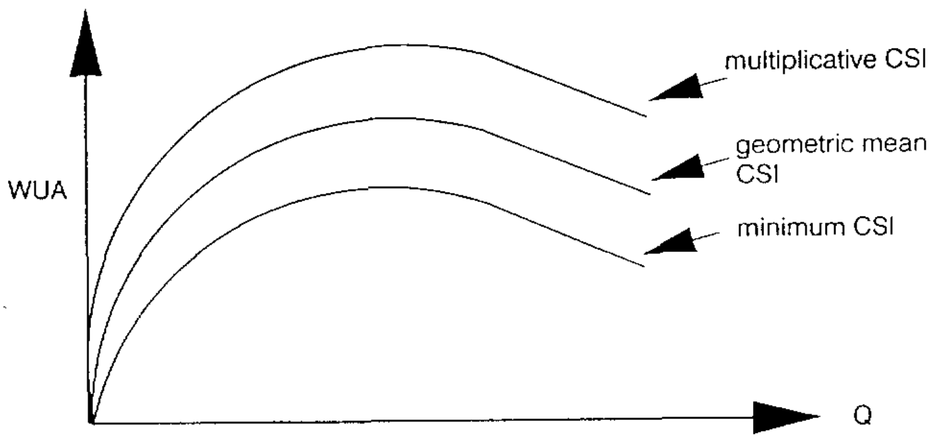


Fig 7.5 Effect of choice of CSI on WUA vs Q relationship

Since in setting EAFs we are generally interested in relative changes of WUA under different flow scenarios the exact choice of CSI in the habitat modelling process is not likely to be an important issue. The form of the individual suitability indices in relation has a much more significant effect upon the model results.

8. Forward look

8.1 PLANNED PROGRESS

Institute of Freshwater Ecology

It is intended that the fish surveys will be completed within the next three months provided that weather and river conditions are favourable and access problems have been solved. Detailed analysis of fish catch data will then begin. This will include density estimates,population structure and growth data.

Fish location maps are an aspect which developed out of the Mill Stream study and were not required by the original contract. As they are very time consuming to construct it will be necessary to reduce effort in other aspects of the work if they are to be drawn up for all of the study rivers.

Habitat preference studies for fish and invertebrates are largely complete. Remaining efforts in this area will be directed towards assessing PHABSIM predictions with reference to results obtained in the fishing surveys.

The study of invertebrate distribution along reaches of the Blithe and Gwash has raised several interesting points regarding the patchiness in distribution of benthic communities. Data from two further sites on the Blithe will be processed in the next six months. Supplementary invertebrate studies require additional data processing : time could be subtracted from this area to supplement the fish location map data if required.

Macrophyte habitat preference data will be considered in more detail, especially in relation to the role of macrophytes as providers of cover and habitat modifiers. Preliminary observations in the Mill Stream have indicated the central role played by macrophytes in habitat modification of lowland rivers. Development of these investigations is not within the remit of the current project but may be viewed as an essential 'next step' in the understanding of low flow effects on stream biota.

A major component of the remaining biological studies will be the detailed assessment of the IFIM/PHABSIM methodology in the light of model results and data from the literature.

Institute of Hydrology

The main emphasis of the studies to date has been in designing and developing techniques to collect and process data in a manner which is compatible with the current PHABSIM format, but flexible enough to cope with refinements which may be necessary if the model is to be applicable to a wide range of different UK rivers. This procedure has been rigorously defined in order that potential users can benefit from the improvements made in the area of data entry and PHABSIM data file construction. Standardisation of this procedure at an early stage will assist in the generation of long term data which is essential for model validation purposes . The collection of ecological data in a PHABSIM compatible format will provide invaluable data for improvement of the understanding of the habitat requirements of aquatic species and consequent refinement of habitat preference information.

Although there was some delay in the establishment of study sites, resulting in the fieldwork program falling slightly behind schedule, sufficient data to begin model calibration will be available shortly. Calibration and testing of the models for all data sets obtained will form a large part of the next phase of study.

Reflecting on the historical development of the IFIM using PHABSIM in the USA it would appear that improvement of the model has been focused on the development and refinement of habitat preference information and that far less effort has been spent refining hydraulic models. Since the hydraulic models are based on well-established techniques we should expect them to perform satisfactorily under UK conditions unless we violate any of their basic assumptions.

For efficient application of the model to practical problems it will be necessary to develop a clear idea of the worth of data. Analysis of model calibration results should allow the recommendation (in terms of minimum number of transects, no of data points per transect, no. of calibration flows etc.) of minimum data requirements in different situations. Clearly it is important to establish how much effort in terms of data collection is necessary to give satisfactory predictions of hydraulic variables. Equally it is important to establish, through sensitivity testing, how accurate we require our hydraulic predictions to be so that we may avoid collecting excessive amounts of data.

The only specific area identified where some refinement of the hydraulic modelling process is almost certainly required is in the modelling of flows affected to a large extent by weed growth. Data from detailed studies on the Mill Stream will be very valuable in this task.

In the habitat modelling phase of PHABSIM studies the user must specify the channel index to be either substrate,cover or any other user-designed index. The only constraint on this choice is that a suitability index must be constructed, relating relative suitability to target species of different values of the channel index. Clearly the more complex the choice of channel index, the more difficult the construction of this suitability information. The data collection procedure we employ facilitates the use of a number of different existing substrate/cover coding schemes. Moreover, collection of data in the manner described here may be used to experiment with entirely new ways of combining cover and substrate information. This area has been identified as one of the key areas of potential model development.

In this study we are considering a wide range of aquatic species.
Results from model simulations will allow comparison of WUA vs Q relationships between species and species life-stages. One of the problems we will face when we are considering the recommendation of Ecologically Acceptable Flows by interpretation of results from IFIM studies is in the choice of target species. If,for a particular species the WUA predicted is insensitive to changes in Q it would not seem appropriate to choose such a species as the target species. Conversely a species for which the WUA is highly sensitive to changes in Q may appear a good choice of target species, but it may prove difficult to sample data to improve and validate habitat preference information for the species. Clearly this is an area to which attention must be directed in the next phase of work if we are to recommend a "standard" approach to the setting of EAFs using the IFIM.

8.2 LONG TERM IMPLEMENTATION

Current pressures upon NRA Regions to deal with low flow conditions existing in many UK rivers after two severe drought years necessitate the development of some means of setting Ecologically Acceptable Flows. Stricter EEC guidelines for environmental assessment will also mean more consideration of ecological needs when future water resource schemes are proposed. Any method chosen for this purpose will have to be defensible in a public enquiry or court of law.

In the USA an IFIM study is a federal requirement as one of the steps in settling any disputes regarding instream water use, and claims made on the basis of evidence from IFIM studies have frequently been upheld. In this setting skills of negotiation may be as important to the outcome as the quality of the study. In the UK application of IFIM, improvement of study design, presentation of IFIM results, and negotiation against competing demands will be areas requiring further input,above and beyond improvement of the exact details of the modelling procedure itself.

PHABSIM has frequently faced criticism for its failure to predict changes in populations of aquatic species. The most common form of defence to this argument is that no other models exist which perform this task, indeed PHABSIM is the only predictive model relating habitat (or population) change to change in the flow regime in current use. Although, given the need for practical tools to deal with current operational problems in the short term, it would seem not unreasonable to defend the model in this manner there is a clear need in the longer term to justify the application of the model more rigorously. The only way this can be achieved is through collection of large data sets relating population estimates (made from field sampling data) to the microhabitat variables depth,velocity substrate and cover used to describe habitat availability in the PHABSIM model. Such data would also be invaluable in the process of improving and validating preference curve information.

In the USA a library of preference curve information for a large number of aquatic species is available in the public domain for use in IFIM studies, indeed federal laws require the use of specific recognised preference curves in certain states. The development of an equivalent library for UK (and European) species is another important task if the IFIM is to become a widely accepted methodology for the assessment of flow requirements to meet ecological demands.

As mentioned previously the habitat-discharge relationship which forms the basic output of any PHABSIM simulation must be coupled with a time-series record of historical flow data if the variation in habitat over the whole flow regime is to be analysed. This step is seen as essential to the setting of EAFs. Although a certain amount of time series analysis will be conducted in the course of this study time constraints may limit us to introducing the methodology and applying it to an example data set. Clearly there will be scope for a more rigorous time series analysis of seasonal habitat variability for the remaining data sets.

In the setting of EAFs the IFIM model may be used in conjunction with other models, eg. temperature models,water quality models, if the influence of these other factors is deemed of potential importance. Integration of the IFIM model with other models of the type is also seen as another area requiring further research effort.

Another possible path for model development is in the use of other variables besides depth,velocity,substrate and cover in the PHABSIM formulation: Possible candidates could be pH and temperature for example. Essentially the model can accommodate any microhabitat variable as long as it is possible to build up a calibrated relationship between that variable and discharge, together with an expression in the form of a univariate curve describing the relative suitability to target species of values of the chosen variable.

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10 Appendices

APPENDIX A

Study site selection details.

1: Summary of the characteristics of groups 1 to 10 derived from the 370 site RIVPACS data set:

Group 1 and 2:	Predominantly headwater sites in the N and W of England and Wales.
Group 3:	Mid to upper sites in N. and S.W. England.
Group 4:	Mid to lower sites in W. Great Britain plus mid to low sites in 2 chalk streams in Southern England and one upper site in Kent.
Group 5 and 6:	Upper sites mainly in C. S. and E. England.
Group 7:	Mid to lower sites in S. England and S. Wales.
Group 8:	Mid-Upper-Low sites in C. S. and E. England.
Group 9:	Upper to lower sites in C. S. and E. England.
Group 10:	Lower sites in S. and E. England.

GROUP	ALT.	SLOPE	SUBSTRATE	TON	ALK.	CHLOR.
1,2	56 - 203	5 - 11	-6.21 to -4.46	0.4 - 1.2	15 - 85	10 - 19.5
3	45 - 127	2 - 6	-5.88 to -5.24	0.5 - 2.4	45 - 137	9 - 26
4	16 - 45	1 - 3	-4.62 to -1.43	1.5 - 3.9	55 - 180	17 - 23
5,6	36 - 46	3 - 5	-2.81 to -0.54	1.4 - 3.8	47 - 223	22 - 31
7	17 - 24	0.6 - 1	-2.83 to +3.08	4.6 - 4.8	159 - 206	27 - 335
8	7 - 22	1 - 2	-1.25 to +0.23	6.2 - 6.9	193 - 227	39 - 74
9	3 - 45	0.5 - 2	+0.91 to +7.11	2.6 - 5.9	95 - 199	37 - 51
10	3 - 13	0.4 - 7	+2.58 to +6.20	7.2 - 7.5	223 - 239	53 - 101

Key:

Grp = RIVPACS group number.
Alt = Altitude (m) of sites.
Slope = Slope of river at site in degrees.
Substrate = Grain size range in phi.
TON = Total oxidised nitrates (mg/l).
Alk = Calcium carbonate levels (mg/l).
Chlor = Chlorides (mg/l)

2: *List of first and second choice rivers:*

GROUP 1:							
FIRST CHOICES							
River	**RIVPACS site data**	**Gauging Stn. data**	**Dist. from Stn. to site (km)**	**Catchment area**	**Length of record**	**NRA**	**Artificial Influence**
EXE	Warren Farm SS791407	Pixton 045009 SS935260	20.5	147.6	81-	S.W	B C
HODDER	Cross Gt. Bridge SD702590	Stocks Res. 071002 SD718546	4.7	37.0	36-80	N.W	A C
HODDER	Cross Gt. Bridge SD702590	Hodder Pl. 071008 SD704399	10.1	261.0	77..	N.W	A C
SECOND CHOICES							
ESK	Westerdale NZ663062	Sleights 027050 NZ865081	20.2	308.0	70..	York	A A
RYE	Broadway					York	
SEVERN	Plynlimon					S.T	

GROUP 2:							
FIRST CHOICES							
River	RIVPACS site data	Gauging Stn. data	Dist. from Stn. to site (km)	Catchment area	Length of record	NRA	Artificial Influence
HABSCORE RIVER IN WALES (to be decided)							
SECOND CHOICES							
TEES	Cauldron Snout NY814288	Cowgreen Res. 025023 NY813288	0.1	58.2	71..	Nort.	A C
TEES	Moorhouse NY762338	Cowgreen res. 025023 NY813288	7.14	58.2	71..	Nort.	A C
DWYFACH (dwyfawr)	Pant Glas					Welsh	
S.TYNE	d/s Knaresdale					Welsh	

GROUP 3:							
FIRST CHOICES							
River	RIVPACS site data	Gauging Stn. data	Dist. from Stn. to site (km)	Catchment area	Length of record	NRA	Artificial Influence
EHEN	Ennerdale Bdg. NY068159	Ennerdale Bdg. 074003 NY084154	DISTANCE =1.6km	44.2	73..	N.W.	A B
EHEN	u/s Keekle NY014130	Braystones NY009061	DISTANCE =6.9KM	125.5	74..	N.W.	B B
EHEN	d/s Keekle NY012125	Braystones NY009061	DISTANCE =6.4km	125.5	74..	N.W.	B B
EHEN	Braystones NY007061	Braystones BY009061	DISTANCE =0.2km	125.5	74..	N.W.	B B
DOVE	Hartingdon SK121598	Isaak Walton SK146509	DISTANCE =0.5km	83.0	69..	S.T.	A A
DOVE	Dovedale SK146504	Isaak Walton SK146509	DISTANCE =0.5km	83.0	69..	S.T.	A A
SECOND CHOICES							
EXE	Edbrooke SS912342	Pixton SS935260	DISTANCE =8.5km	147.6	81..	S.W.	B C
EXE	Exbridge					S.W.	

GROUP 4:							
FIRST CHOICES							
River	RIVPACS site data	Gauging Stn. data	Dist. from Stn. to site (km)	Catchment area	Length of record	NRA	Artificial Influence
BLITHE	Hamstall Rid. SK109190	Hamstall Rid. SK109192	DISTANCE =0.2km	163.0	37..	S.T.	B C
SECOND CHOICES							
OTTER	Monkton ST184030	Fenny Bridges SY115986	DISTANCE =8.1km	104.2	74..	S.W.	B A
OTTER	Colhayes Farm					S.W.	

GROUP 5:							
FIRST CHOICES							
River	RIVPACS site data	Gauging Stn. data	Dist. from Stn. to site (km)	Catchment area	Length of record	NRA	Artificial Influence
ROTHER	U/S Liss Stn. SU749307	Princess Marsh SU772270	DISTANCE =0.3km	37.2	72..	S.	A B
ROTHER	Stodham Park SU769260	Princess Marsh	DISTANCE =1.0km	37.2	72..	S.	A B
ROTHER	Durford Bridge SU78234	Ipling Mill SU852229	DISTANCE =6.9km	154.0	66..	S.	A A
SECOND CHOICES							
DUDWELL	Burwash Weald TQ655224	Burwash Weald TQ679240	DISTANCE =2.8km	27.5	71..	S.	B A
Gt. EAU WENSUM TILLINGBOURNE	Swaby S. Raynham u/s Albury					Ang. Ang. Thames	

GROUP 6:							
FIRST CHOICES							
River	RIVPACS site data	Gauging Stn. data	Dist. from Stn. to site (km)	Catchment area	Length of record	NRA	Artificial Influence
LYMINGTON S.	Balmorlawn SU297036 042003	Brokenhurst SU318019	DISTANCE =2.7km	98.9	60..		A A
SECOND CHOICE							
ROTHER	Hawkley Mill SU747307	Princess Marsh SU772270	DISTANCE =4.3km	37.2	72..	S.	A B
Gt.EAU	Ruckland TF332779	Claythorpe Mill TF416793	DISTANCE =5.2km	77.4	62..	Anglian	C A

GROUP 7:							
FIRST CHOICE							
River	RIVPACS site data	Gauging Stn. data	Dist. from Stn. to site (km)	Catchment area	Length of record	NRA	Artificial Influence
FROM	E. Stoke SY866867	E. Stoke SY866867	DISTANCE =0km	414.4	66..	Wessex	B B
SECOND CHOICE							
W. AVON	Rushall SU132558	Upavon SU133559	DISTANCE =0.1km	76.0	71..	Wessex	A B
Gt.EAU	Ruckland TF332779	Claythorpe Mill TF416793	DISTANCE =5.2km	77.4	62..	Anglian	A B
LYMINGTON	Boldre Bg SZ320984	Brockenhurst Pk. SU318019	DISTANCE =3.5km	98.9	60..	S.	A A

GROUP 8:							
FIRST CHOICE							
River	RIVPACS site data	Gauging Stn. data	Dist. from Stn. to site (km)	Catchment area	Length of record	NRA	Artificial Influence
MIMRAM	Whitwell TL193207	Whitwell 038017 TL184212	DIStANCE =0.1km	39.1	70..	Thames	B C
MIMRAM	Panshanger TL282133	Panshanger Pk. 038003 TL282133	DISTANCE =0.1km	133.9	52..	Thames	A B
SECOND CHOICE							
WENSUM	South Mill Fm. TF881282	Fakeham 034011 TF919294	DISTANCE =3.9km	127.1	67..	Ang.	A A
WENSUM	Gt. Ryburgh TF919294	Fakeham 034011 TF919294	DISTANCE =4.9km	127.1	67..	Ang.	A A
COLNE	d/s Headingham TL798323	Poolstreet 037012 TL771364	DISTANCE =4.9km	65.1	63..	Ang.	A B
W. AVON	Putney SU071585	Uphavon 043017 SU133559	DISTANCE =6.7km	76.0	71..	Wessex	A B
THET	Red Bridge TL996924	Red Bridge 033046 TL996923	DISTANCE =0.1km	145.3	67..	Ang.	A A
Gt.EAU	Bellam TF403777	Claythorpe Mill 029002 TF416793	DISTANCE =2.0km	77.4 C A 1962	62..	Ang.	A A 1974
Gt.EAU	Withern TF425826	Claythorpe Mill 029002 TF416793	DISTANCE =3.4km	77.4 C A 1962	62..	Ang.	A A 1974

GROUP 9:							
FIRST CHOICE							
River	RIVPACS site data	Gauging Stn. data	Dist. from Stn. to site (km)	Catchment area	Length of record	NRA	Artificial Influence
GWASH							
SECOND CHOICE							
Gt.EAU	Theddlethorpe. TF452867	Claythorpe Hill 029002 TF416793	DISTANCE =8.2km	77.4	63-85 C A 1962	Ang.	A A 1974

GROUP 10:							
FIRST CHOICE							
River	RIVPACS site data	Gauging Stn. data	Dist. from Stn. to site (km)	Catchment area	Length of record	NRA	Artificial Influence
Gt.OUSE	Shornbrook TL010590	(Bed.Ouse) Bedford 033002 TL055495	DISTANCE =10.5km	1460.0	33..	Ang.	
Gt.OUSE	Roxton Loxk TL160535	Offord 033026 TL216619	DISTANCE =10.0km	2570.0	70..	Ang.	A C
SECOND CHOICE							
THAMES	Malthouse SU225984	Buscot 039097 SU230981	DISTANCE =0.5km	997.0	80..	Thames	B B
THAMES	Shillingford SU590932	Days Weir 039002 SU568935	DISTANCE =2.2km	3444.7	38.. B B 1938	Thames	A B 1969

Appendix B

A: Survey sheet for channel cross section curves and current metering.

SITE:		DATE:			
CROSS SECTION No.		SHEET No. OF:			
WATER ELEVATIONS:		LEFT			
STAFF INVOLVED:		CENTRE			
R OR L BANK (PEG Nos)		RIGHT			
LEFT PEG HT:	RIGHT PEG HT:				

No OF POINT	DIST.ACROSS TRANSECT	ELEVATION (STAFF)	DEPTH	VELOCITY	NOTES
CURRENT METER TYPE:					
VELOCITY READING DURATION:					
LEVEL TYPE:	No:				

B: Survey sheet for substrate and cover measurements.

SITE:				DATE:				
CROSS SECTION No:				SHEET NO: OF:				
STAFF INVOLVED:								
POINT No.	DIST.	SMALL OBJ.%	LARGE OBJ.%	O.H. VEG %	INST. VEG INDEX	U.C. BANK	SUBST INDEX	PACK INDEX