Further Validation of PHABSIM for the Habitat Requirements of Salmonid Fish

R&D Technical Report W6-036/TR

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EXECUTIVE SUMMARY

Background

PHABSIM (the Physical Habitat Simulation system) is a set of hydraulic and hydro-ecological models that define changes in physical habitat availability for target species given a change in river flow or channel geometry. The PHABSIM methodology was conceived and developed by the US Fish and Wildlife Service and has been further developed for use in the UK by the Institute of Hydrology (now CEH Wallingford). It has been used at more than 76 sites on 44 rivers in the UK. About half of these have been applied studies to determine the potential impacts of abstraction and channel restoration, and half have been research studies. In particular it has been its use by the Environment Agency for assessing the effect of groundwater and river abstraction on salmonid habitat availability. To support the application of PHABSIM to these issues, the Environment Agency established a programme of research and development entitled "Ecologically Acceptable Flows" (EAF). Phase I of the programme included a wide ranging review of how the PHABSIM models works and confirmed its general applicability to rivers of England and Wales, where management objectives relate particularly to salmonid fish or coarse fish with particular depth and velocity requirements.

Phase II developed a range of techniques required for successful application of PHABSIM to water resource issues. The major outputs were

- a formalised Environment Agency version of the model, which was able to take metric input data and contained routines for graphical display of model inputs and outputs
- time series analysis procedures and advice on their application
- quantitative habitat mapping procedures and the conclusion that, for the rivers studied, it would be possible to identify suitable representative reaches
- a theoretical study of the effects of macrophyte growth on PHABSIM calibration
- a software manual.

During the EAF programme, PHABSIM was applied on a range of rivers, both Chalk and upland, and the results were generally accepted as informative and useful to the Agency in defining ecological impacts of water resource schemes. Training courses were run and a field guide produced.

Following a review of research priorities by the PHABSIM User Forum and scrutiny of PHABSIM at a Public Inquiry (over its use to assess the impact on the River Kennet of abstraction from Axford), three major research issues were highlighted.

(1) the utility of collecting habitat suitability data at an application site versus the use of habitat suitability indices collected elsewhere;

(2) the reliability of the hydraulic model and physical habitat predictions within PHABSIM;
(3) the relationship between fish populations and physical habitat availability.

The Environment Agency and the Centre for Ecology and Hydrology jointly agreed to fund a third phase of the EAF programme to address these issues.

Objectives of this project

The overall objective of the project was to test PHABSIM further as a tool for assessing water resources issues, specifically assessing prescribed minimum flows with the aim of setting river flow objectives. Specific objectives were to evaluate:

1. the use of site specific Habitat Suitability Indices (HSIs) versus generalised HSIs
2. PHABSIM predictions of physical habitat,
3. the relationship between brown trout/salmon populations and physical habitat availability.

These objectives were tested on four target areas: two upland rivers (River Walkham, Devon and River Senni, South Wales) and two Chalk streams (Rivers Piddle and Frome, Dorset). In this way it was possible to compare results between sites, that would traditionally be considered as similar in "type", and between rivers of different types. The techniques outlined in Environment Agency R&D Reports W20 and W34 were applied.

Fulfilment of objectives

1.Use of site specific Habitat Suitability Indices (HSIs) versus generalised HSIs

Both the statistical means and distributions of the physical habitat variables used by salmonids were affected by site, season, fish size and species. Many of these differences in habitat use could be attributed to changes in the habitat availability between sites and seasons. Habitat use varied between all the study areas even within the two river types.

Preferential habitat use was more similar between study areas than actual habitat use. In three out of four species/size groups the preferential habitat use within each study area fell within the confidence limits of the preference index for the other study area. The only exception to this was the lowest velocity class for small (0-7 cm) trout, where the data collected were few and from a small number of sites.

Alternative HSI formulations were compared by running them through the PHABSIM habitat model for selected sites. This highlighted the considerable differences between "river type" and generic HSIs. However curves derived from upper and lower confidence intervals for the generic HSIs illustrated similar shapes of response to reduced discharges.

Recommendation 1

Site-specific HSIs based on observations of habitat use are expensive to develop, are heavily influenced by habitat availability at the time of development and are not independent of discharge. It is not practical to develop HSIs on a “river type” basis as there are too many factors influencing habitat use to take account of whilst designating river type.

HSIs should be treated as representing a biological response to habitat. Given the similarity in preferential habitat use, in this study, between sites with different characteristics, a generic HSI would be the most appropriate to apply within PHABSIM. This conclusion is given further weight as other published HSIs fell within the envelope of the generic HSI presented in this report. Generic HSIs are developed and illustrated from a combination of preferential habitat use and actual habitat use observed in this and other studies for two size groups of salmon and trout juveniles. These should be used in any future UK application of PHABSIM under the following conditions.

- In time series analysis these generic HSIs should not be used outside the period May to September and neither should they be applied in cold periods (<12^{o}C) as habitat use by these fish is very temperature sensitive.
- Where there is deep water (> 70 cm) the HSIs produced in this report for depth must have a cover criteria attached so that the habitat is counted as zero unless adequate cover is available to the fish within 50 cm.

Although generic HSIs are presented that represent current best knowledge, there was considerable uncertainty in the suitability values for some habitat variables. This uncertainty needs to be properly quantified and reduced with further measurements, particularly covering the issue of deeper water. The importance of cover similarly needs better quantification.

Where possible the principle of using generic HSIs should be developed for other time periods, life stages and species. A regular, periodic review should be made of recommended HSIs to be use.

The treatment of HSIs within PHABSIM should be improved to take account of the varying importance of each variable, a greater number of variables and the interactions between variables.

2. Testing / validation of PHABSIM predictions of physical habitat

For each main site, the accuracy of the PHABSIM model output was tested in two ways. First, the PHABSIM predicted depths and velocities were compared with the transect-measured depth and velocity data (which was termed model verification). Second the predictions were compared with independent, unbiased, measured physical habitat availability surveys for an entire reach (termed validation). In each case, this was undertaken for multiple (usually three separate) flows. Weighting was used to ensure that as far as possible, the PHABSIM transects were scaled to represent the proportion of habitats present in the sector.

For the model verification, a chi-squared test was used to test the significance of differences between measured and modelled values. In all but one case (a marginal failure for the high calibration flow on the River Senni) the model predictions passed at the 5% confidence level. This demonstrates the ability of PHABSIM to reproduce calibration input data accurately, confirming confidence in the hydraulic models. It also illustrates for the first time the basis of a useful model calibration tool for practical PHABSIM application.

Examination of modelled depths and velocities against the independent reach scale measured data showed that PHABSIM is less well able to predict accurately depths and velocities for an entire reach. In general predictions at lower flows were better than at higher flows. Implicit in these tests of the reach scale predictions is testing of the habitat mapping procedure of PHABSIM (in addition to the hydraulic model performance). It was felt that strict application of a chi-squared test was not appropriate in this case. Instead it was considered more appropriate to assess quantitatively the impacts of any errors in depth and velocity on physical habitat calculation. Two size classes of salmon were chosen for illustrative purposes. Differences between PHABSIM predictions and independently-measured physical habitat ranged between 3 and 31%. In some cases, particularly for low discharges there was minimal difference between PHABSIM modelled data and habitat availability data. At the Chalk stream sites, some problems arose from deficiencies in the habitat mapping procedures, and also in accounting for macrophyte growth.

These levels of confidence compare favourably with other types of models used frequently in hydrology, including rainfall-runoff models and those for estimating floods and low flows. Even the flow data from a gauging station is at best only accurate to 5% (for structures) to 10% (for open channel sections).

Recommendation 2
PHABSIM models can represent sector-scale hydraulic conditions in upland rivers, provided that hydraulic data are collected over a wide range of discharges. Macrophyte growth must be accounted for in Chalk rivers, using targeted additional survey data. Improved habitat mapping and typology procedures are required for Chalk rivers.

3. Relationship between brown trout/salmon populations and physical habitat availability

For three sites (Walkham, South Winterbourne, Senni), datasets were assembled for the comparison of hindcasted physical habitat time series with data on salmon and trout population levels. Time series of discharges were predicted at the study sites using historical gauged discharges and regression relationships between gauge data and site spot gaugings. Various summary indices of time-varying physical habitat were plotted against population densities, but no strong relationships were found. It is clear from this work that there are no simple relationships of this sort, probably due to the many other factors that affect fish densities/population numbers. Nevertheless, failure to find simple relationships should not in any way reflect on the validity of PHABSIM itself. Such relationships can only be defined under controlled conditions, where all factors are held constant other than physical habitat. Worldwide, several suitable experimental facilities exist.

Recommendation 3

The results of PHABSIM should be considered in terms of potential physical habitat for target species. This clearly varies with discharge / channel form, but does not provide a complete description of habitat. The implications for fish populations/densities should only be evaluated in the light of changes in other variables.

4. General

The Ecologically Acceptable Flows programme has covered a detailed examination of the original US PHABSIM model, confirming it potential application to the conditions in the rivers of England and Wales. It has produced new routines for graphical display of model inputs and outputs and novel methods of time series analysis. It has defined a method of habitat mapping to identify suitable representative reaches and explored the effects of macrophyte growth on model calibration. The PHABSIM hydraulic model has been tested and found to work better on upland rivers than on Chalk streams, the habitat model works best at lower flows. A more efficient method of defining habitat suitability indices has been derived. In summary, the EAF programme has produced a formalised Environment Agency version of PHABSIM that has been rigorously tested, a software manual, field application guide and training courses. It has confirmed the use of PHABSIM as a tool for assessing water resources issues, specifically assessing prescribed minimum flows with the aim of setting river flow objectives.

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1. INTRODUCTION

1.1 Background to PHABSIM

PHABSIM (the Physical Habitat Simulation system) is a set of hydraulic and hydro-ecological models. It was created in the USA as part of a wider conceptual and analytical framework, the Instream Flow Incremental Methodology (IFIM), for problem solving water resources issues in rivers. It models habitat for target species which have preferences for certain physical characteristics, such as water depth or velocity. Any change in this characteristic, say a reduction in depth, therefore produces a direct change in the available habitat for this species. This method defines the change in physical habitat availability for key target species given a change in river flow. It does not specify the expected population of any species or what level of change is significant or a threshold below which a target species or ecosystem cannot be sustained. Consequently, the actual level of an acceptable flow remains a political or social decision. PHABSIM was developed by the US Fish and Wildlife Service and has been adapted for use in the UK by the Institute of Hydrology (later CEH Wallingford) and used at 76 sites on 44 rivers to determine the potential impacts of abstraction and channel restoration.

The primary driving force for development of PHABSIM in the UK has been its use by the Environment Agency for assessing the effect of groundwater and river abstraction on salmonid habitat availability. To support the application of PHABSIM to these issues, the Agency established a programme of research and development entitled "Ecologically Acceptable Flows". Phase I of the programme assessed the applicability of PHABSIM to conditions in the rivers of England and Wales (Johnson *et al.* 1993), whilst Phase II developed habitat time series analysis (Dunbar *et al.* 1996) and methods of choosing a representative study reach (Dunbar *et al.* 1997), assessed the impacts of macrophyte growth (Hearne *et al.* 1994) and produced customised software with manual (Elliott *et al.* 1996a). In parallel, MAFF has funded development of the method for predicting the suitability of flood channel restoration schemes, such as on the River Wey for roach, chub and brown trout and for macrophytes (Elliott *et al.*, 1996b). In addition, the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) has funded an assessment of the applicability of PHABSIM to the rivers and issues of Scotland and Northern Ireland. (Elliott *et al.*, 2000).

1.2 Background to the Project

A model, such as PHABSIM, is a simplification of the real world, but which retains key characteristics of significance to a particular issue. PHABSIM needs to be sufficiently simple to allow easy and cost effective application to water resource issues and yet to retain key characteristics of the river's ecology, hydrology and hydraulics to enable decision-makers to set ecologically acceptable flows with confidence. To achieve a satisfactory balance between these two aims, the model requires development, refinement and testing against field data. In its review of research requirements in 1996, the PHABSIM User Forum identified the transferability of habitat suitability indices within and between rivers and the relationship between available habitat and species populations as two Priority A topics[1].

PHABSIM was scrutinised intensively during the 1996 Axford Public Inquiry . The Inquiry Inspector assessed an appeal by Thames Water Utilities Ltd against the decision of the National Rivers Authority to limit the amount of water they could abstract from boreholes near the River Kennet in Wiltshire. PHABSIM had been used as part of the assessment of the impact of the abstraction, as the river is an important brown trout fishery. Hydrological and hydraulic measurements had been made in the reaches that would suffer flow depletion due to the abstraction. Information on the suitability for trout of the resulting physical conditions (habitat suitability indices, HSIs) had been taken from the Rivers Piddle and Bere (Chalk streams in Dorset). The rationale for this was that HSIs should not be developed on rivers, such as the Kennet, suffering from a lack of habitat, whether due to flow regulation or channelisation.

The Inquiry Inspector concluded that PHABSIM was a suitable tool for assessment and that it had been properly applied. However he did question why the transfer of HSIs from the River Piddle had not been investigated in a more rigorous fashion (such as a numerical "transferability test"). It was immediately apparent that a very few research papers had been published on this topic, all based upon research undertaken in the USA. There was no published, independent evidence as to the performance of these tests, and no assessment of them in a UK-context. Questions surrounding the "representativeness" of the PHABSIM reaches on the Kennet were also asked. Thus the Environment Agency concluded that further testing of PHABSIM was important to ensure that water resource management decisions made on the basis of the model were robust and able to withstand detailed examination. The Environment Agency allocated funds to undertake further validation of PHABSIM. The Centre for Ecology and Hydrology (CEH) agreed to support the initiative through basic science funding from NERC.

1.3 Project Objectives

The overall objective of the project is to test PHABSIM as a tool for assessing water resources issues, specifically assessing prescribed minimum flows with the aim of setting river flow objectives.

[1] Hydro-ecology. The Newsletter of the PHABSIM User Forum Issue 3, August 1996. Institute of Hydrology, Wallingford.

Specific objectives are:

1. to evaluate the implications of development and use of site specific Habitat Suitability Indices (HSIs) versus the selection and application of generalised HSIs

2. to test that PHABSIM predictions of physical habitat are robust and reflect the availability of physical habitat (defined as combinations of depth, velocity and substrate) within a study sector

3. to evaluate the relationship between temporal changes in brown trout and salmon population and physical habitat availability at four sites.

Objective 1 was modified to the above following discussion with the project board: the original objective made more specific reference to HSI "transferability tests". This is discussed in Section 3.1 with reference to site selection and in more detail in Section 4.1 with reference to analysis methods.

2. PROJECT STRUCTURE

2.1 Project Tasks and their Relationship to Objectives

Eight tasks were defined in order to manage implementation of the project. These are:

Table 2.1: Project tasks

Task no	Task name	Short description	Lead CEH site*
1	PHABSIM hydraulics	PHABSIM data collection and modelling	CEH W
2	Physical habitat surveys	Measurement of availability of physical habitat and attributes at the locations of fish	CEH W
3	CEH W Project Management		CEH W
4	Collaboration with USU	Collaboration with Utah State University	
5	Site selection, electric fishing, HABSCORE	Selection of field sites and measurement of fish population densities	CEH D
6	Snorkelling	Snorkelling to document salmonid fish habitat use in the target rivers	CEH D
7	Hydrology	Hydrological analysis to produce flow time series	CEH W
8	CEH D Project Management		CEH D

* W: Wallingford, D: Dorset

Task 1 (CEH W) consists of PHABSIM data collection and modelling, following procedures outlined in Agency R&D Report W20 and repeated in Appendix E. PHABSIM habitat availability predictions from this Task feed into the data analysis element of Task 2, in order to achieve Objective 2 (PHABSIM hydraulics validation and testing). Time series of PHABSIM physical habitat will be produced as part of Task 1, in order to achieved Objective 3 (testing of relationships with long-term fish population data).

Tasks 2 (CEH W) and 6 (CEH D) are closely linked. Task 6 entails snorkelling to document salmonid fish habitat use in the target rivers. Task 2 entails simultaneous fieldwork to measure both the physical habitat attributes of the locations the fish are using, and to measure the availability of those habitats in the target rivers.

The measurements of habitat availability and use will be analysed as part of Task 6 to test hypotheses concerning the stability of HSIs in space and time. The measurements of habitat availability at one site per target area will also be analysed, as part of Task 2, to test the capability of the PHABSIM hydraulic models to represent robustly the physical habitats present in a river sector (Objective 2).

Tasks 3 (CEH W) and 8 (CEH D) cover project management activities for the two CEH sites.

Task 4 (CEH W/CEH D) involves collaboration between the project team and the Institute for Natural Systems Engineering, Utah State University. Professor Hardy of the INSE will make visits to the UK to advise the project team and to attend Project Board meetings.

Task 5 (CEH D) comprises selection of sites for fish surveys at the beginning of each year, and the undertaking of HABSCORE surveys (electric fishing surveys and catchment / site data collection for the HABSCORE form. This will enable a comparison of the actual fish population densities with carrying capacities predicted by the HABSCORE model.

Task 7 (CEH W) covers hydrological analysis required to produce historical flow time series at each PHABSIM site location.

2.2 Relationship Between Project Objectives and Tasks

Figure 2.1 indicates the relationship between the Objectives and the Tasks:

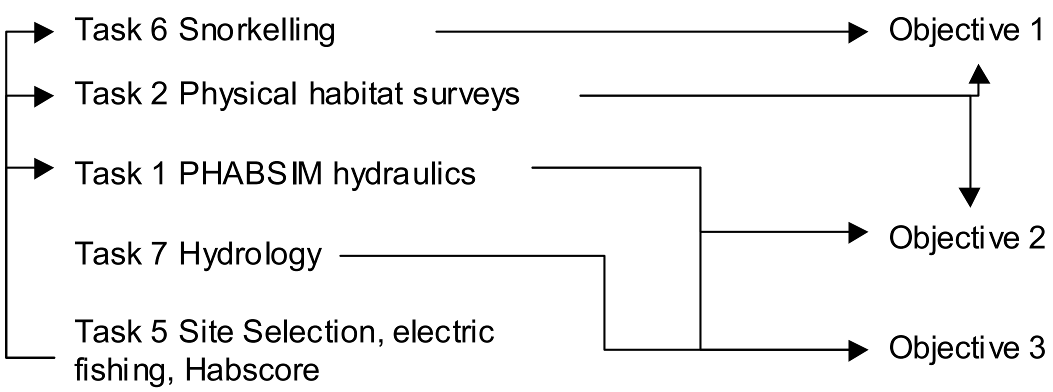


Figure 2.1: Relationship between project objectives and tasks.

2.3 Project Management and Responsibilities

Bryony Howlett (Agency South West Region) was project manager for the Environment Agency for most of the project. Doug Wilson (Agency Thames Region) took over project management in the final stages. Support on financial aspects of the project was provided by Toby Hutcherson (R&D Management Support Officer, Agency South West Region).

Mike Acreman was project manager for CEH, with overall responsibility for achieving project objectives, project finances and reporting and formal communications with the Agency (Task 3). Mike Dunbar was responsible for day-to-day running of Tasks 1, 2 and 7, and Anton Ibbotson was responsible for Tasks 4, 5 and 8.

A Project Board was established to monitor overall progress on the project, advise on its strategic direction and to approve, where necessary, changes to project methods, approach and budget. The Board chairman was Terry Newman (Water Resources, Environment Agency) and includes the following specialist staff from the Agency: Robin Wyatt (Fisheries); Andy Strevens (Fisheries), Bryony Howlett / Doug Wilson (Water Resources), Dave Jowett (Head Office), Mike Owen (topic leader), Toby Hutcherson (R&D). CEH representatives were Alan Gustard (CEH W), Mike Acreman (CEH W), Mike Dunbar (CEH W), Anton Ibbotson (CEH D).

Professor Thom Hardy, Utah State University, USA, and Dr Ian Maddock, University College Worcester, UK acted as independent members of the Project Board. Professor Hardy also played a major part in the conception and experimental design of the project.

3. SITE SELECTION

3.1 Introduction

Sites in four distinct areas of the country (Devon, Wales, Dorset, Hampshire) were initially examined for suitability for planned fieldwork. Various sites were visited and discussions held with Agency staff. Further details are outlined in Sections 3.1-3.6. One candidate area (Hampshire: Itchen catchment) was discounted following initial fieldwork.

Alteration of Objective 1: implications for site selection

The original project plan included the collection of data from four sites, two upland sites (in Devon and South Wales) and two chalk stream sites (in Dorset). This would allow comparison of results between similar rivers and between different river types. The initial project plan concentrated on use of one site in each target area for collection of the observations for the development of Habitat Suitability Indices (HSIs) and for PHABSIM hydraulic testing. The intention was to investigate the development of HSIs and test PHABSIM hydraulics for different 'river types'. Within any particular river type, there is a range of channel forms and associated flow characteristics. In addition, physical habitat will vary even between apparently similar channel forms. Consequently, if genuine 'river type' indices are to be produced, sample sites need to incorporate the full range of channel forms and, ideally, several examples of each channel form, such that inherent variability can be assessed.

Currently, there are no guidelines on the number of sites required to ensure that all the habitat available within a river type is used in developing the HSI. In addition, there is a limit to the number of sites that can be surveyed within the resources of the project. It was decided that three or four sites, which together included all the available habitat types for that 'river type', was preferable to the single site approach. At each site, habitat availability data were collected concurrently with the fish habitat use surveys.

However, the resources available meant that for PHABSIM testing, a single "main site" was chosen in each study area where both PHABSIM, availability and fish habitat use data were collected. At each main site, the availability surveys were more intensive, and were undertaken totally independently of the PHABSIM surveys, and at multiple flows. Commonly three sets of data were collected, corresponding to June, July/August and September/October, however only two sets of data were collected for the South Winterbourne because the extensive rain in October 2000 made continued fieldwork impossible. As the South Winterbourne "site" comprises two separate reaches – main channel and carrier, four comparisons are possible. For each survey, the discharge was gauged so that at a later date, the PHABSIM model could be run for the conditions surveyed.

3.2 Devon

A subset of four sites were selected from eight that had been used by Heggenes *et al.* (1998) to develop HSIs for use with a PHABSIM application on the River Tavy. This subset represented a compromise between resources available to collect data for developing HSIs and ensuring that all the habitat types available in the catchment were included in the study. Comparisons between the two developed HSIs will allow an assessment of the stability of the HSIs between two different years and survey teams. Their attributes are presented in Table 3.1 and locations in Figure 3.1.

Table 3.1: Devon sites: description

River	Site	Length (m)	Grid Reference (SX)	Mean width (m)	Altitude (m)	Dominant habitat types	Catchment Area (km^2) Mean Flow, Q95 (m^3/s)[1]
Walkham	Ward Bridge	400	544 723		145	Rapids, Riffle, Run, Glide	21 / 0.88 / 0.17
Meavy	Dewerstone	150	534 643		100	Rapids, Boil	40 / 1.25 / 0.097
Plym	Ham	150	530 621		35	Run (deep)	71 / 2.43 / 0.33
West Dart	Crocken Tor	300	755 345		343	Run, Riffle	9 / 0.44 / 0.034

[1] *figures estimated by Micro LOW FLOWS*

Walkham at Ward Bridge
Both salmon and trout are present in good numbers. The river is a perfect size for survey with intermediate, but varying gradient and a wide variety of habitat types. It was selected as the primary site for collecting HSI data as well as for the testing of PHABSIM hydraulics.

Meavy at Dewerstone
This site is dominated by trout, although there are good numbers of salmon as well, but primarily it was selected because of its high gradient habitats, with large boulders and chutes.

Plym at Ham
The fish population at this site is dominated by salmon, although there are also trout present. The habitat was different here as the river is further downstream and there are deeper glides/pools not present at other sites.

West Dart at Crockern Tor
This represents a smaller upstream site which is dominated by trout, with lower numbers of salmon present. It was harder to survey physically because of its small size.

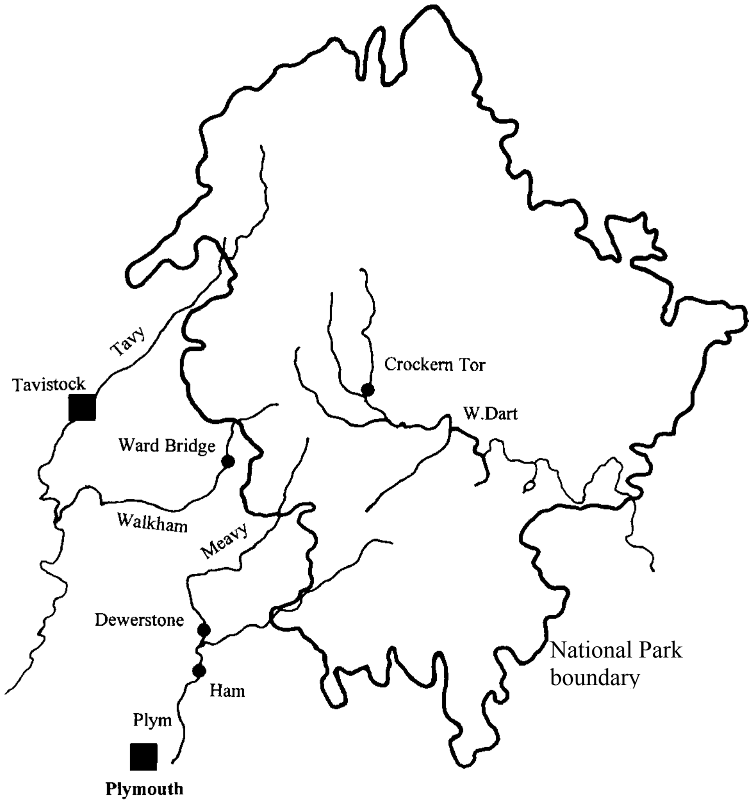


Figure 3.1: Devon: site locations

3.3 Piddle / Bere Catchment

Four sites were selected which included three that had been used to develop HSIs for use on various operational PHABSIM investigations in South West Agency Region (Bird *et al.* 1995). Their attributes are presented in Table 3.2 and locations in Figure 3.2.

Table 3.2: Piddle / Bere sites: description

River	Site	Length	Grid reference	Mean width (m)	Altitude (m)	Mesohabitat types
Piddle	Higher Hyde downstream	300	SY860 921	9.3	20	Run, Glide (deep, shallow), Riffle)
Piddle	Higher Hyde upstream	200			21	Run, Glide (shallow), Riffle, Still
Piddle	Throop	200	SY829 933	6.0	32	Run, Glide (overhanging vegetation)
Bere	Higher Hyde	300		7.2	21	Riffle, Run (shallow)

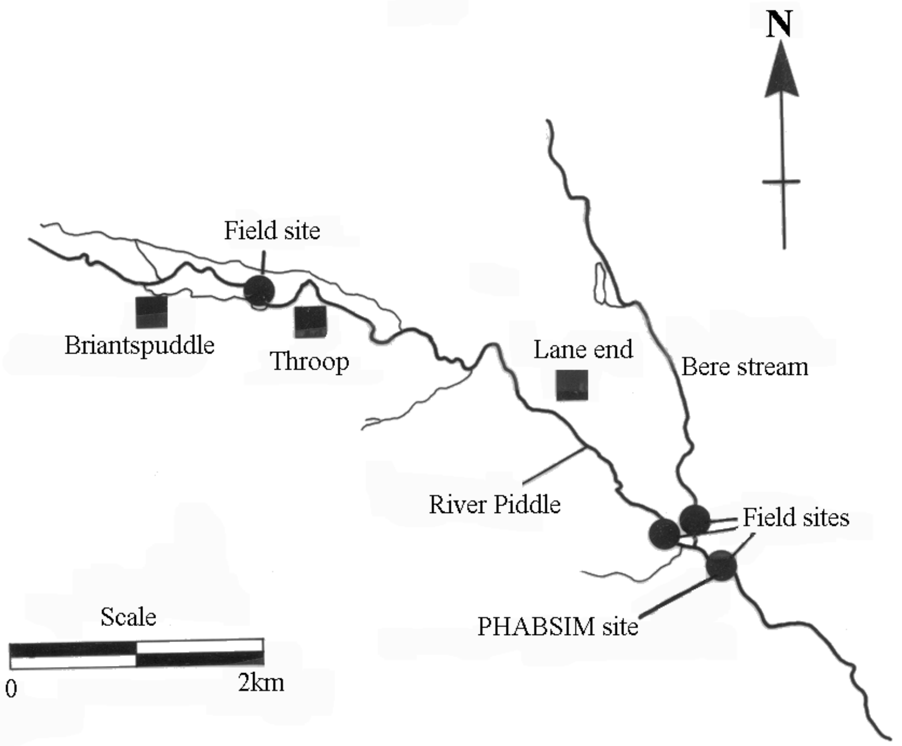


Figure 3.2: Piddle / Bere: site locations

3.4 Frome Catchment

The following candidate locations were selected for survey:

South Winterbourne and carrier at West Stafford
There was 120m of main channel available for survey at this site, and 200+m of the carrier channel which starts at the Louds Mill gauge on the main Frome. This site was chosen as a main site as historical fish population data were available.

Water Barn stream at East Burton
This site is another carrier which splits from the main Frome channel. It was dominated by salmon and contained extensive macrophytes beds during the summer months.

Cerne at Godmanstone
This site was dominated by trout.

Information on these sites is given in Table 3.3 and their locations in Figure 3.3.

A series of further reserve candidate sites were chosen, but were discounted for various reasons, these included: the Frome at Maiden Newton, North Stream near Woodsford, Sydling Brook, main Frome at Bockhampton.

Table 3.3: Frome sites: description

River	*Site*	Grid Reference (SY)	Mean width (m)	Length (m)	Altitude (est) (m)	Mesohabitat types
South Winterbourne	West Stafford	725897-726897	5.45	198	40 40	Deep Glide, Shallow Glide, Riffle
Carrier	West Stafford	727897	3.2	190	40	Shallow Glide, Riffle
Water Barn stream	East Burton	833872	6.2	340	20	Deep Glide, Shallow Glide
Cerne	Godmanstone	667973	3.9	300	80	

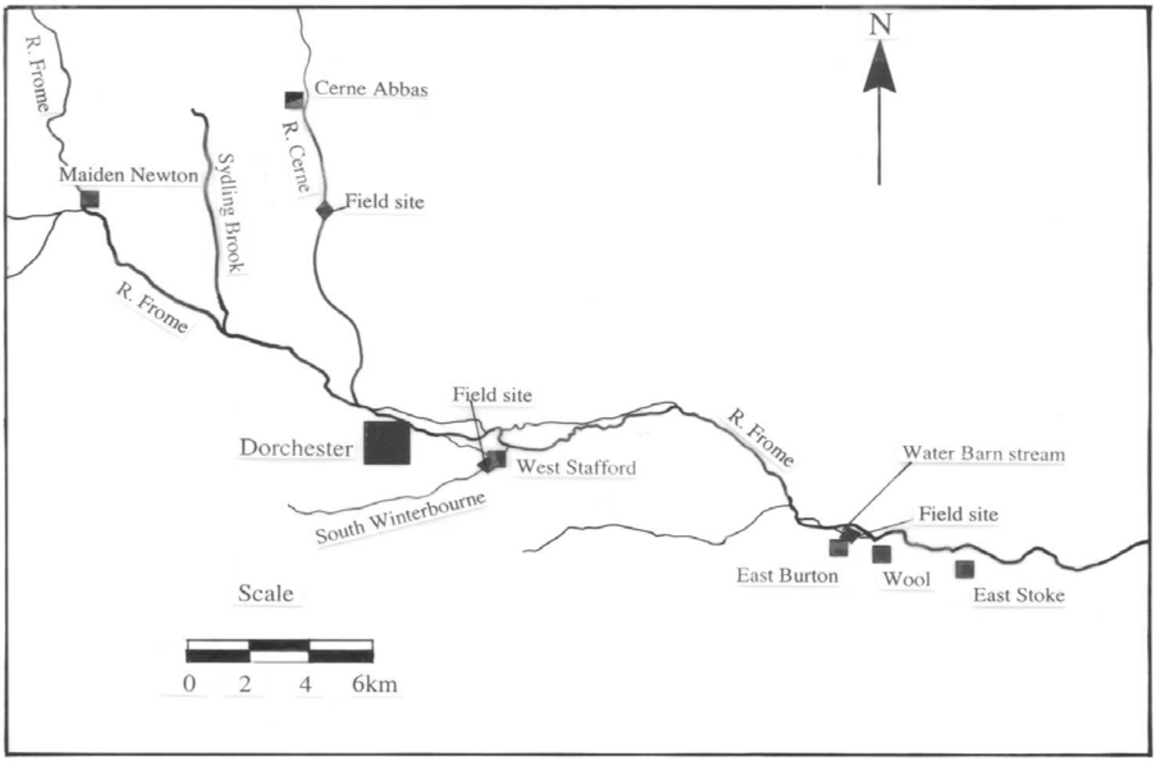


Figure 3.3: Frome: site locations

3.5 Usk Catchment

The following sites were chosen after a reconnaissance visit on 6-7 January 2000.

Senni at Abersenni
Historical fish data showed variable numbers of both salmon and trout, with salmon dominant. The river looked to be a perfect size for survey and was analogous to the Walkham / Ward Bridge site in Devon. The habitat was varied and there were replicates of all the major habitat types. This was the main site utilising approximately 400m below the bridge.

Cilieni at Pentre-bach
Historical fish data showed variable numbers of trout and salmon, however the numbers of trout in this river were higher than in other sites where there is information of fish abundance. The river is smaller than the Senni and thus represents a different habitat and is analogous to the Crockern Tor site in Devon. Some 160m of this site were used.

Ysgir upstream of Pont-ar-Yscir
Historical fish data showed variable numbers of trout and salmon, again dominated by salmon with low numbers of trout. The river contained broken, unbroken and rippled flow and was intended to supplement data obtained from the Senni. It differed from the Senni in that it did not have the large substrate particles (boulders). The chosen site extended for 200m upstream of the bridge.

Information on these sites is given in Table 3.4 and their locations in Figure 3.4.

Table 3.4: Wales sites: descriptions

River	Site	Length	Grid reference	Mean Width	Altitude (est) (m)	Mesohabitat types	Catchment Area (km^2) Mean Flow, Q95 (m^3/s)[1]
Senni	Abersenny	400	SN930268	8.7	200	Riffle, Run, Pool, Glide, Cascade, Chute	27 / 1.32 / 0.373
Cilieni	Pentre-bach	160	SN909329	9.6	249	Riffle, Run, Glide	29 / 0.98 / 0.118
Ysgir	Pont-ar-Yscir	200	SO004307	10.8	152	Riffle, Run, Pool, Glide, Cascade, Chute (fewer large boulders than Senni)	60 / 1.89 / 0.218

[1] figures estimated from Micro LOW FLOWS

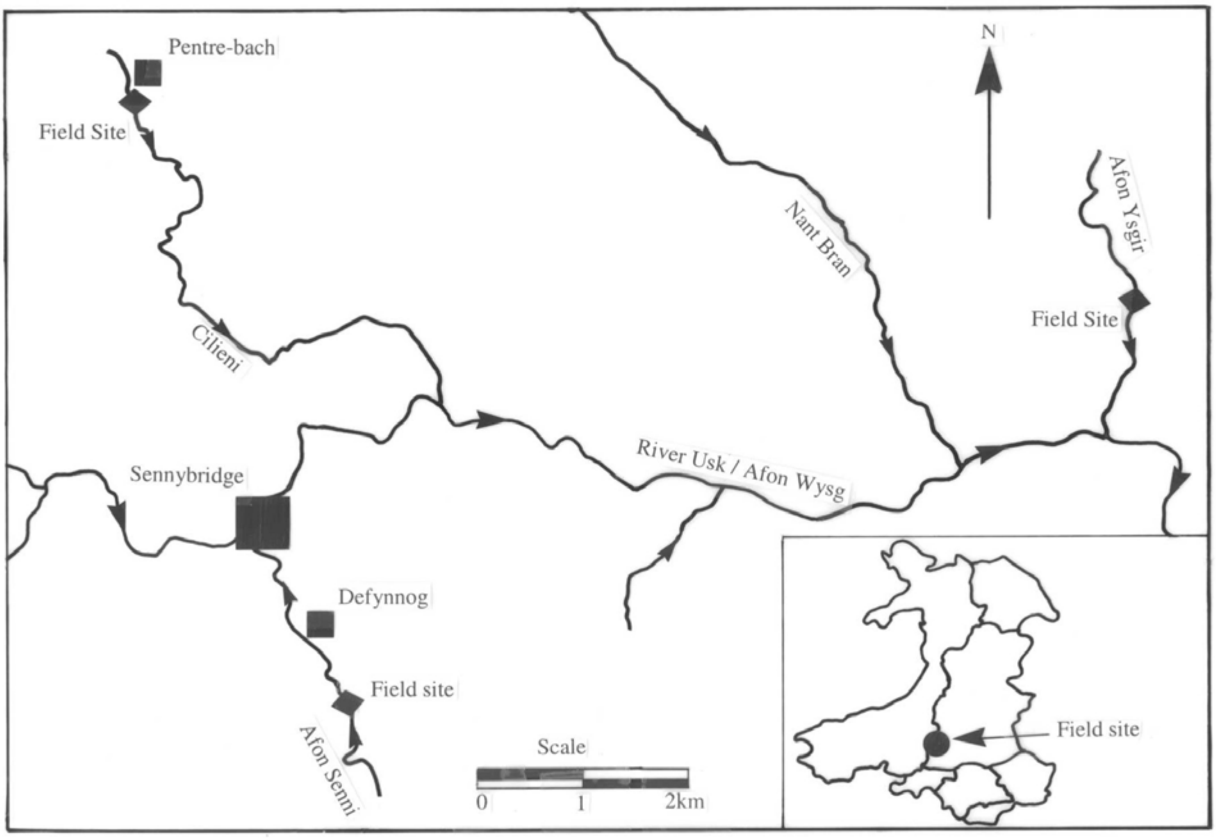


Figure 3.4: Wales: site locations

3.6 Itchen Catchment

Four sites were surveyed in the Itchen catchment between 17th and 19th May 2000:

- Arle at Alresford
- Itchen at Winchester (nr swimming pool)
- Itchen Navigation at Allbrook
- Itchen at Bishopstoke

We found insufficient numbers of fry/juvenile fish at these sites. The following graph illustrates the sizes of trout found during the three days of the survey, across all sites.

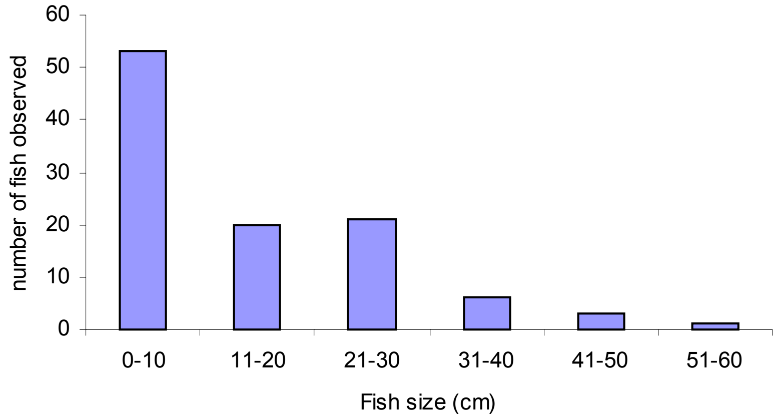


Figure 3.5: Sizes of trout observed in the Itchen

Because of the lack of suitable fish, the Itchen catchment was replaced in the fieldwork plan by the River Frome catchment.

4. HABITAT SUITABILITY INDICES

4.1 Introduction

Habitat Suitability Indices (HSIs) are used in PHABSIM to convert the hydraulic descriptions of streams into an aggregate measure of habitat quantity and quality, termed Weighted Usable Area (WUA). This intermediate stage of any PHABSIM application is sensitive to the HSI selected and consequently crucial in determining the water resource decisions resulting from such a study. As a result, the choice of HSI for use in a PHABSIM study has often become a source of debate between parties attempting to select the HSI that provides their preferred 'solution'.

HSIs represents the association of an organism with particular habitat characteristics. There has been a wide ecological debate about the use of association with habitat to make predictions about population or habitat quality. Although this report is not the place to give a full account of this debate, there is value in giving a summary as it puts the HSIs developed for fish in this report into the context of other ecological disciplines. The debate can be summarised by the following points:-

Habitat modelling, the use of an organism's association with particular habitat types, is a useful and important tool in wildlife conservation and management (Verner *et al*. 1986). These models are applied across a wide variety of scales and purposes, but typically they are used to predict how the target organism will respond to habitat modification. The greatest advantage of these models is the ease with which data on habitat/organism associations can be collected and their general simplicity. This enables wildlife and conservation managers to make decisions on the often pressing and conflicting use of resources (Edwards *et al*. 1996) within short timescales.

Habitat modelling makes the assumption that an organism's pattern of observed habitat use represents habitat quality (Beutel, *et al*. 1999). This assumption is rarely tested and is often difficult to test without extensive habitat manipulations or experimental procedures. Frequently in many ecological disciplines observed habitat use in one area varies substantially with observed habitat use in other areas (e.g. Lindenmayer *et al*. 1994; Fielding & Haworth 1995) and populations often do not respond to habitat modification in the way that habitat modelling would predict. The reasons for these observations are many and include the interdependence of habitat types in determining habitat quality (e.g. feeding conditions in the vicinity of cover) (Mysterud & Ims 1998). Frequently the observations of habitat use are only stable within a restricted range of conditions. And non-linear ecological responses (reproduction and mortality) to changes in habitat quality and quantity as a result of complex behavioural and physiological interactions.

Some suggest a solution to these problems is to develop individual behaviour based models (Sutherland 1996a & b) that have been demonstrated to make accurate predictions at the population level of habitat modification even outside the range of experience. This type of modelling does deal with many of the assumptions that are ignored in habitat modelling, however, they can take considerable resources over many years to develop (e.g. Stillman *et al*. 2000).

Habitat use for trout and salmon juveniles in streams has been shown to vary with many factors (Bachman 1984, Fausch 1984, Orth 1987, Slaney & Martin 1987, Morhardt & Hanson 1988, Shirvell 1989, Heggenes 1990). These include:-

- Species
- Size
- Life stage
- Temperature regime
- Season
- Time of day
- Food availability or productivity
- Interactions with other organisms – predation/competition
- Physiological state – hungry or otherwise
- Habitat availability/interactions with channel shape and discharge
- Light levels
- Population level

HSIs for juvenile trout and salmon for use within PHABSIM are derived from frequency histograms of habitat use. The most frequent variables measured are depth and velocity, although substrate and cover are also sometimes used. Depth is the water depth at the point the fish is observed and velocity is the mean column velocity at that point. It is important to note that it is not usually the velocity experienced by the fish, although in a particular river there are generally consistent relationships between mean column velocity and the velocity at any height in the water column dependent on stream roughness.

HSIs can be developed for individual sites (site specific HSIs) or can be generalised at different scales, for example by area, river/geographical type or for species/size groups. HSIs can be detailed, affording subtle differences in the habitat quality of habitat classes, or they can be simple making habitat suitable or unsuitable (binary HSIs), or they can be derived from knowledge of the biology of the fish (i.e. swimming capabilities).

Some authors have found differences between site specific HSIs and generalised HSIs, because of the wide degree of variation in habitat use caused by the interactive effects of all the factors listed above, and this may warrant the use of site specific criteria. The high cost and sometimes impractability of developing site specific HSIs has led to other authors considering alternatives. Belaud *et al*. (1989) reported similarities between four site specific HSIs and generalised HSIs suggesting that generalised HSIs may be more useful.

In these cases the required HSIs must be selected from a library of generalised HSIs or HSIs developed in other streams. Generalised HSIs can be derived for a particular region or river type. The selection and use of non-site-specific HSIs is based on the premise that the selected HSI can be applied to a destination stream.

Other authors have approached this debate by attempting to develop 'transferability' tests (Thomas & Bovee 1993, Groshens & Orth 1994). However, these tests also require the collection of some data at the destination stream, this is not always possible. Further, these tests are little more than statistical tests on simplified HSIs and as such are controversial. That is, it should be possible to design a test to suit the preferred solution of any particular party (Dunbar *et al*. 2000).

There is clearly a need to provide guidance in the selection of HSIs for application within PHABSIM. The original objective for this study was to develop a protocol for transfering HSIs between rivers. However, at an interim stage, it was agreed that statistical transferability tests would be flawed and that the objective of the study should be extended to consider the merits of using site specific HSIs rather than the various generalised HSIs.

The current study makes use of HSI data collected from the two chalk river target areas and two upland river target areas, to evaluate the implications of development and use of site specific HSIs versus the selection and application of generalised HSIs.

To do this the report

- Explores the determinants of habitat use by trout and salmon juveniles in four separate study areas, two upland types and two chalk river types.
- Uses the HSIs developed on these rivers to examine their similarities or differences and most importantly look at the impacts of using each within a PHABSIM application in each area.
- Assesses the merits of site specific and generalised HSIs.
- Identifies any gaps in knowledge which are required to be filled to improve the use of HSIs in the application of PHABSIM.

4.2 Statistical Analysis

Analysis of variance was used to explore differences between means of depth and velocity. Measured depths and velocities were transformed to ensure the data fitted the normal distribution. Depths were converted to square root depths and velocities were transformed using natural logs of the square root of velocity + 0.18.

However, HSIs are derived from frequency distributions and therefore the general shape of the distributions is as important as the means. The Kolmogorov-Smirnov two sample test was used to look for differences in the shape of frequency distributions.

All fish were put into one of two size groups (0-7 cm and 8-20 cm) for analysis and data from each sampling occasion was put into one of three seasons (spring, summer and autumn).

Availability

Measures of availability at each site were adjusted to take account of differences in the density of points measured at each site and the abundance of each species/size group to ensure that habitat availability were not biased by sites where fish were absent or at low population levels.

Preference Indices

Preference indices were calculated using Jacobs Selectivity Index (Jacobs, 1974) calculated as

$$D_i = (r_i - p_i)/(r_i+p_i-2r_ip_i).$$

Where r = the proportion of habitat used in that class and p = the proportion of habitat available in that class. Positive indices indicate selective use of that habitat class and negative values indicate avoidance of that habitat class.

Where the proportion of available habitat fell below 5% of the total availability, habitat classes were grouped to reduce the level of uncertainty surrounding selection of habitats in these cases.

Confidence limits for this index were estimated by applying the first-order approximation of Taylor's theorem. The approximate variance of selectivity index estimator D_i is given by:

$$V(D_i) = 4(r_i^2(1-r_i)^2V(p_i)+p_i^2(1-p_i)^2V(r_i)/(r_i+p_i-2r_ip_i)^4$$ (Marker *et al*. 1986)

Where $V(p_i)$ is equal to the variance in the proportion of the habitat available in each class and $V(r_i)$ is equal to the proportion of the habitat use in each class.

95% confidence limits for the HSIs were then estimated by $D_i \pm 2\sqrt{V(D_i)}$, and rescaling to fit the HSI criteria of being between 0 and 1.

4.3 Results

4.3.1 Factors affecting habitat use by trout and salmon juveniles

Activity

There were significant differences in the mean depths used by feeding and resting salmon but no difference in the mean velocities used (ANOVA, $F_{1,4342} = 17.8$, $p<0.0001$; ANOVA, $F_{1,4338} = 0.25$, n.s.). There were significant differences in the mean depths and velocities used by feeding and resting trout (ANOVA, $F_{1,2697} = 5.6$, $p<0.05$; ANOVA, $F_{1,2688} = 4.2$, $p<0.05$). Similarly there were significant differences in the shape of all the distributions of depths and velocities used by feeding and resting salmon (KS two-sample test, $p<0.001$; $p<0.05$) and trout, with the exception of velocities used by trout (KS two-sample test, $p<0.05$; n.s.).

Future analyses and development of HSIs were only conducted using feeding salmon and trout. The justification for this was that it removes the complicating influence of physiological state and the provision of feeding conditions are more likely to be affected than provision of resting conditions, by habitat loss or degradation through alterations to the discharge regime.

Fish size

Over all seasons and all study areas fish were observed between 2 and 99 cm in length. The vast majority of fish were in the range 2 to 20 cm, with larger fish difficult to approach by the field observers without causing disturbance. The subject of this report are those fish below 20 cm and therefore these are the only fish for which length frequency histograms are drawn (Figs. 4.1-4.4).

In each study area salmon and trout between 2 and 7 cm in length became less frequent as the year progressed and they grew in size. They were most frequent in the spring, much less frequent in the summer and nearly absent in the autumn (Figs. 4.1-4.4).

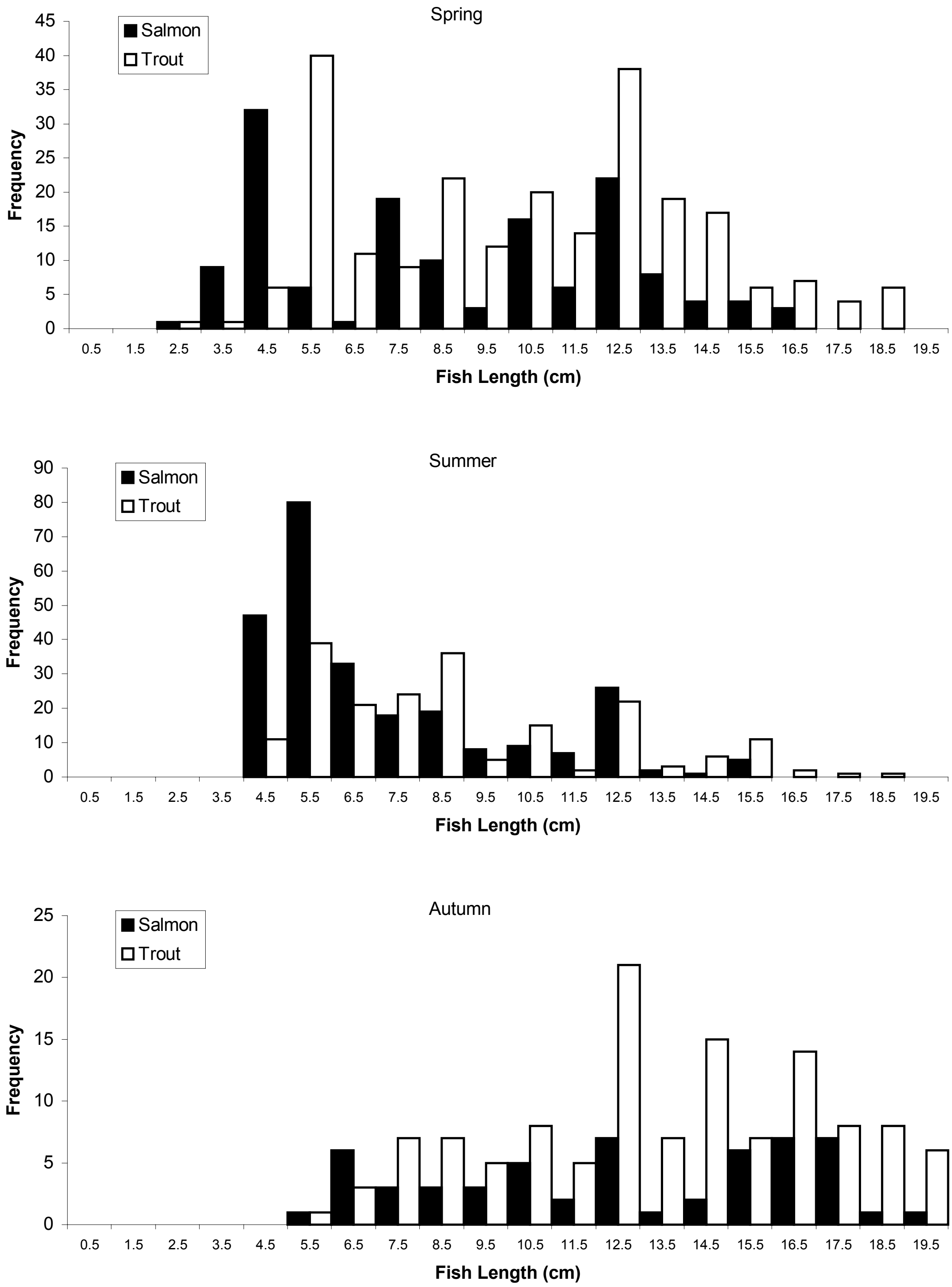


Figure 4.1: Frequency of different lengths of active salmon and trout observed by snorkelling in the Devon study area in spring, summer and autumn.

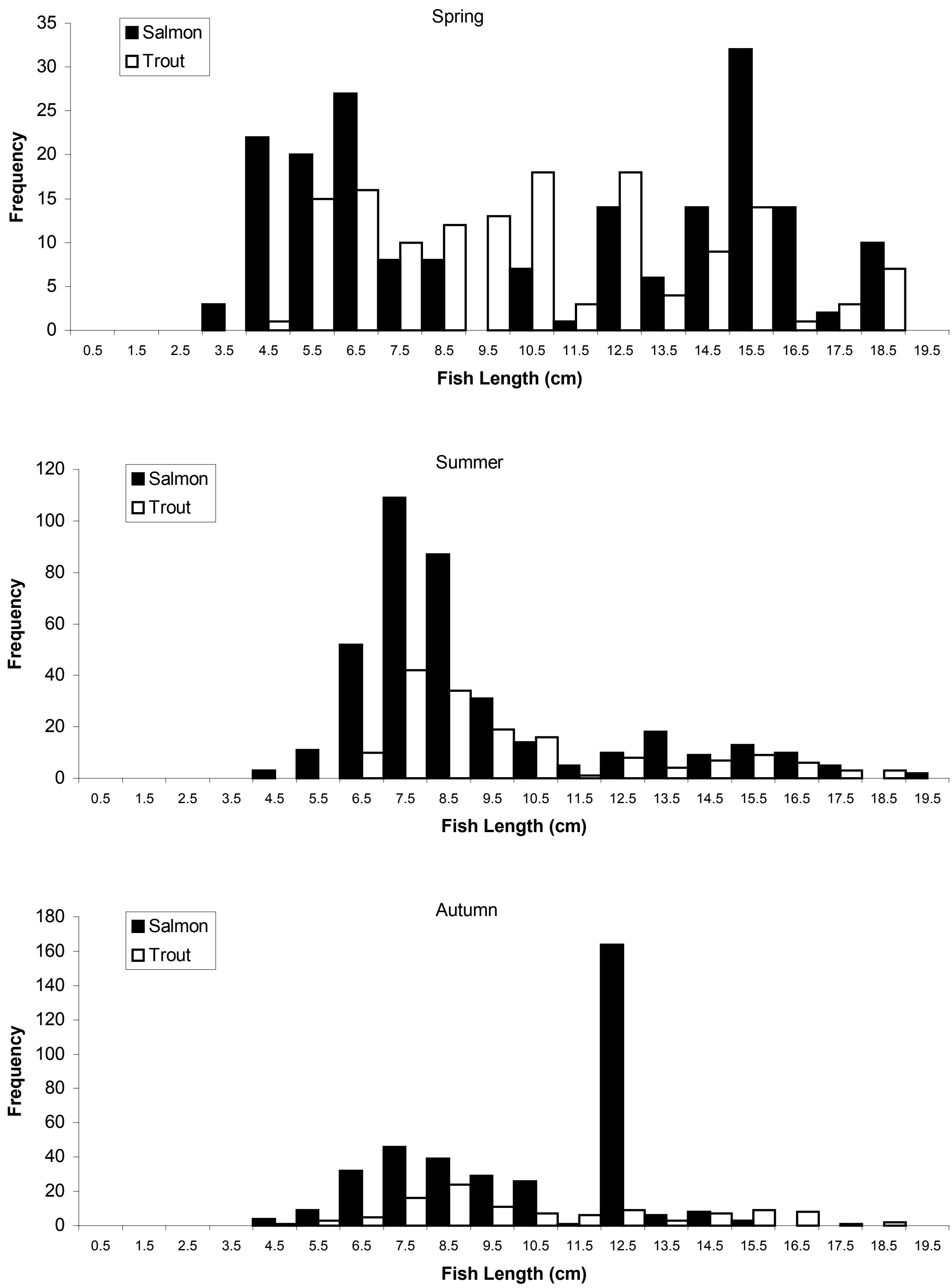


Figure 4.2: Frequency of different lengths of active salmon and trout observed by snorkelling in the Wales study area in spring, summer and autumn.

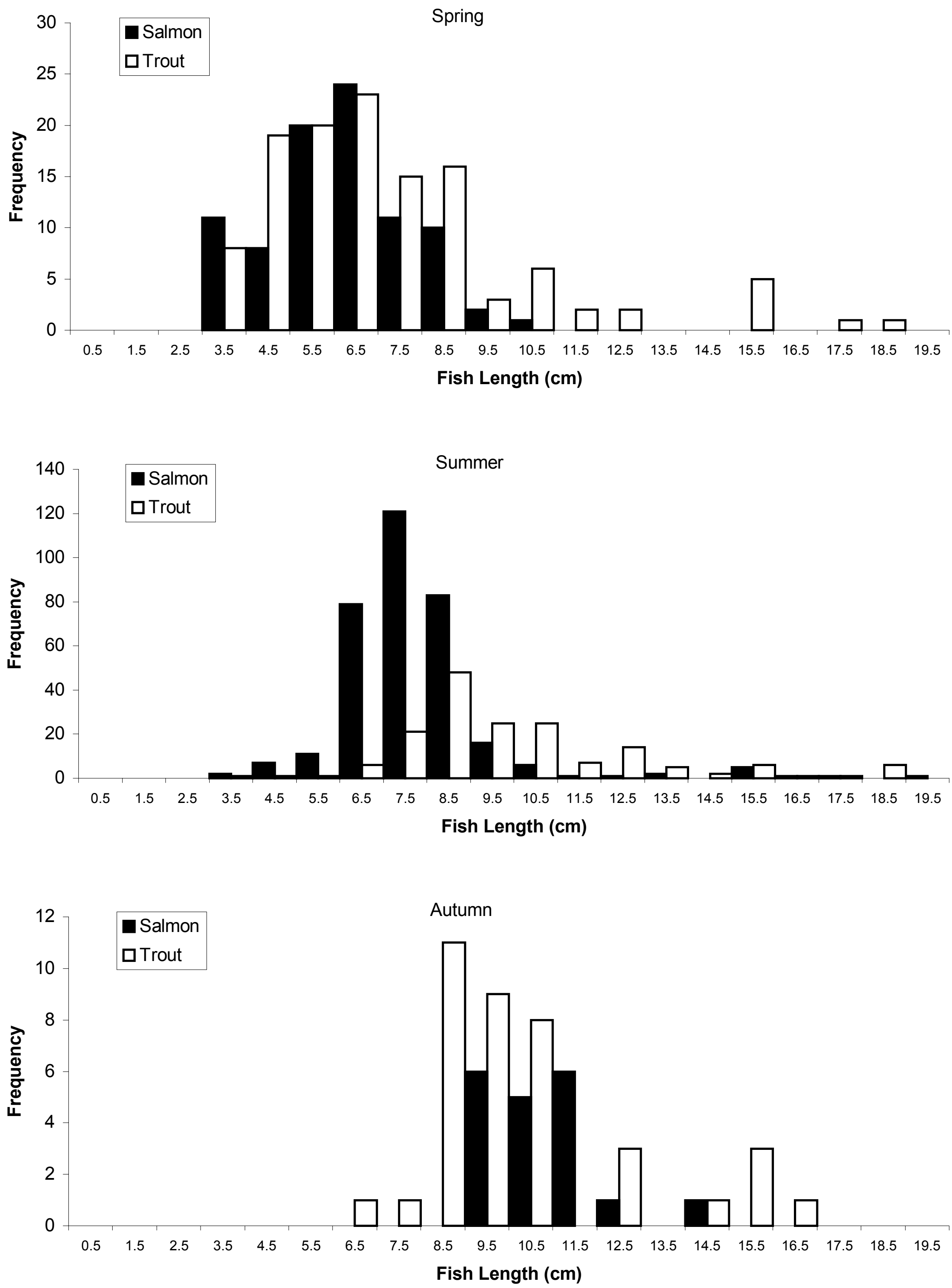


Figure 4.3: Frequency of different lengths of active salmon and trout observed by snorkelling in the Frome study area in spring, summer and autumn.

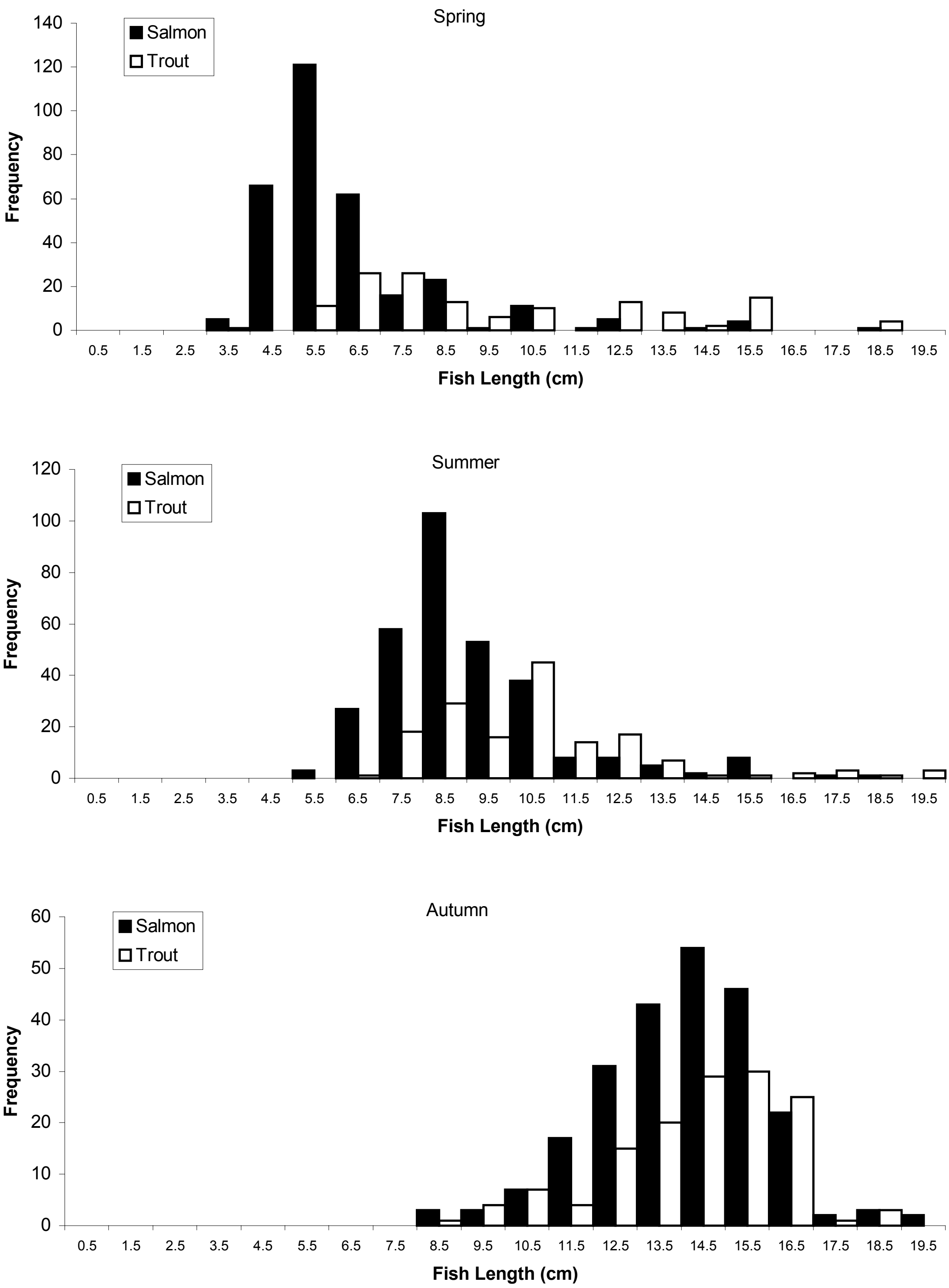


Figure 4.4: Frequency of different lengths of active salmon and trout observed by snorkelling in the Piddle study area in spring, summer and autumn.

Depth

Size group (three-way ANOVA, $F_{1,4334}$ = 170, p<0.000001), study area (three-way ANOVA, $F_{3,4334}$ = 141, p<0.000001) and species (three-way ANOVA, $F_{1,4334}$ = 30, p<0.000001) all showed significant effects on the mean depths used (Fig. 4.5). All interaction effects between these three factors were also significant indicating that the effects of size group, study area, and species are all modified by complicated relationships with the other variables. Individual post-hoc comparisons (Tukey test) showed that whilst there were not always statistical differences between the mean depths used by species/size groups in different study areas, statistical differences were more common than not (Table 4.1).

Within each study area, site and season both showed significant effects on mean depths used (two-way ANOVA, Devon Season $F_{2,1005}$ = 154, p<0.000001, Site $F_{3,1005}$ = 40.1, p<0.000001; Wales Season $F_{1,830}$ = 71.5, p<0.000001, Site $F_{2,830}$ = 31.1, p<0.000001; Frome Season $F_{1,719}$ = 56.3, p<0.000001, Site $F_{3,719}$ = 125, p<0.000001; Piddle Season $F_{2,1316}$ = 89, p<0.000001, Site $F_{3,1316}$ = 112, p<0.000001) (Figs 4.5-4.9).

Table 4.1: The results of individual comparisons (Tukey test) between mean depths used by two size groups of trout and salmon in four study areas (*=p<0.05, **=p<0.01, ***=p<0.001).

			Dev	Dev	Dev	Dev	Wal	Wal	Wal	Wal	Fro	Fro	Fro	Fro	Pid	Pid	Pid	Pid
			Sal	Sal	Trt	Trt	Sal	Sal	Trt	Trt	Sal	Sal	Trt	Trt	Sal	Sal	Trt	Trt
			0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20
Dev	Sal	0-7		***	n.s.	***	***	***	n.s.	***	***	***	n.s.	**	***	***	***	***
Dev	Sal	8-20			***	n.s.	n.s.	n.s.	***	**	n.s.	n.s.	***	**	***	***	n.s.	***
Dev	Trt	0-7				***	***	***	**	***	***	***	**	***	***	***	***	***
Dev	Trt	8-20					***	n.s.	***	n.s.	**	n.s.	***	***	***	n.s.	n.s.	**
Wal	Sal	0-7						***	**	***	n.s.	n.s.	*	*	***	***	*	***
Wal	Sal	8-20							***	n.s.	**	*	***	***	***	n.s.	n.s.	***
Wal	Trt	0-7								***	***	**	n.s.	n.s.	***	***	***	***
Wal	Trt	8-20									***	**	***	***	**	n.s.	n.s.	n.s.
Fro	Sal	0-7										n.s.	***	***	***	***	n.s.	***
Fro	Sal	8-20											**	*	***	***	n.s.	***
Fro	Trt	0-7												n.s.	***	***	***	***
Fro	Trt	8-20													***	***	***	***
Pid	Sal	0-7														n.s.	n.s.	n.s.
Pid	Sal	8-20															n.s.	n.s.
Pid	Trt	0-7																n.s.

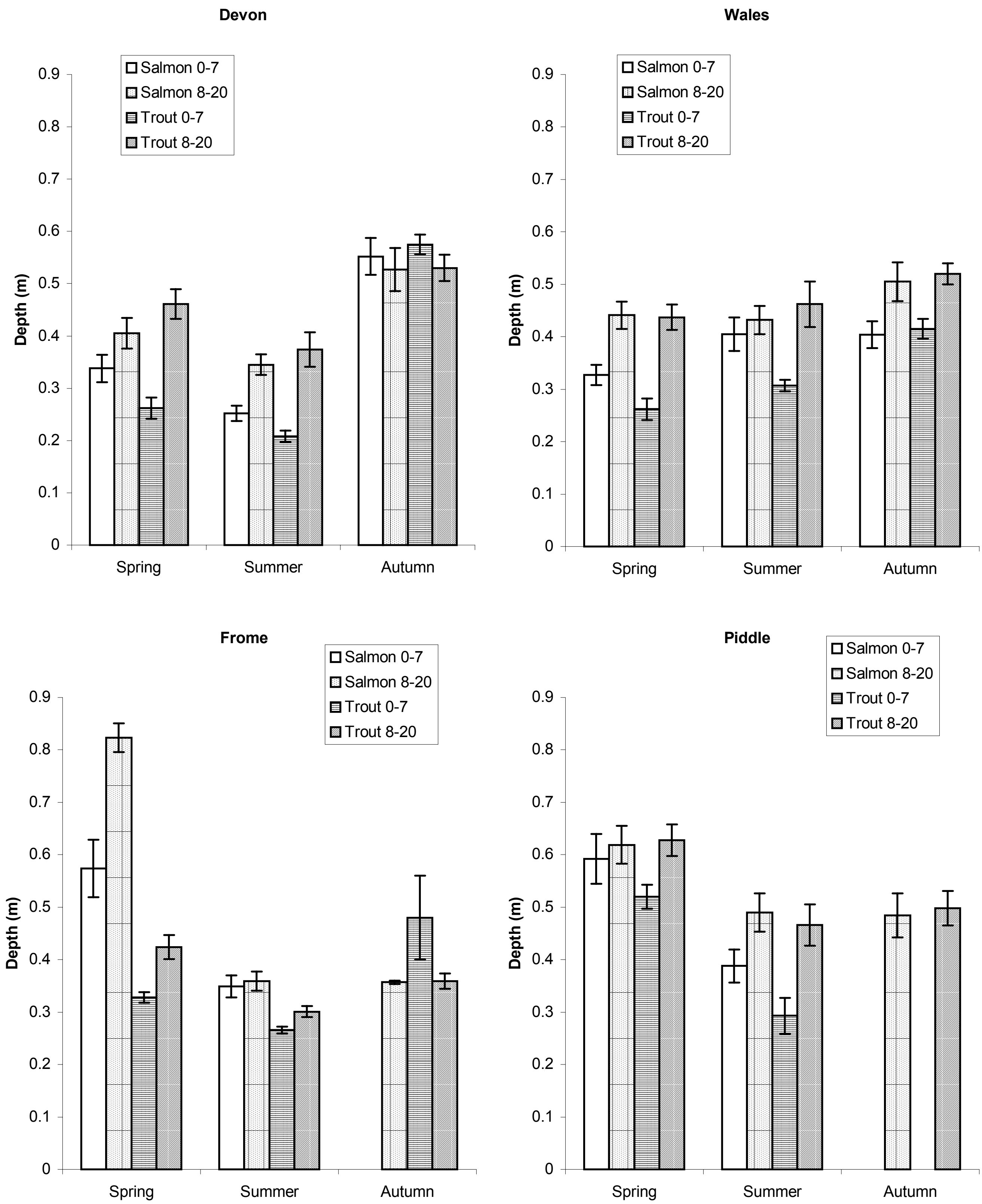


Figure 4.5: Mean depths used by two size groups of salmon and trout during spring, summer and autumn in four study areas.

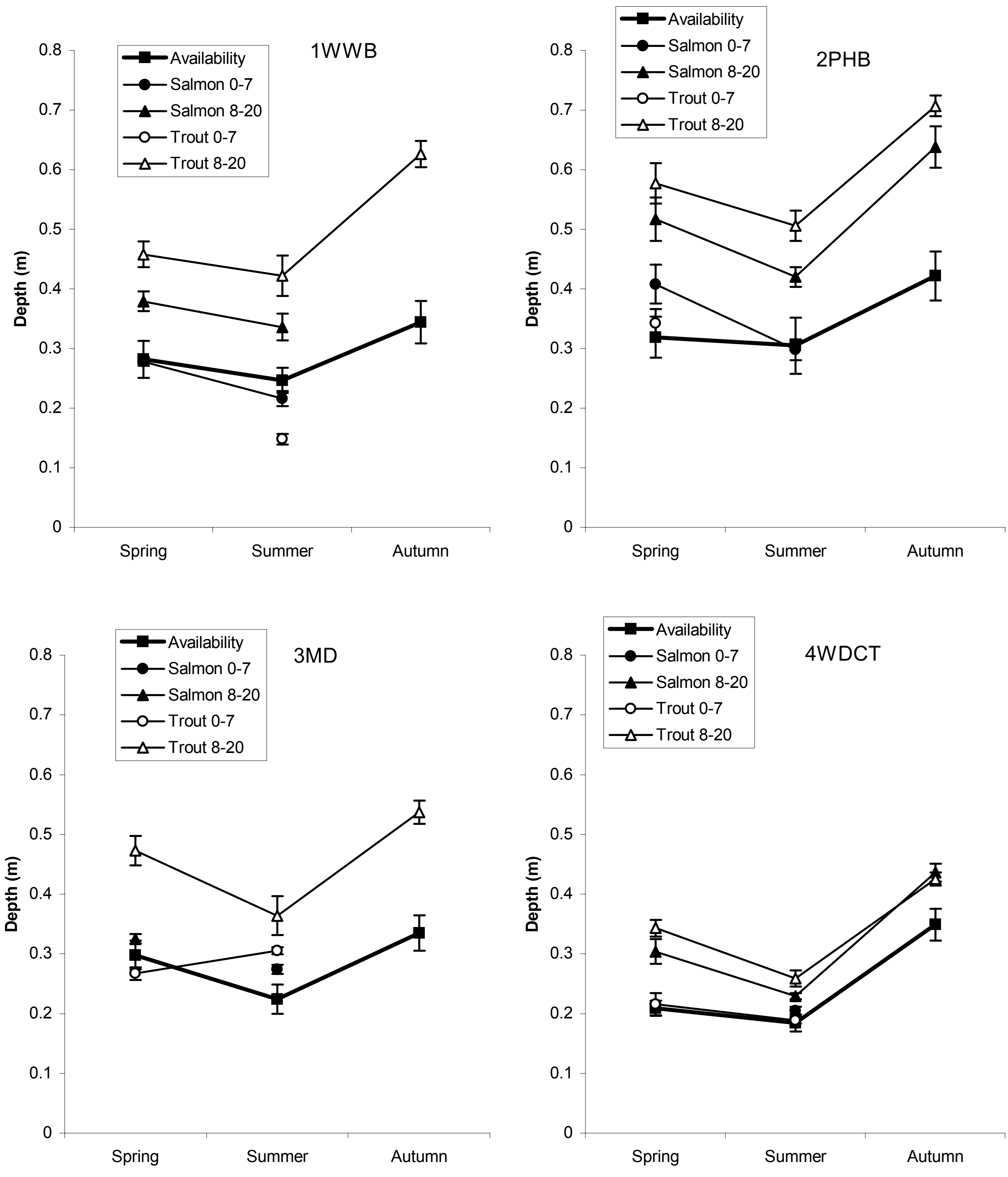


Figure 4.6: Mean depths used by two size groups of salmon and trout together with mean depth available in spring, summer and autumn in the four sites making up the Devon study area.

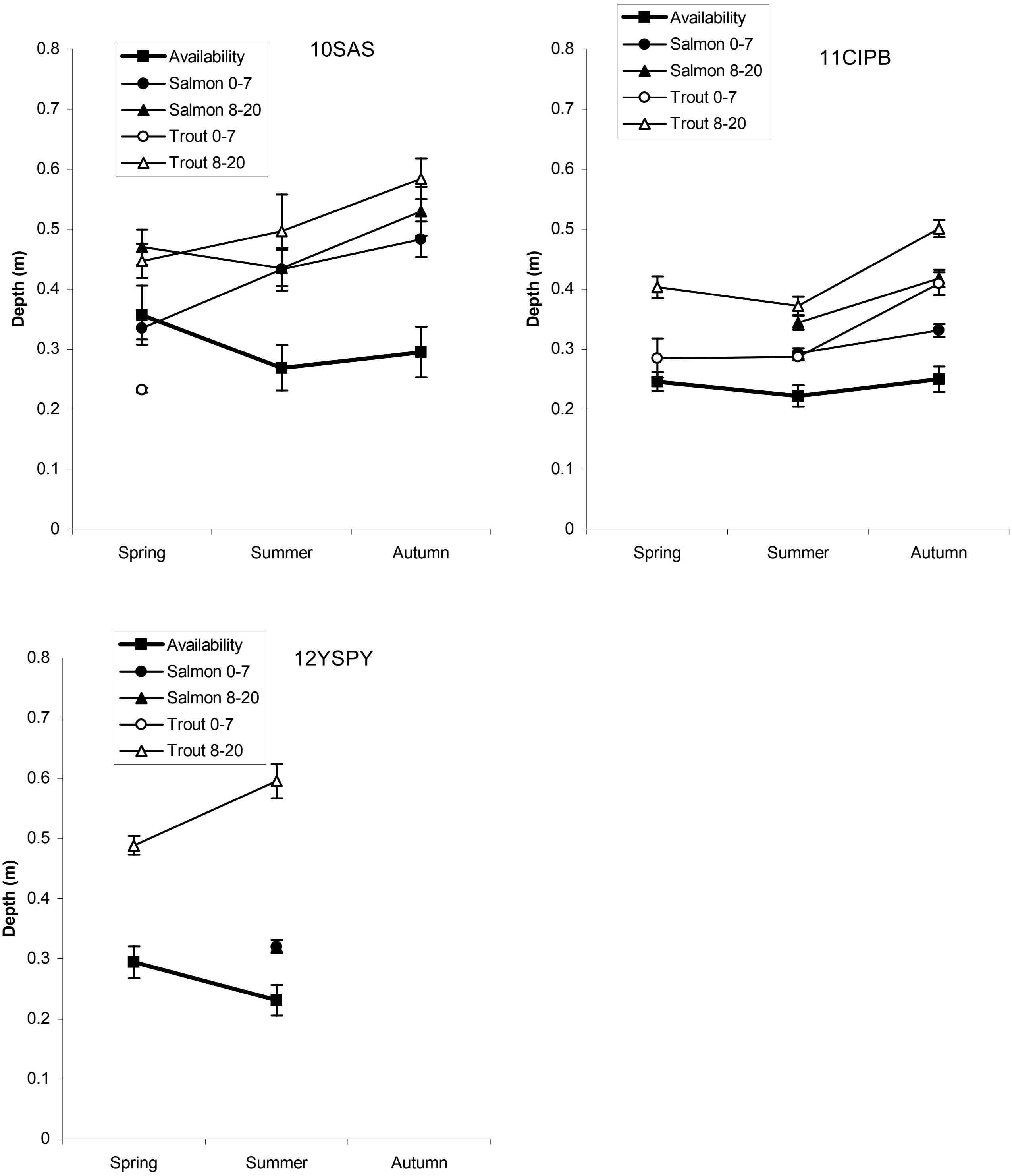


Figure 4.7: Mean depths used by two size groups of salmon and trout together with mean depth available in spring, summer and autumn in the three sites making up the Wales study area.

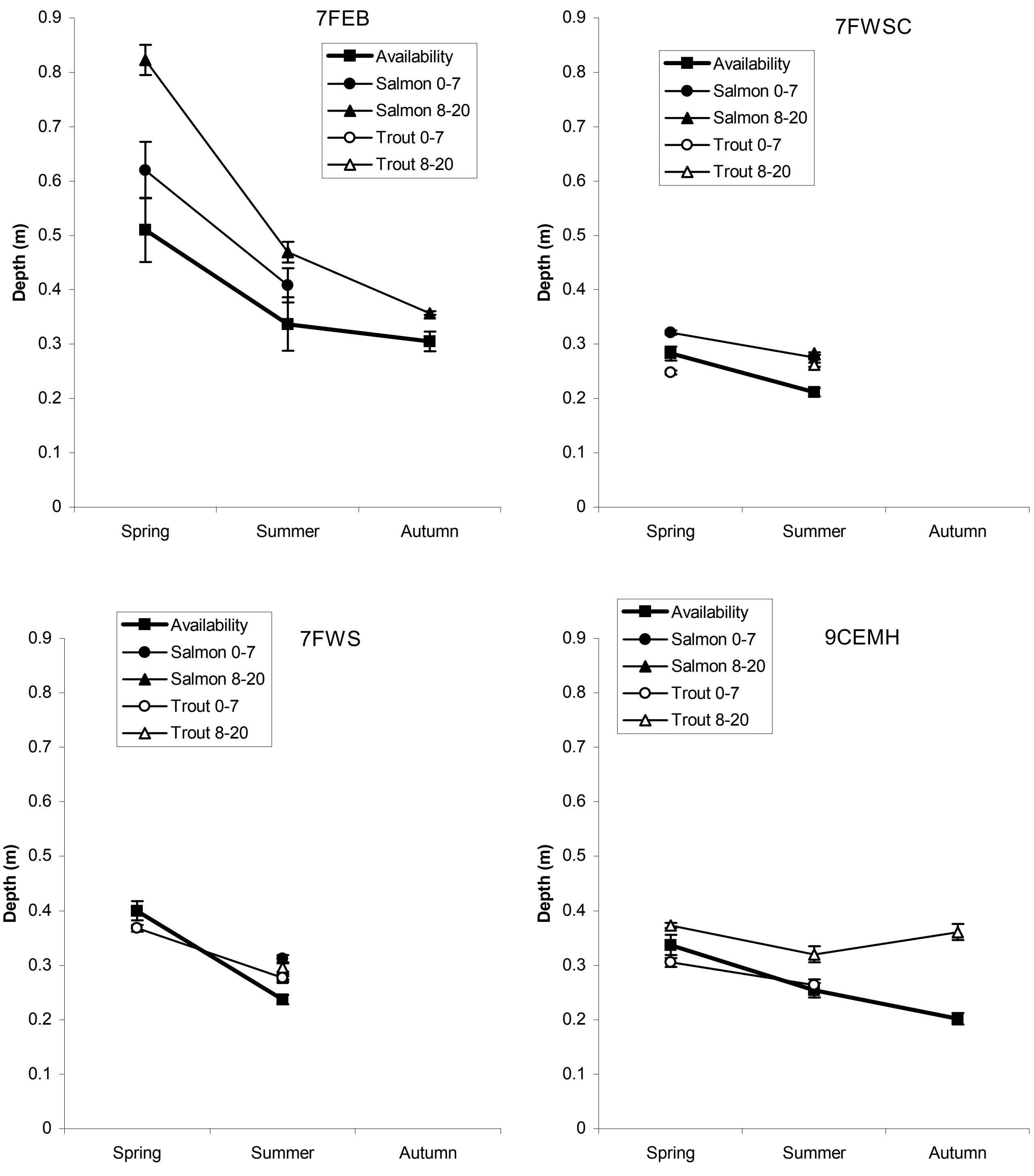


Figure 4.8: Mean depths used by two size groups of salmon and trout together with mean depth available in spring, summer and autumn in the four sites making up the Frome study area.

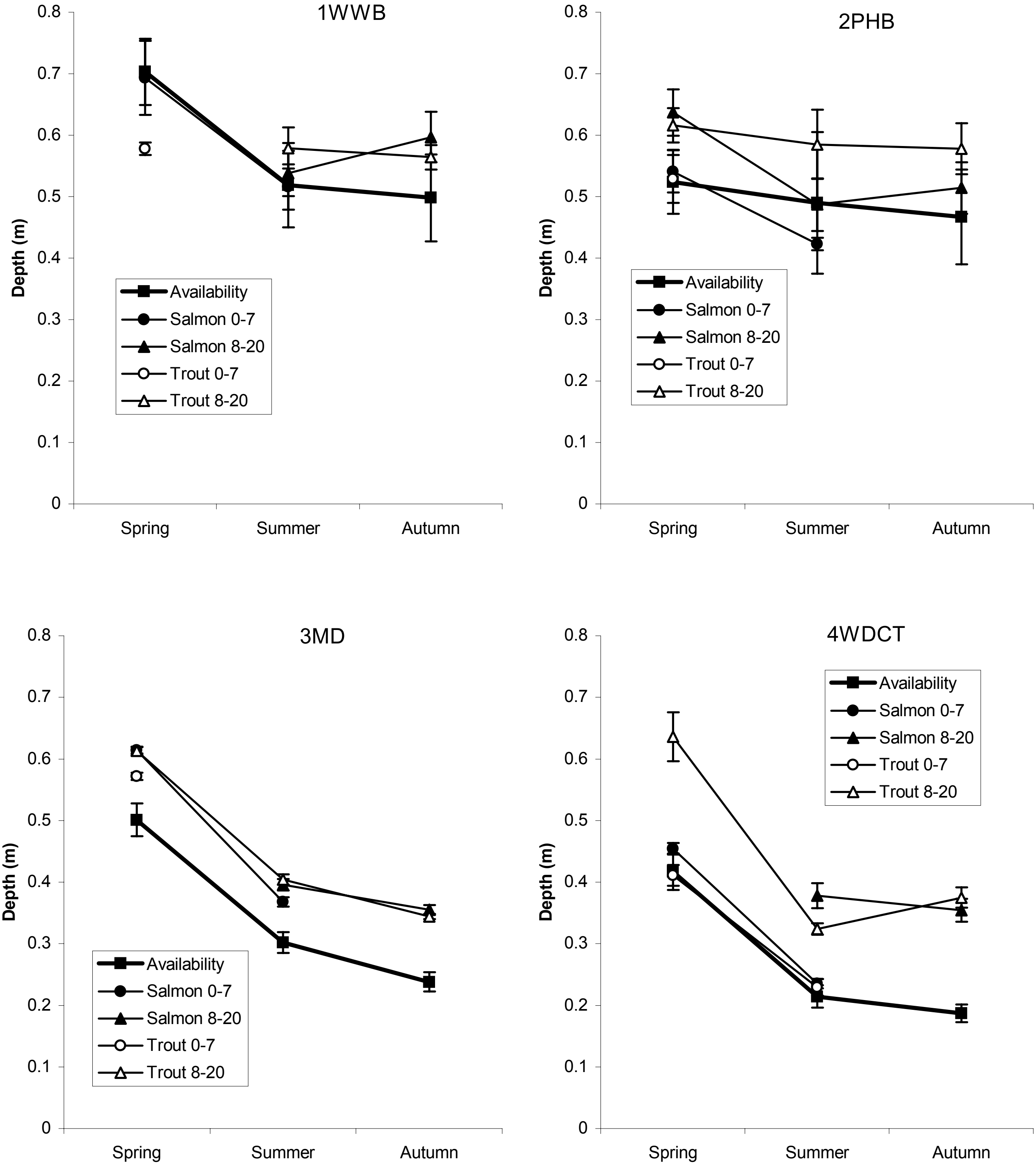


Figure 4.9: Mean depths used by two size groups of salmon and trout together with mean depth available in spring, summer and autumn in the four sites making up the Piddle study area.

Velocity

Size group (three-way ANOVA, $F_{1,4320} = 179$, $p<0.000001$), study area (three-way ANOVA, $F_{3,4320} = 140$, $p<0.000001$) and species (three-way ANOVA, $F_{1,4320} = 28$, $p<0.000001$) all showed significant effects on the mean velocities used (Fig 4.10). All interaction effects between these three factors were also significant indicating that the effects of size group, study area, and species are all modified by complicated relationships with the other variables. Individual post-hoc comparisons (Tukey test) showed that whilst there were not always statistical differences between the mean velocities used by species/size groups in different study areas, statistical differences were more common than not (Table 4.2).

Within each study area, site and season both showed significant effects on mean velocities used with the exception of season in Wales (two-way ANOVA, Devon Season $F_{2,994} = 149$, $p<0.000001$, Site $F_{3,994} = 40.2$, $p<0.000001$; Wales Season $F_{1,877} = 1.75$, n.s., Site $F_{2,877} = 20.5$, $p<0.000001$; Frome Season $F_{1,719} = 54.6$, $p<0.000001$, Site $F_{3,719} = 119$, $p<0.000001$; Piddle Season $F_{2,1315} = 93$, $p<0.000001$, Site $F_{3,1315} = 114$, $p<0.000001$) (Figs. 4.11-4.14).

Table 4.2: The results of individual comparisons (Tukey test) between mean velocities used by two size groups of trout and salmon in four study areas (*=p<0.05, **=p<0.01, ***=p<0.001).

			Dev	Dev	Dev	Dev	Wal	Wal	Wal	Wal	Fro	Fro	Fro	Fro	Pid	Pid	Pid	Pid
			Sal	Sal	Trt	Trt	Sal	Sal	Trt	Trt	Sal	Sal	Trt	Trt	Sal	Sal	Trt	Trt
			0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20
Dev	Sal	0-7		***	n.s.	***	***	***	n.s.	***	***	***	n.s.	**	***	***	***	***
Dev	Sal	8-20			***	*	n.s.	*	***	**	n.s.	n.s.	***	**	***	***	n.s.	***
Dev	Trt	0-7				***	***	***	**	***	***	***	**	***	***	***	***	***
Dev	Trt	8-20					***	n.s.	***	n.s.	**	*	***	***	***	n.s.	n.s.	**
Wal	Sal	0-7						***	**	***	n.s.	n.s.	*	*	***	***	*	***
Wal	Sal	8-20							***	n.s.	**	*	***	***	***	n.s.	n.s.	***
Wal	Trt	0-7								***	***	**	n.s.	n.s.	***	***	***	***
Wal	Trt	8-20									***	**	***	***	**	n.s.	n.s.	n.s.
Fro	Sal	0-7										n.s.	***	***	***	***	n.s.	***
Fro	Sal	8-20											**	*	***	***	n.s.	***
Fro	Trt	0-7												n.s.	***	***	***	***
Fro	Trt	8-20													***	***	***	***
Pid	Sal	0-7														n.s.	n.s.	n.s.
Pid	Sal	8-20															n.s.	n.s.
Pid	Trt	0-7																n.s.

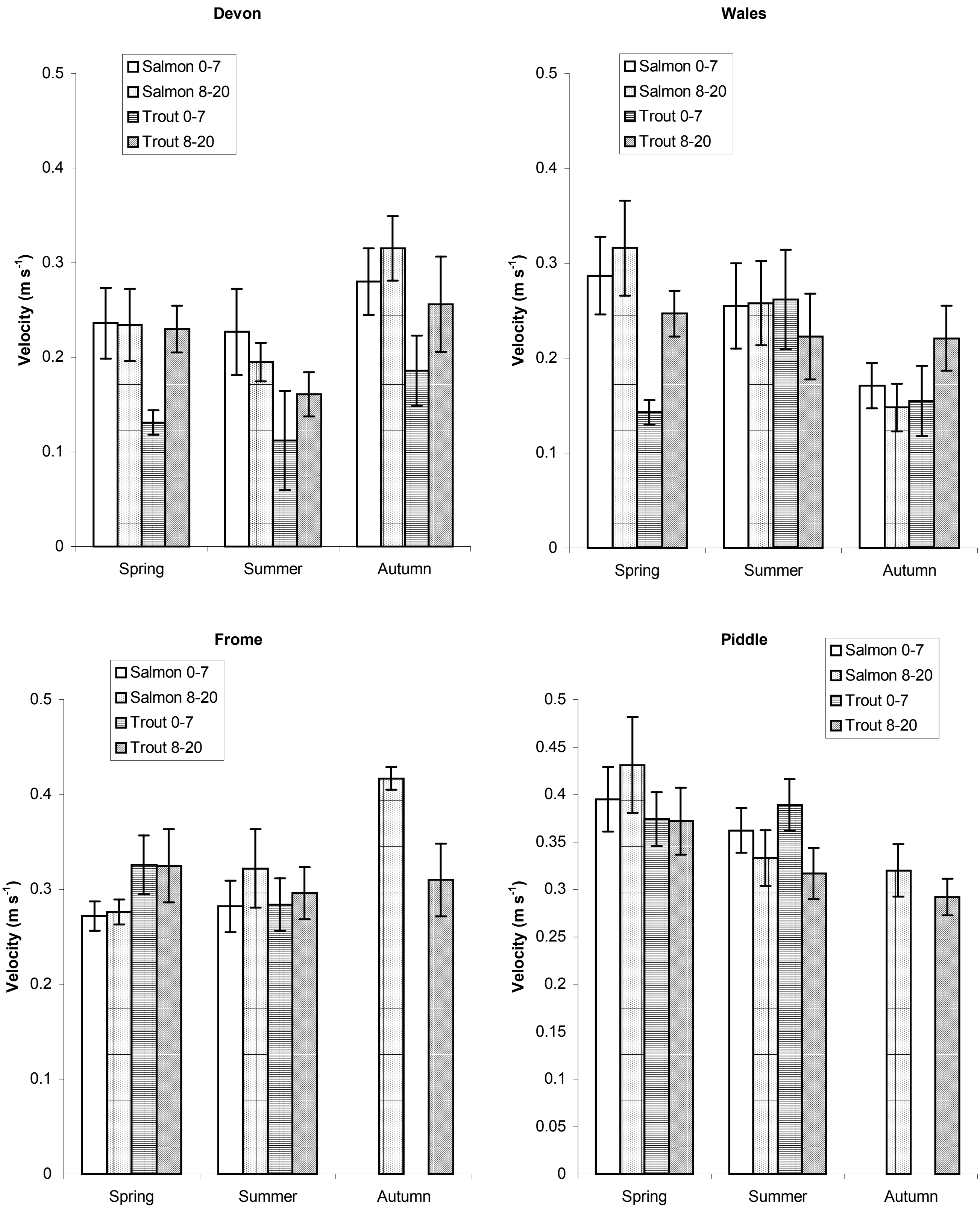


Figure 4.10: Mean velocities used by two size groups of salmon and trout during spring, summer and autumn in four study areas.

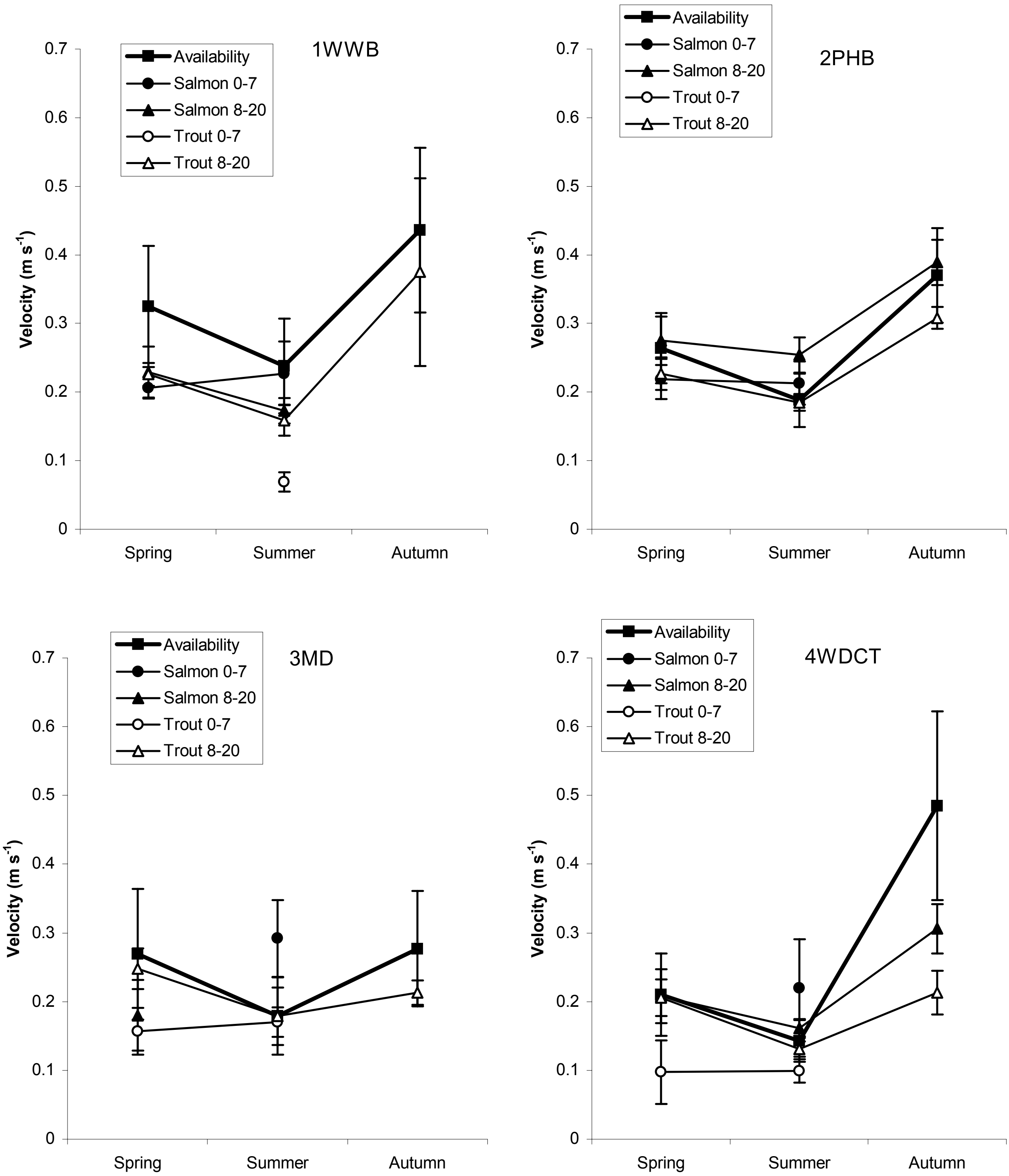


Figure 4.11: Mean velocities used by two size groups of salmon and trout together with mean depth available in spring summer and autumn in the four sites making up the Devon study area.

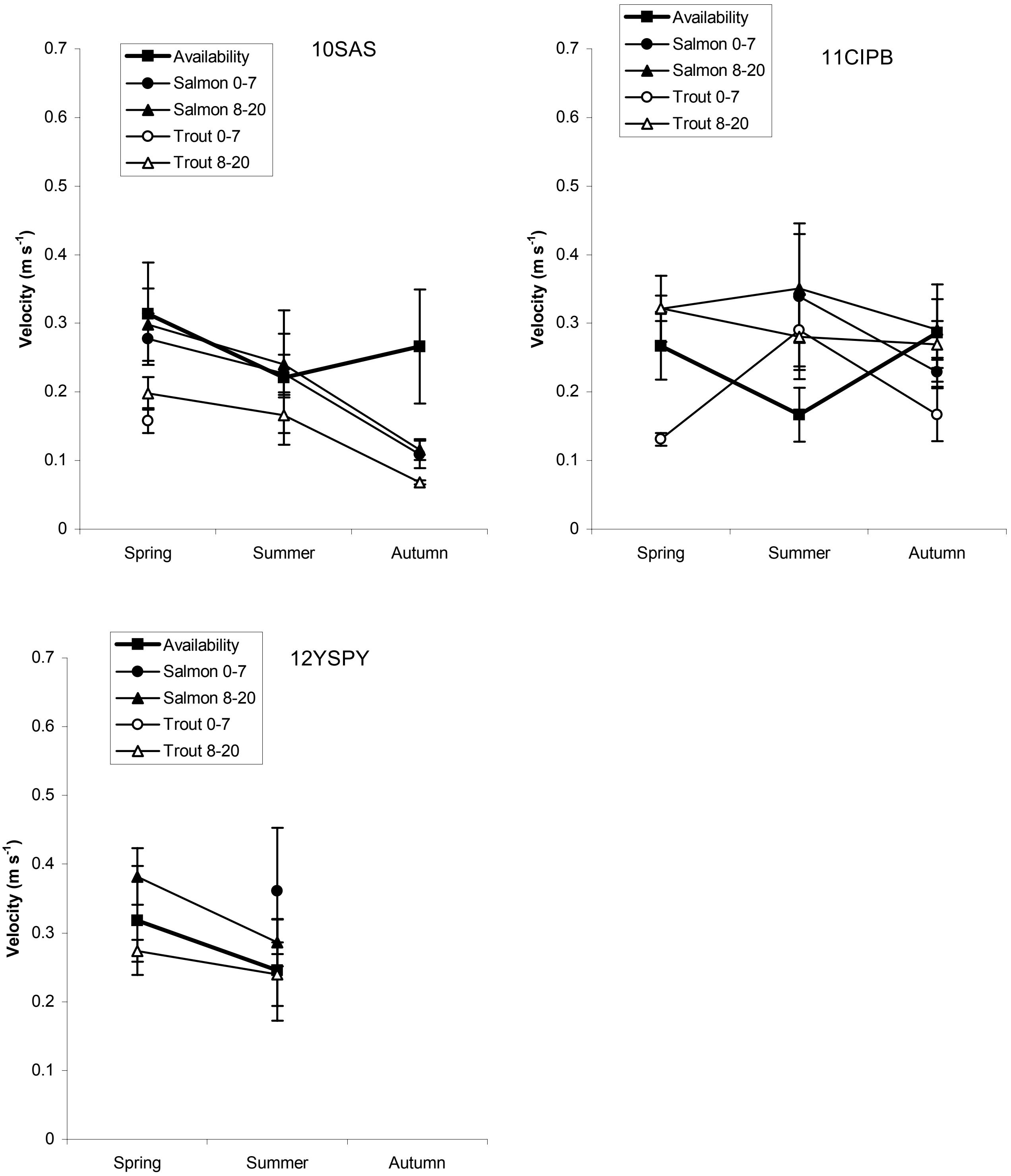


Figure 4.12: Mean velocities used by two size groups of salmon and trout together with mean depth available in spring summer and autumn in the four sites making up the Wales study area.

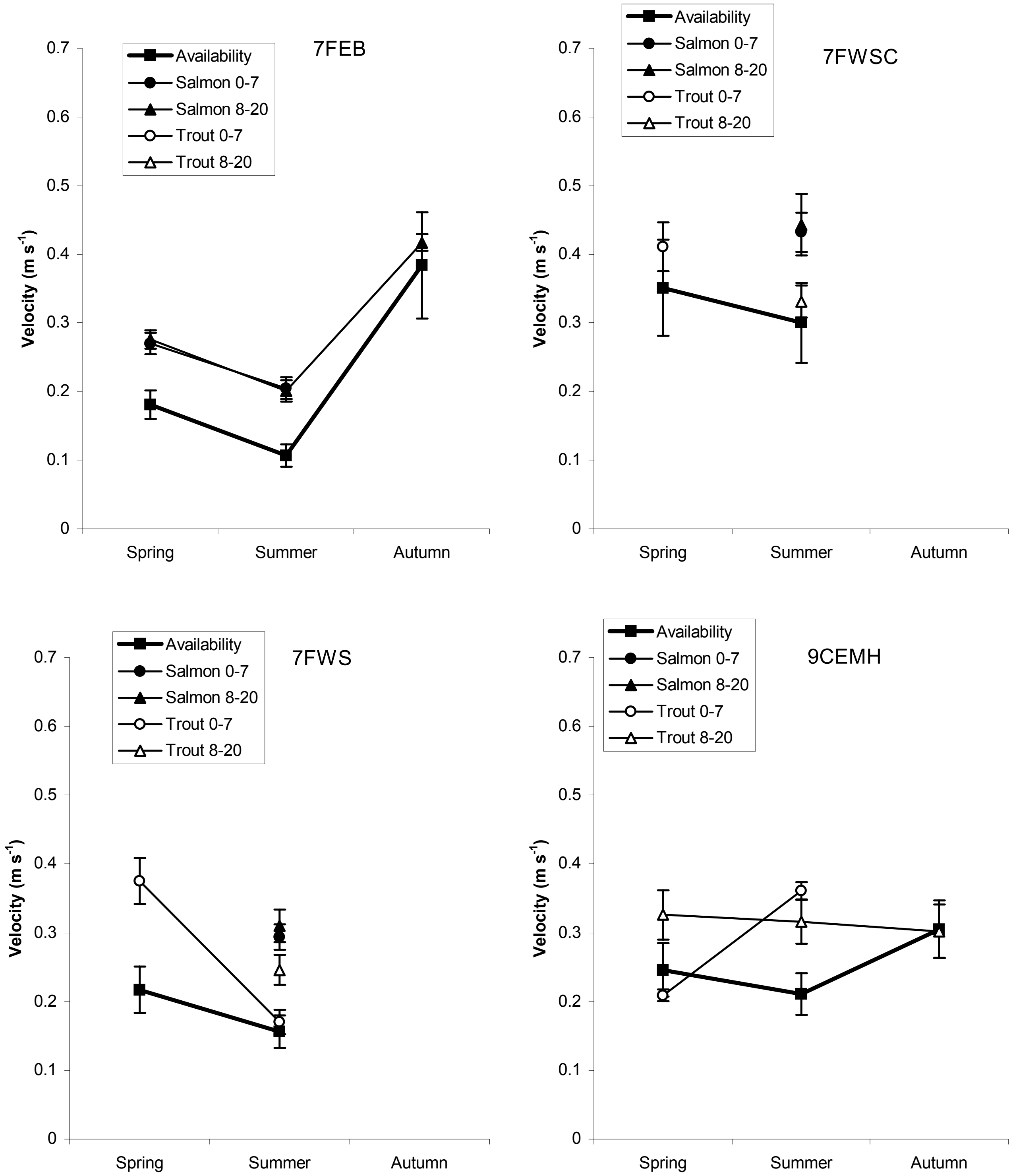


Figure 4.13: Mean velocities used by two size groups of salmon and trout together with mean depth available in spring, summer and autumn in the four sites making up the Frome study area.

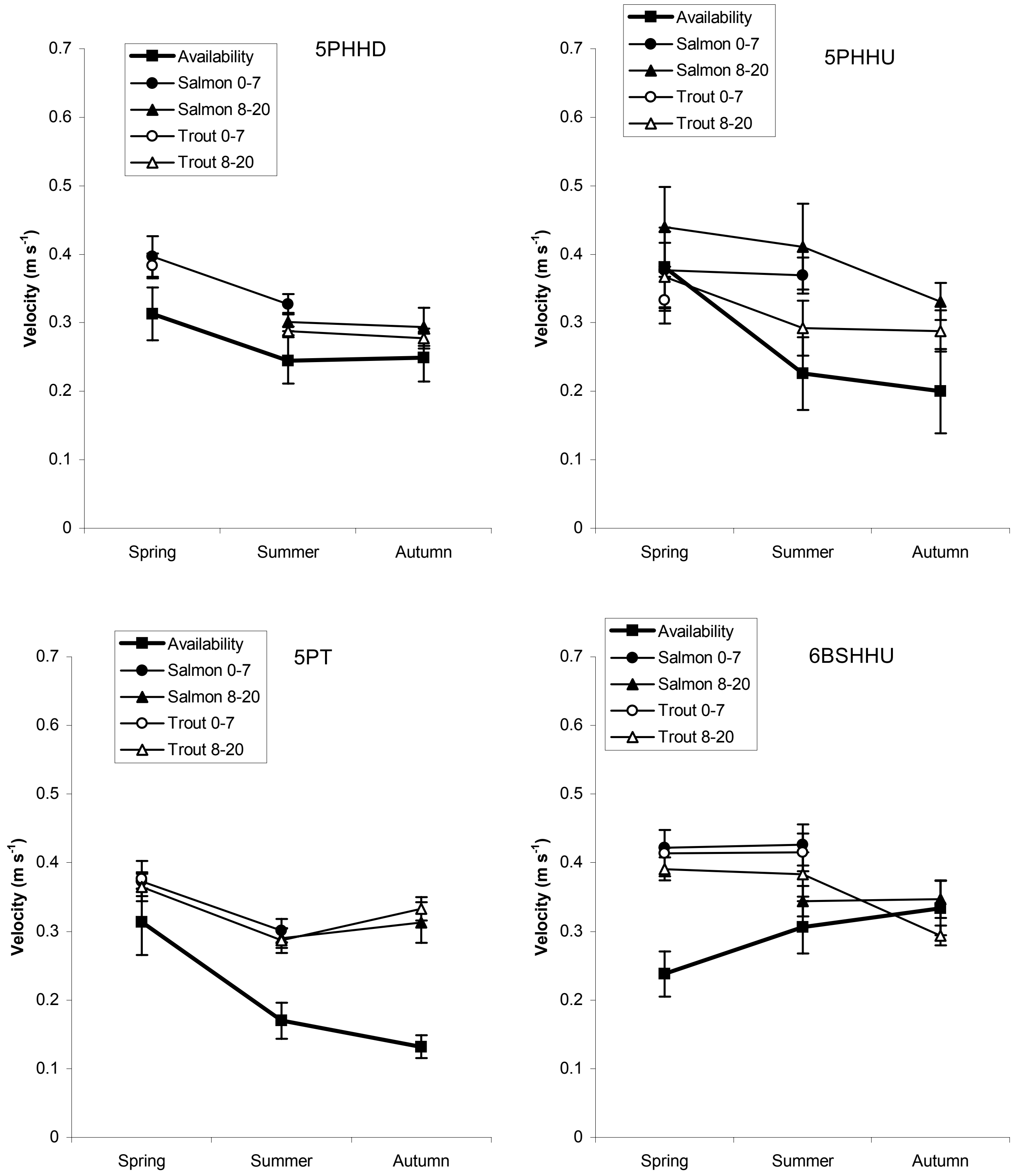


Figure 4.14: Mean velocities used by two size groups of salmon and trout together with mean depth available in spring summer and autumn in the four sites making up the Piddle study area.

4.4 Habitat use by Different Fish Size Groups across Four Study Areas

In all study areas the larger size group (8-20 cm) of salmon and trout tended to use greater mean depths and greater mean velocities than the smaller size group (0-7 cm) (Table 4.3). Species differences in habitat use were much less obvious. Within each study area the small size group of salmon used greater mean depths than the small size group of trout and also greater mean velocities with the exception of the Frome study area (Table 4.3).

Conversely the larger size group of salmon used shallower mean depths than the larger size group of trout in each of the study areas with the exception of the Frome and faster mean velocities in all study areas (Table 4.3).

Table 4.3: The mean (± s.d.) depths and velocities used by two size groups of salmon and trout in four study areas.

		Study Area			
		Mean Depth ± s.d.			
Species	Size group	Devon	Wales	Frome	Piddle
Salmon	0-7 cm	0.287±0.149	0.387±0.167	0.407±0.197	0.542±0.226
Salmon	8-20 cm	0.406±0.180	0.457±0.176	0.400±0.185	0.499±0.201
Trout	0-7 cm	0.259±0.146	0.314±0.137	0.313±0.103	0.468±0.185
Trout	8-20 cm	0.456±0.179	0.470±0.176	0.332±0.124	0.514±0.196
		Mean Velocity ± s.d.			
Species	Size group	Devon	Wales	Frome	Piddle
Salmon	0-7 cm	0.232±0.210	0.241±0.199	0.280±0.156	0.387±0.178
Salmon	8-20 cm	0.236±0.177	0.239±0.210	0.330±0.191	0.337±0.177
Trout	0-7 cm	0.125±0.159	0.197±0.194	0.312±0.173	0.377±0.166
Trout	8-20 cm	0.215±0.180	0.231±0.186	0.304±0.176	0.319±0.162

Distributions of depth and velocity use varied between each of the study areas for each of the species/size groups in most cases (Tables 4.4 & 4.5). There were some similarities between study areas, for example large trout in the Devon study area used the same distribution of depths and velocities as large trout in Wales. However, these similarities were rare in comparison to the more general observation that each of the distributions of habitat use differed between study areas and between species/size groups within each of the study areas.

This applied to comparisons within each of the river types. From viewing the distributions of depths and velocities used by the species/size groups in each study area it appears that in general the habitat use in the two upland study areas are more similar to each other than the chalk study areas (Figs. 4.15-4.18). This is most obvious in the velocities used where the most frequently used velocities in the upland study areas are between 0 and 0.1 m s^{-1}, whereas it tends to be between 0.2 and 0.4 m s^{-1} in the chalk study areas. However, despite this observation it would not be true to say that there were many less significant differences in the distributions of habitat used within each of the river type groups than between river type groups. In either case the number of significant differences exceeded cases when there were no significant differences. Indeed some of the non-significant comparisons appeared to be nonsense, for example, large salmon in Devon use the same habitat as small trout on the Piddle (Tables 4.4 & 4.5).

Within each of the study areas both the distributions of depth and velocity use changed with season. Some study areas were not sampled every season, but where comparisons were possible it was generally the case that different habitats were used by each of the species/size groups within different seasons (Tables 4.6 & 4.7).

Table 4.4: The results of individual comparisons (KS two sample test) between the distributions of depths used by two size groups of trout and salmon in four study areas together with differences in the distribution of depths available in each study area and distribution of depths available and used within each study area (*=p<0.05, **=p<0.01, ***=p<0.001)

	Dev Sal 0-7	Dev Sal 8-20	Dev Trt 0-7	Dev Trt 8-20	Wal Sal 0-7	Wal Sal 8-20	Wal Trt 0-7	Wal Trt 8-20	Fro Sal 0-7	Fro Sal 8-20	Fro Trt 0-7	Fro Trt 8-20	Pid Sal 0-7	Pid Sal 8-20	Pid Trt 0-7	Pid Trt 8-20
Dev Sal 0-7		***	n.s.	***	***	***	n.s.	***	***	***	n.s.	**	***	***	***	***
Dev Sal 8-20			***	*	n.s.	*	***	**	n.s.	n.s.	***	**	***	***	n.s.	***
Dev Trt 0-7				***	***	***	**	***	***	***	**	***	***	***	***	***
Dev Trt 8-20					***	n.s.	***	n.s.	**	*	***	***	***	n.s.	n.s.	**
Wal Sal 0-7						***	**	***	n.s.	n.s.	*	*	***	***	*	***
Wal Sal 8-20							***	n.s.	**	*	***	***	***	n.s.	n.s.	***
Wal Trt 0-7								***	***	**	n.s.	n.s.	***	***	***	***
Wal Trt 8-20									***	**	***	***	**	n.s.	n.s.	n.s.
Fro Sal 0-7										n.s.	***	***	***	***	n.s.	***
Fro Sal 8-20											**	*	***	***	n.s.	***
Fro Trt 0-7												n.s.	***	***	***	***
Fro Trt 8-20													***	***	***	***
Pid Sal 0-7														n.s.	n.s.	n.s.
Pid Sal 8-20															n.s.	n.s.
Pid Trt 0-7																n.s.

				Respective species size group for each study area			
				Salmon	Salmon	Trout	Trout
STUDY AREA	Wales Avail	Frome Avail	Piddle Avail	0-7 cm	8-20 cm	0-7 cm	8-20 cm
Devon Avail	n.s.	***	***	n.s.	***	***	***
Wales Avail		***	***	***	***	***	***
Frome Avail			***	***	***	**	***
Piddle Avail				***	***	n.s.	***

Table 4.5: The results of individual comparisons (KS two sample test) between the distributions of velocities used by two size groups of trout and salmon in four study areas together with differences in the distribution of velocities available in each study area and distribution of velocities available and used within each study area (*=p<0.05, **=p<0.01, ***=p<0.001).

			Dev	Dev	Dev	Dev	Wal	Wal	Wal	Wal	Fro	Fro	Fro	Fro	Pid	Pid	Pid	Pid
			Sal	Sal	Trt	Trt	Sal	Sal	Trt	Trt	Sal	Sal	Trt	Trt	Sal	Sal	Trt	Trt
			0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20	0-7	8-20
Dev	Sal	0-7		***	n.s.	***	***	***	n.s.	***	***	***	n.s.	**	***	***	***	***
Dev	Sal	8-20			***	*	n.s.	*	***	**	n.s.	n.s.	***	**	***	***	n.s.	***
Dev	Trt	0-7				***	***	***	**	***	***	***	**	***	***	***	***	***
Dev	Trt	8-20					***	n.s.	***	n.s.	**	*	***	***	***	n.s.	n.s.	**
Wal	Sal	0-7						***	**	***	n.s.	n.s.	*	*	***	***	*	***
Wal	Sal	8-20							***	n.s.	**	*	***	***	***	n.s.	n.s.	***
Wal	Trt	0-7								***	***	**	n.s.	n.s.	***	***	***	***
Wal	Trt	8-20									***	**	***	***	**	n.s.	n.s.	n.s.
Fro	Sal	0-7										n.s.	***	***	***	***	n.s.	***
Fro	Sal	8-20											**	*	***	***	n.s.	***
Fro	Trt	0-7												n.s.	***	***	***	***
Fro	Trt	8-20													***	***	***	***
Pid	Sal	0-7														n.s.	n.s.	n.s.
Pid	Sal	8-20															n.s.	n.s.
Pid	Trt	0-7																n.s.

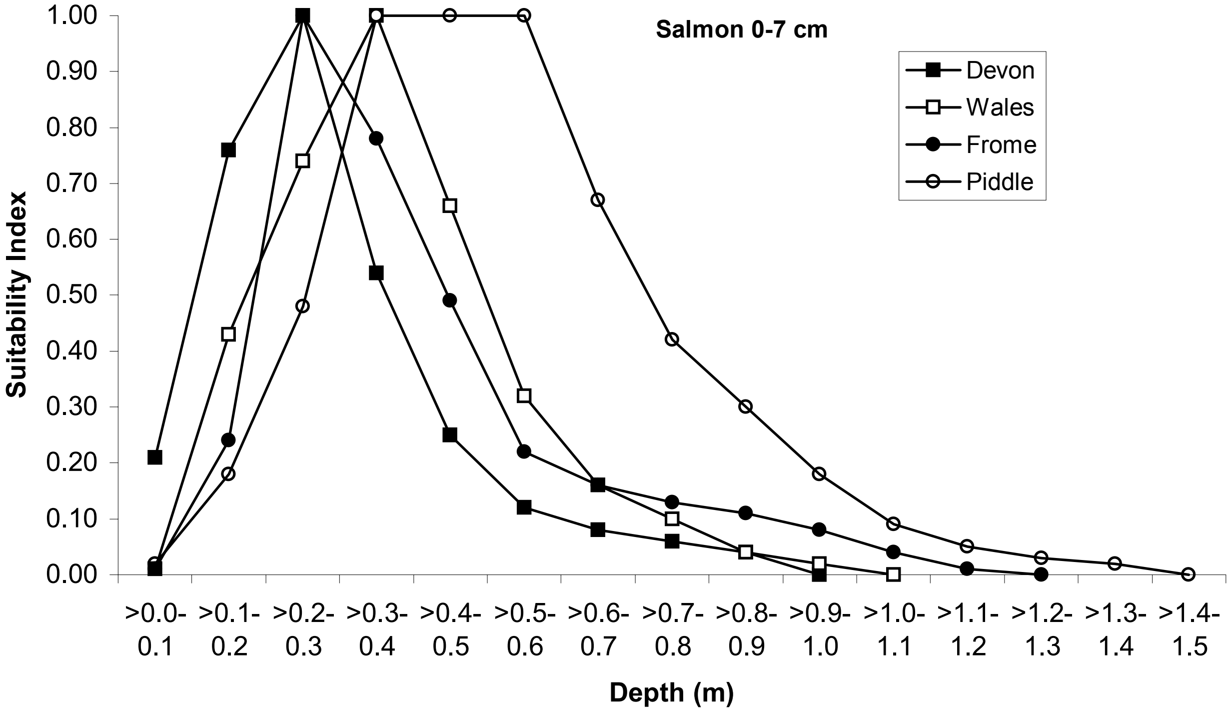
				Respective species size group for each study area			
				Salmon	Salmon	Trout	Trout
STUDY AREA	Wales Avail	Frome Avail	Piddle Avail	0-7 cm	8-20 cm	0-7 cm	8-20 cm
Devon Avail	***	***	***	***	**	***	***
Wales Avail		***	***	***	*	*	n.s.
Frome Avail			***	***	***	***	***
Piddle Avail				***	***	***	***

Table 4.6: Results of KS two sample test comparing the distributions of depths available and depths used by two size groups of salmon and trout in different seasons in four study areas. Some comparisons were not made as data from some seasons were not collected due to inclement conditions. (* = p<0.05, ** = p<0.01, ** = p<0.001).

			Salmon		Salmon		Trout		Trout	
	Avail		0-7 cm		8-20 cm		0-7 cm		8-20 cm	
Devon	Sum	Aut	Sum	Aut	Sum	Aut	Sum	Aut	Sum	Aut
Spr	***	***	***	***	n.s.	***	n.s.	**	**	***
Sum		***		***		***		***		***
Wales										
Spr	***		n.s.		*		*		n.s.	
Sum										
Frome										
Spr	***		***		***		***		***	
Sum										
Piddle										
Spr	***	***	***		***	***	***		***	***
Sum		n.s.				*				n.s.

Table 4.7: Results of KS two sample test comparing the distributions of velocities available and velocities used by two size groups of salmon and trout in different seasons in four study areas. Some comparisons were not made as data from some seasons were not collected due to inclement conditions. (* = p<0.05, ** = p<0.01, ** = p<0.001).

			Salmon		Salmon		Trout		Trout	
	Avail		0-7 cm		8-20 cm		0-7 cm		8-20 cm	
Devon	Sum	Aut	Sum	Aut	Sum	Aut	Sum	Aut	Sum	Aut
Spr	***	***	*	*	**	**	n.s.	n.s.	***	n.s.
Sum		***		***		***		**		***
Wales										
Spr	***		***		***		n.s.		***	
Sum										
Frome										
Spr	***		***		n.s.		n.s.		n.s.	
Sum										
Piddle										
Spr	***	***	***		***	***	n.s.		***	***
Sum		n.s.				n.s.				n.s.



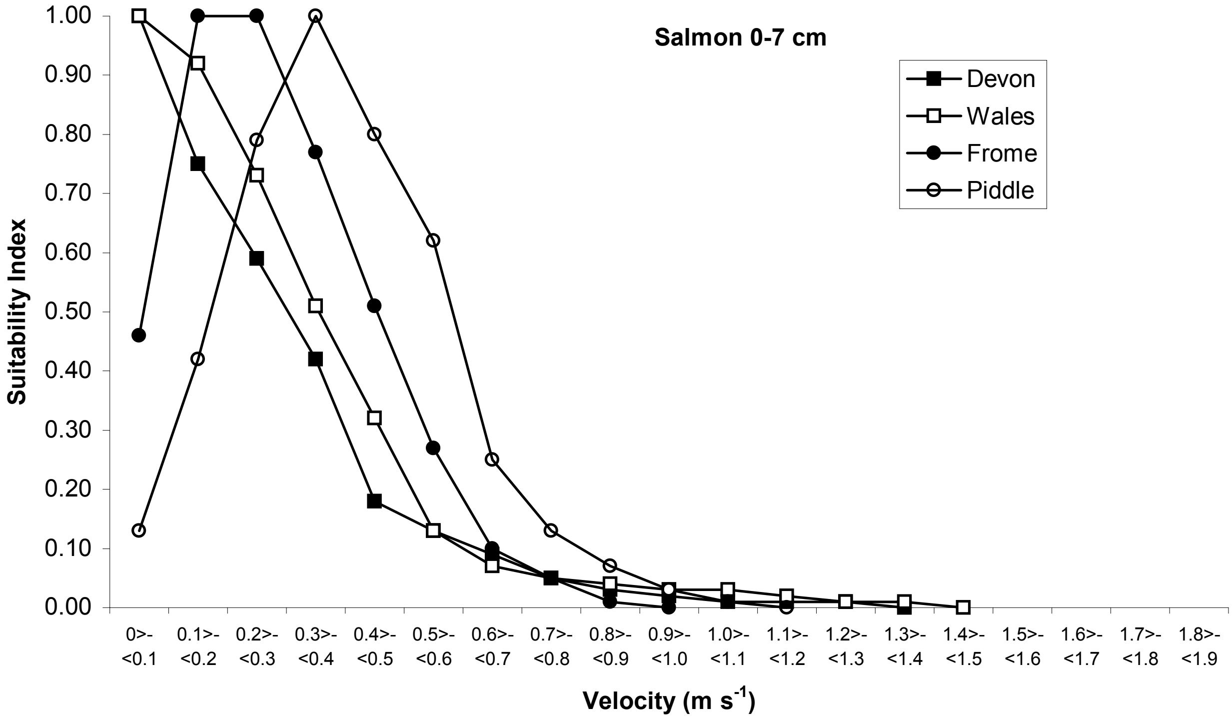


Figure 4.15: Smoothed habitat use indices for depth and velocity use by salmon less than 7 cm in length in four study areas.

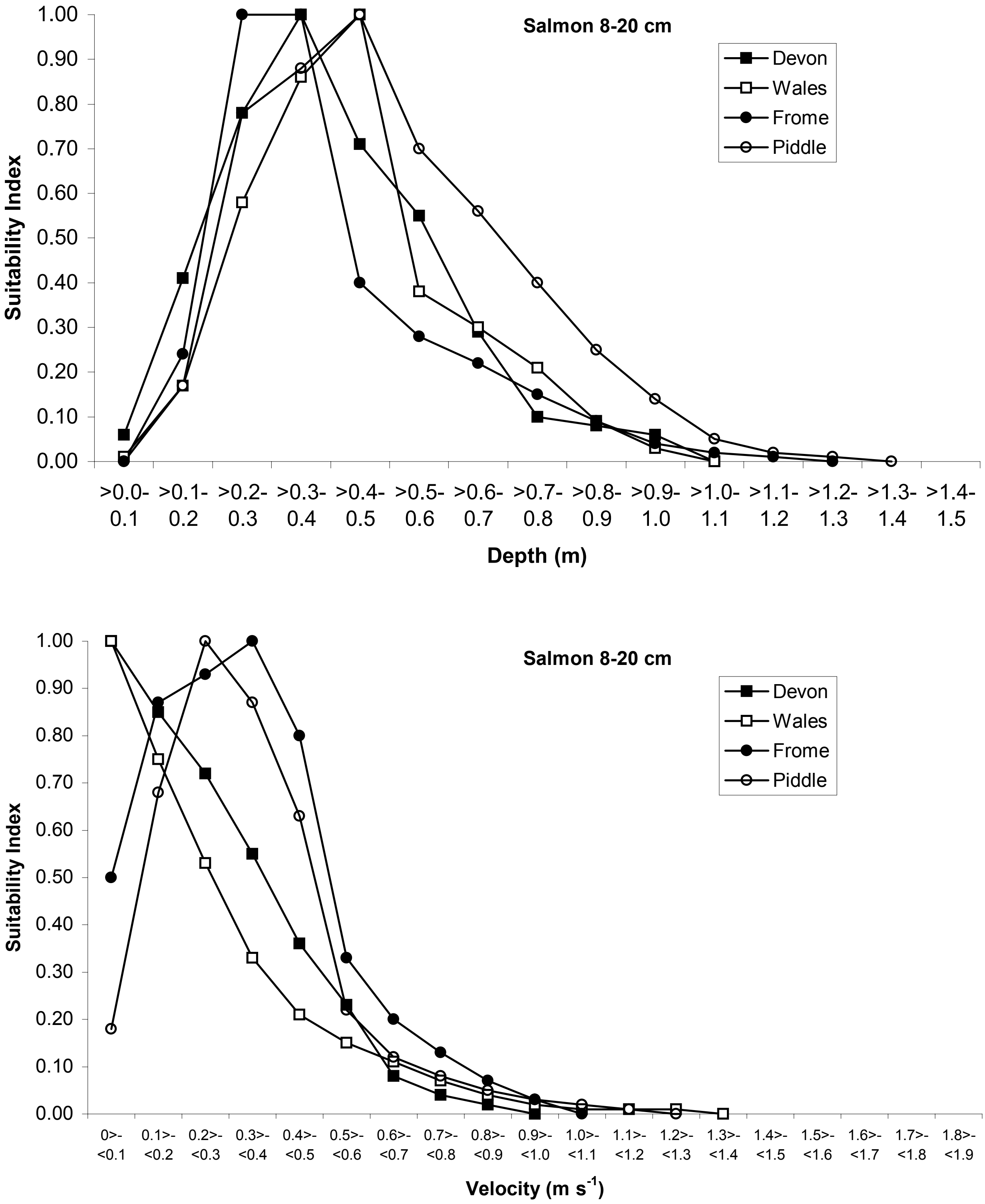


Figure 4.16: Smoothed habitat use indices for depth and velocity use by salmon between 8 and 20 cm in length in four study areas.

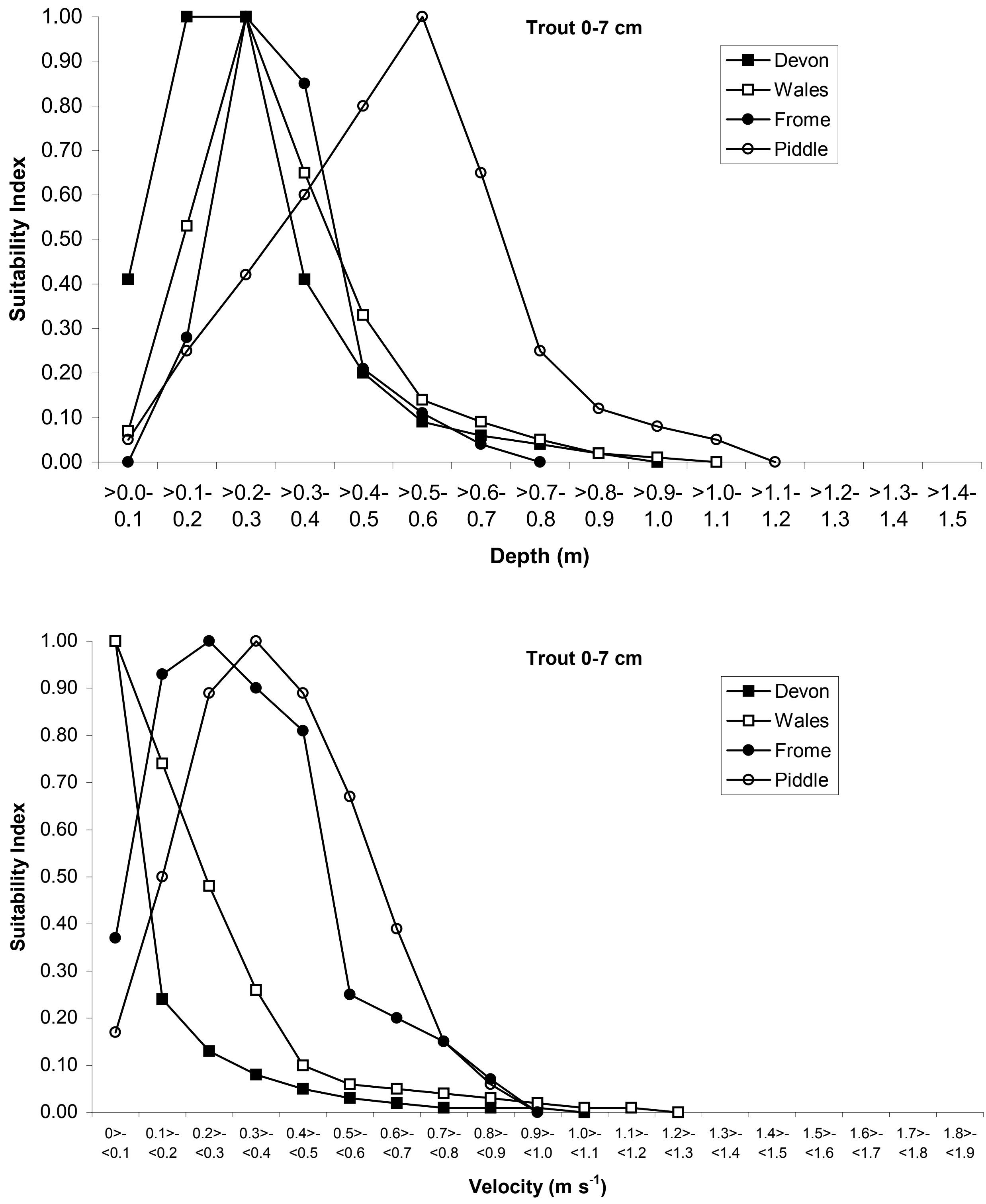


Figure 4.17: Smoothed habitat use indices for depth and velocity use by trout less than 7 cm in length in four study areas.

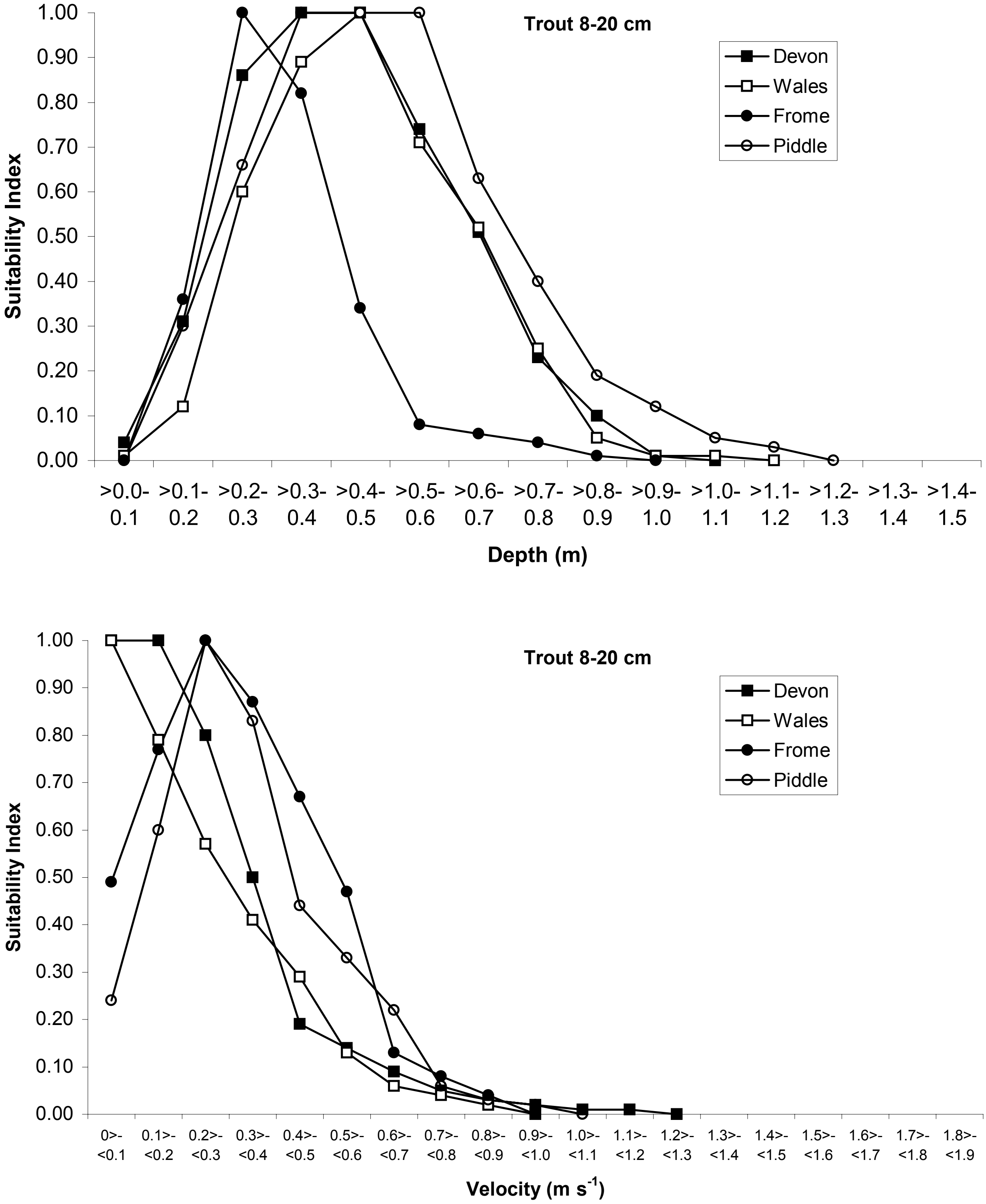


Figure 4.18: Smoothed habitat use indices for depth and velocity use by trout between 8 and 20 cm in length in four study areas.

4.4.1 Influence of habitat availability

The mean depth available at each site and season had a large effect on the mean depth used by all sizes of trout and salmon (Fig. 4.19). A combination of mean depth available and size group explained 70% of the variation in the mean depth used with depth available explaining 56% of the variation on its own (step-wise regression). Fish species had no significant effect. Within individual species/size groups mean depth available explained between 55% and 80% of the mean depths used.

The mean velocity available at each site and season had a significant but much smaller effect on the mean velocity used by all size groups of trout and salmon (Fig. 4.19). A combination of mean velocity available and species explained 12.6% of the variation in the mean velocity used with velocity available explaining 9.5% of the variation on its own (step-wise regression). Size group had no significant effect.

The distributions of habitat available in each site within each study area were significantly different (KS two-sample test) in most cases (Table 4.8). The only real exception to this was the distribution of velocities in Wales. In all other study areas each of the sites were different to the others.

Table 4.8: Results from the KS two sample test comparisons in the distribution of depths and velocities available at each of the sites within each study area (* = p<0.05, ** = p<0.01, *** = p<0.001).

Site	Depth			Velocity		
DEVON	2 PHB	3 MD	4 WDCT	2 PHB	3 MD	4 WDCT
1WWB	***	n.s.	***	**	***	***
2PHB		***	***		***	**
3 MD			*			**
WALES	11 CIPB	12 YSPY		11 CIPB	12 YSPY	
10 SAS	***	*		n.s.	n.s.	
11 CIPB		n.s.			n.s.	
FROME	7 FWSC	7 FWS	9 CEMH	7 FWSC	7 FWS	9 CEMH
7 FEB	***	***	***	***	**	***
7 FWSC		***	***		***	***
7 FWS			***			***
PIDDLE	5 PHHU	5 PT	6 BSHHU	5 PHHU	5 PT	6 BSHHU
5 PHHD	***	***	***	***	***	**
5 PHHU		***	***		**	***
5 PT			***			***

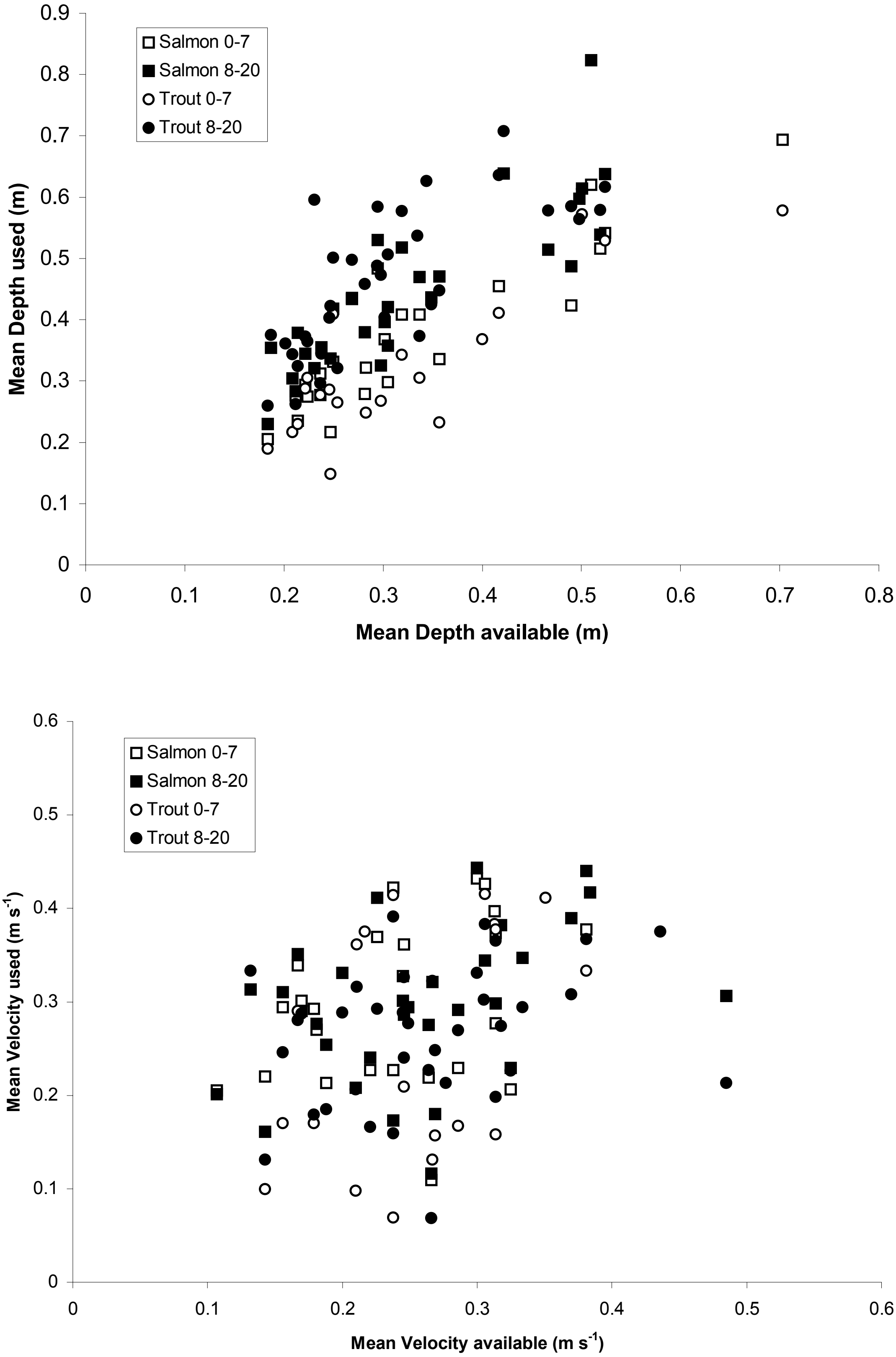


Figure 4.19: Mean depths and mean velocities available against mean depths and mean velocities used by two size groups of salmon and trout during three seasons at 15 sites in the UK.

4.4.2 Preferential habitat use

Although the depths and velocities available in each of the study areas had a large influence on the habitats used by each of the species/size groups, there were also significant differences in the distributions available and those used (Tables 4.4 & 4.5). None of the four species/size groups used the same depth and velocity distributions as were available.

This indicates that the salmon and trout were selecting depths and velocities from those available. For depths Jacobs selectivity indices closely followed the use of depth in the shallower parts of the depth distribution, that is, shallow water tended to be avoided (Figs. 4.20 –4.23). Conversely deeper water appeared to be selected by all the species/size groups. This compares to declining use of progressively deeper water (Figs. 4.20-4.23).

Similarly low velocities appeared to be avoided in favour of velocities between 0.2 and 0.4 cm s^{-1}. This compares to habitat use in the upland rivers which was mostly of the lowest velocities (Figs. 4.20-4.23). The only exception to this was small trout (0-7 cm) in upland rivers which appeared to also select the lowest velocities (Fig. 4.22). Beyond the preferred velocities, the preference indices appear to decline, although at this point the lack of availability made it difficult to estimate preference indices reliably (Figs. 4.20-4.23).

Apart from velocity use by small trout in upland rivers there appeared to be reasonable consistency in the shape of the distribution of habitat preferences between the river types. The 95% confidence intervals for the suitability indices derived from the Jacobs selectivity indices were large (Figs. 4.24, 4.25), especially for the small size group of trout (0-7 cm).

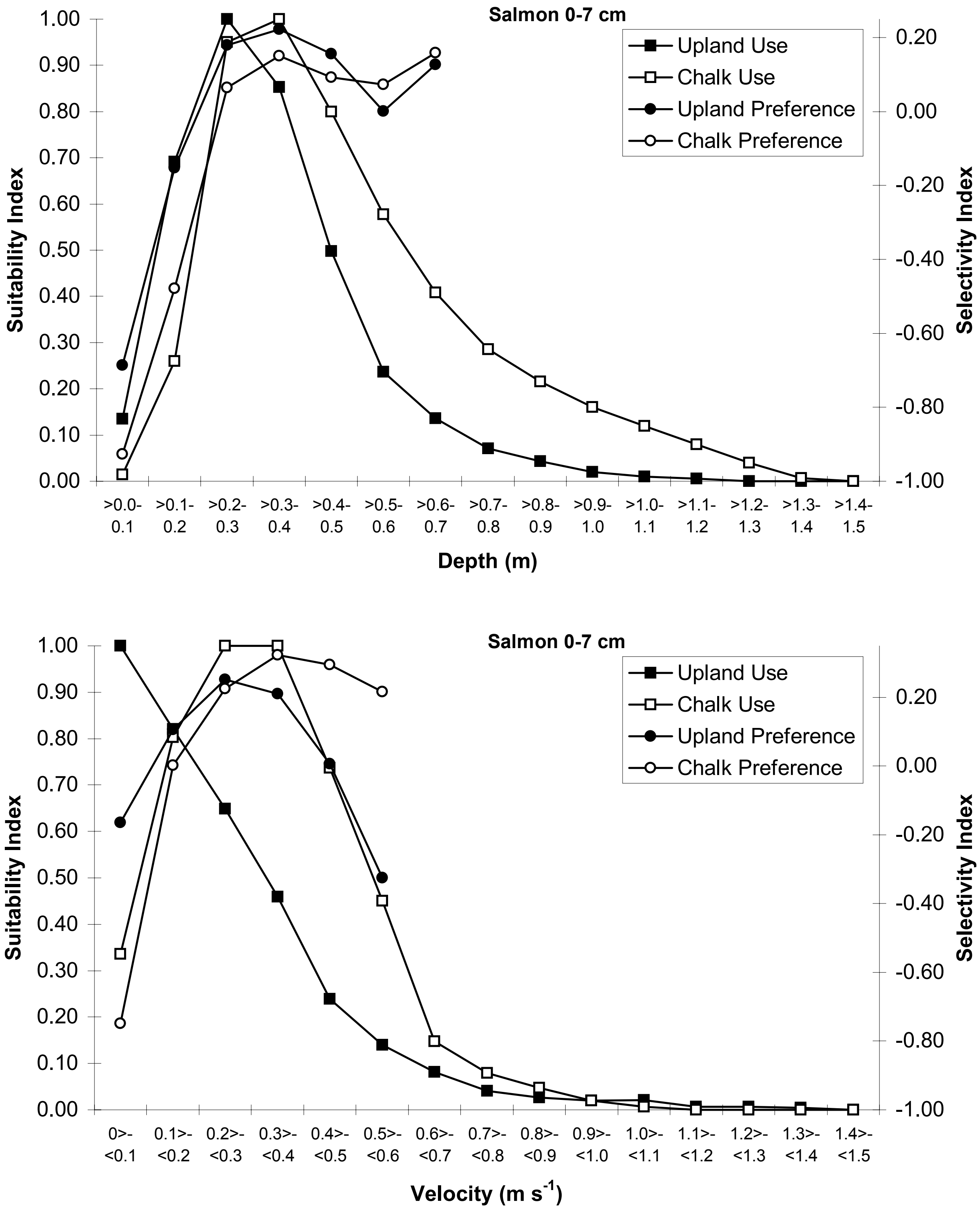


Figure 4.20: Smoothed habitat use indices and smoothed preference indices for depth and velocity use by salmon less than 7 cm in length in upland and chalk study areas.

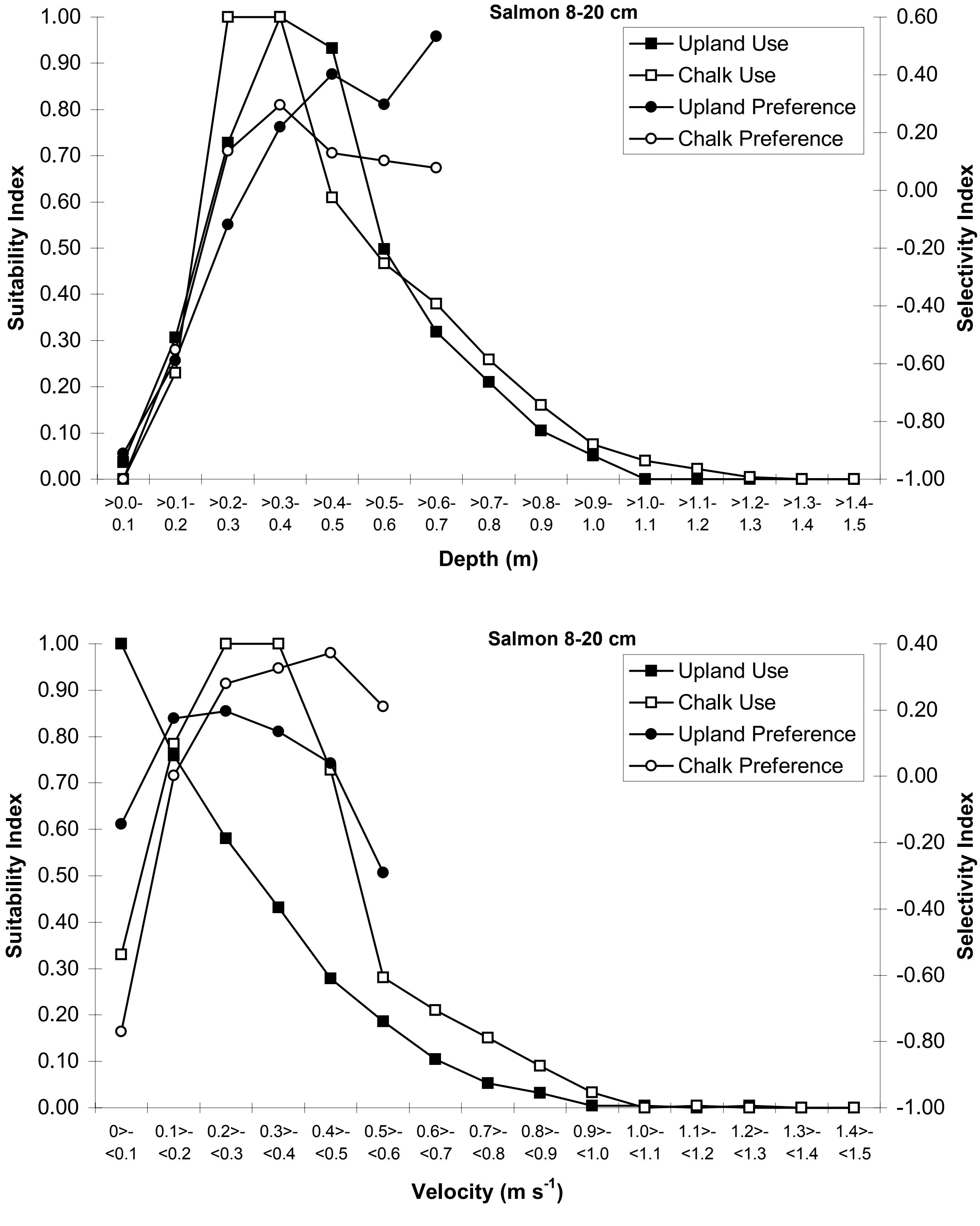
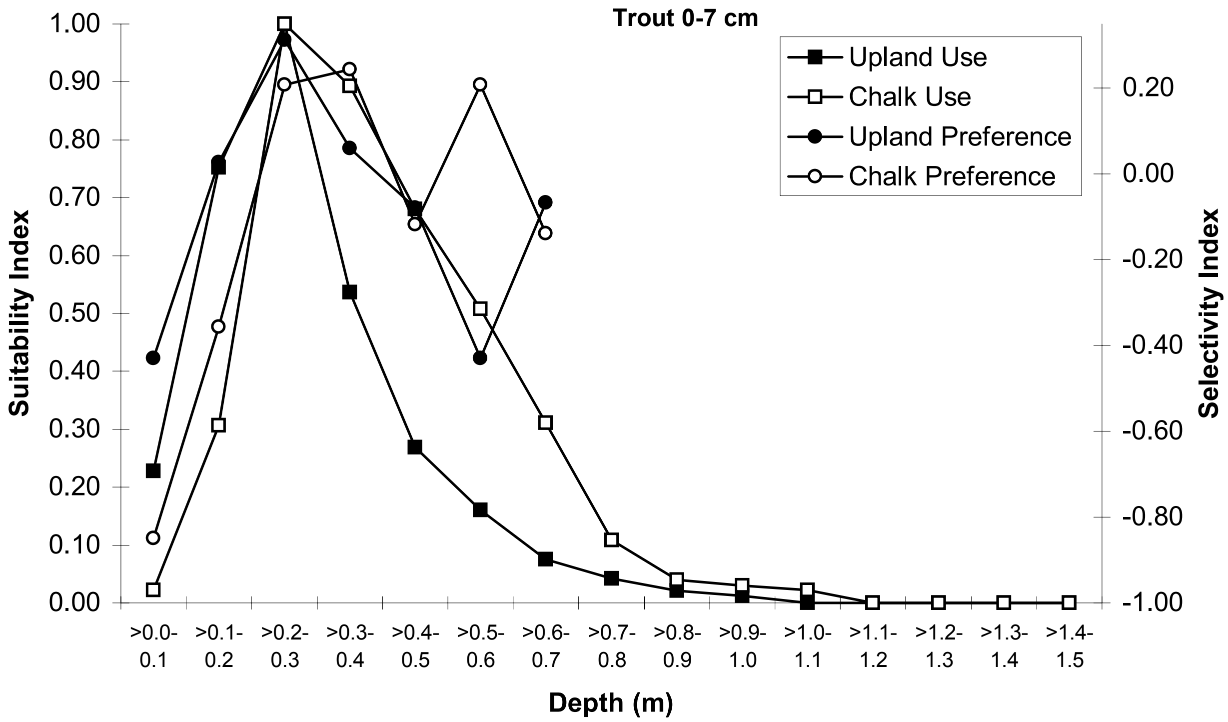


Figure 4.21: Smoothed habitat use indices and smoothed preference indices for depth and velocity use by salmon between 8 and 20 cm in length in upland and chalk study areas.



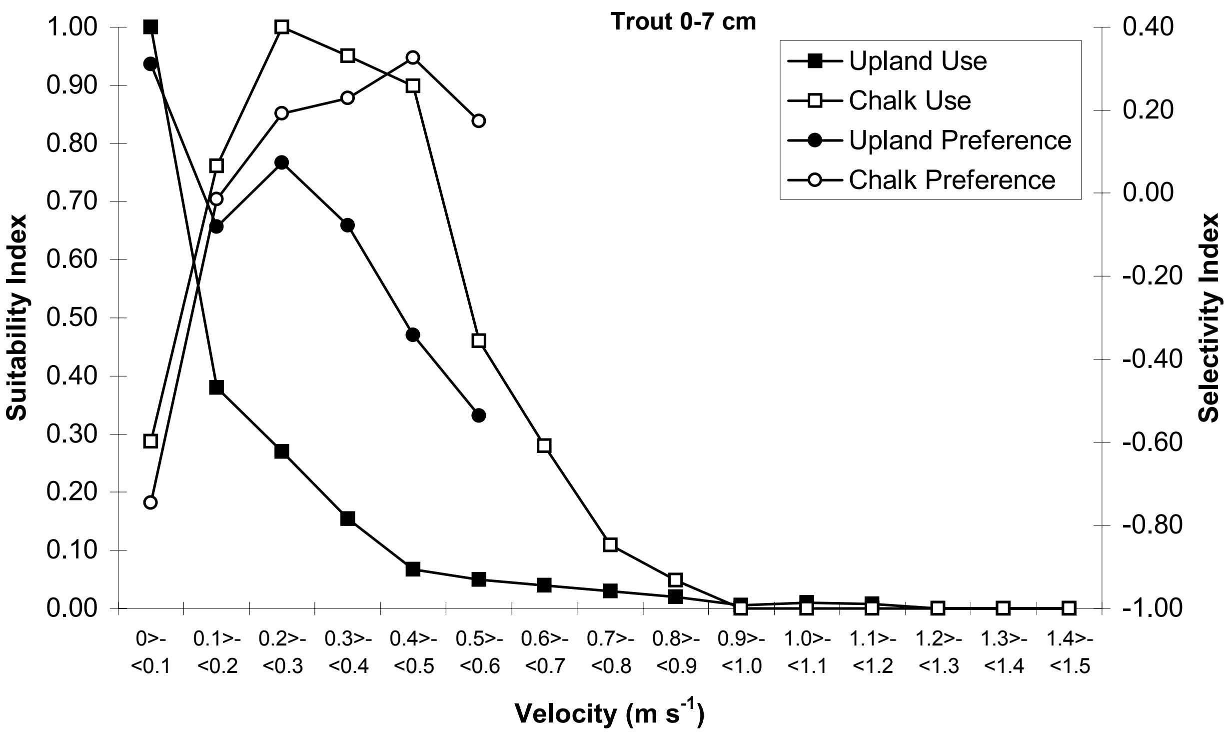


Figure 4.22: Smoothed habitat use indices and smoothed preference indices for depth and velocity use by trout less than 7 cm in length in upland and chalk study areas.

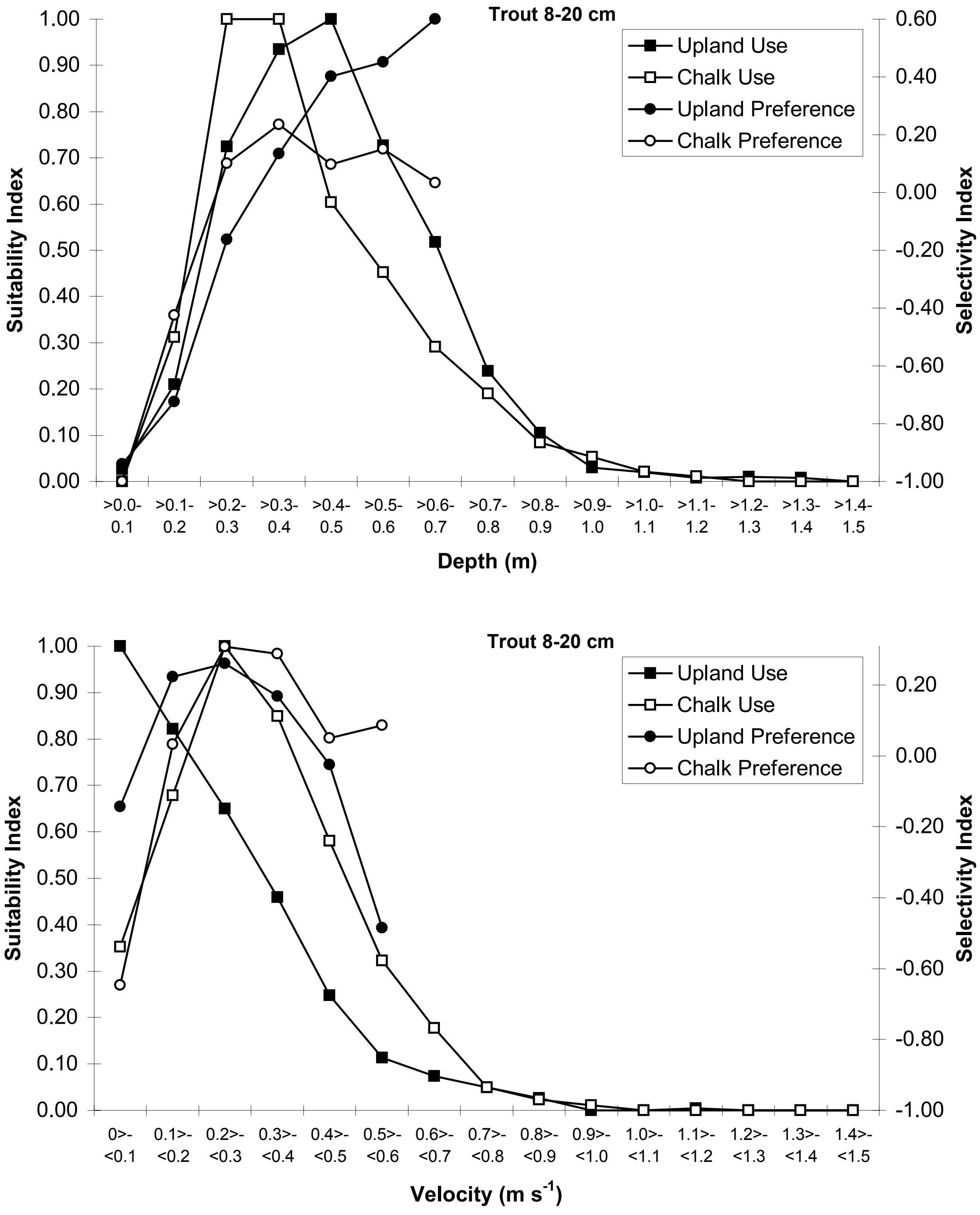


Figure 4.23: Smoothed habitat use indices and smoothed preference indices for depth and velocity use by trout between 8 and 20 cm in length in upland and chalk study areas.

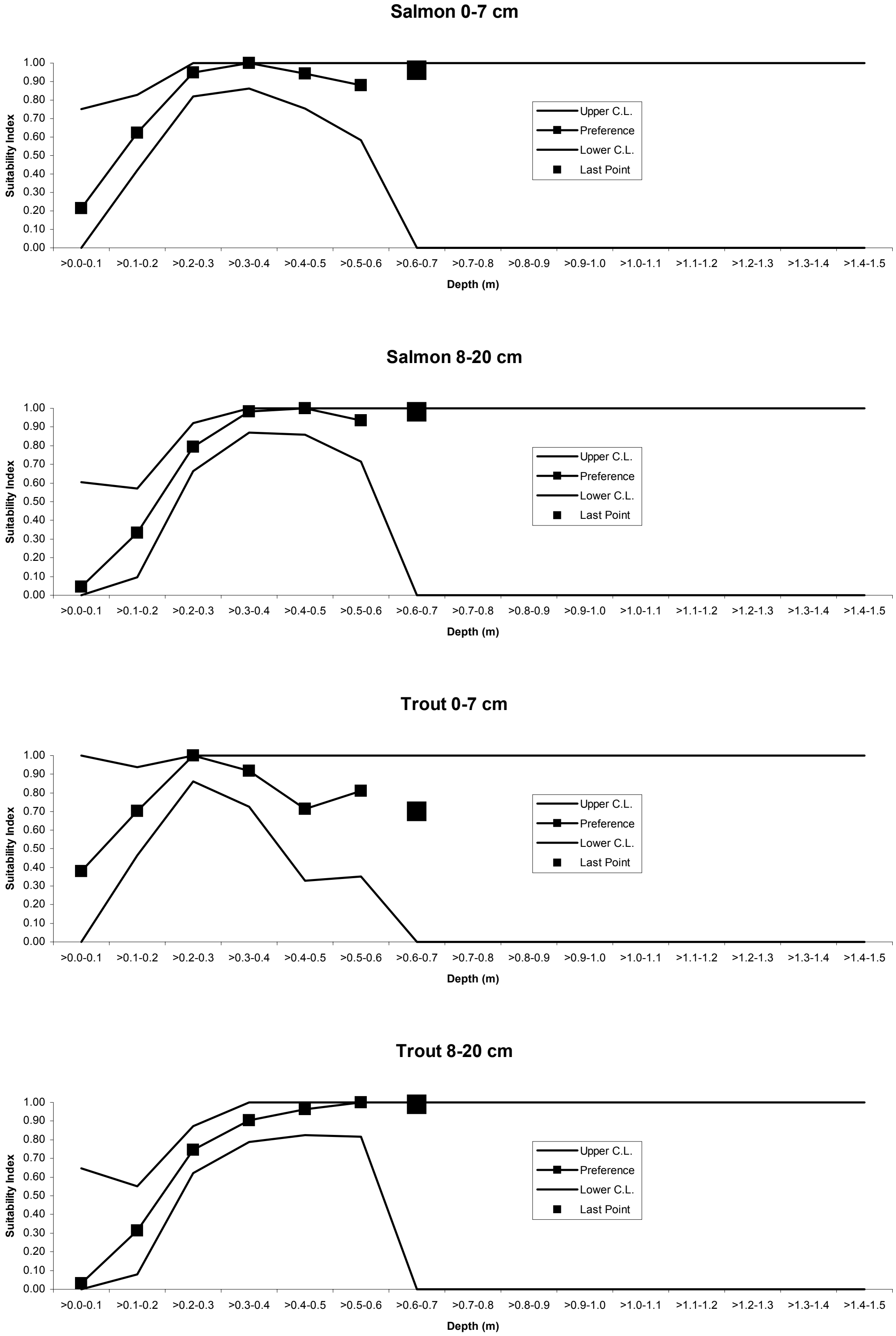


Figure 4.24: Suitability indices (with 95% C.L.) derived from preference for depth use by two size groups of salmon and trout. Last point represents combined data for greater depths.

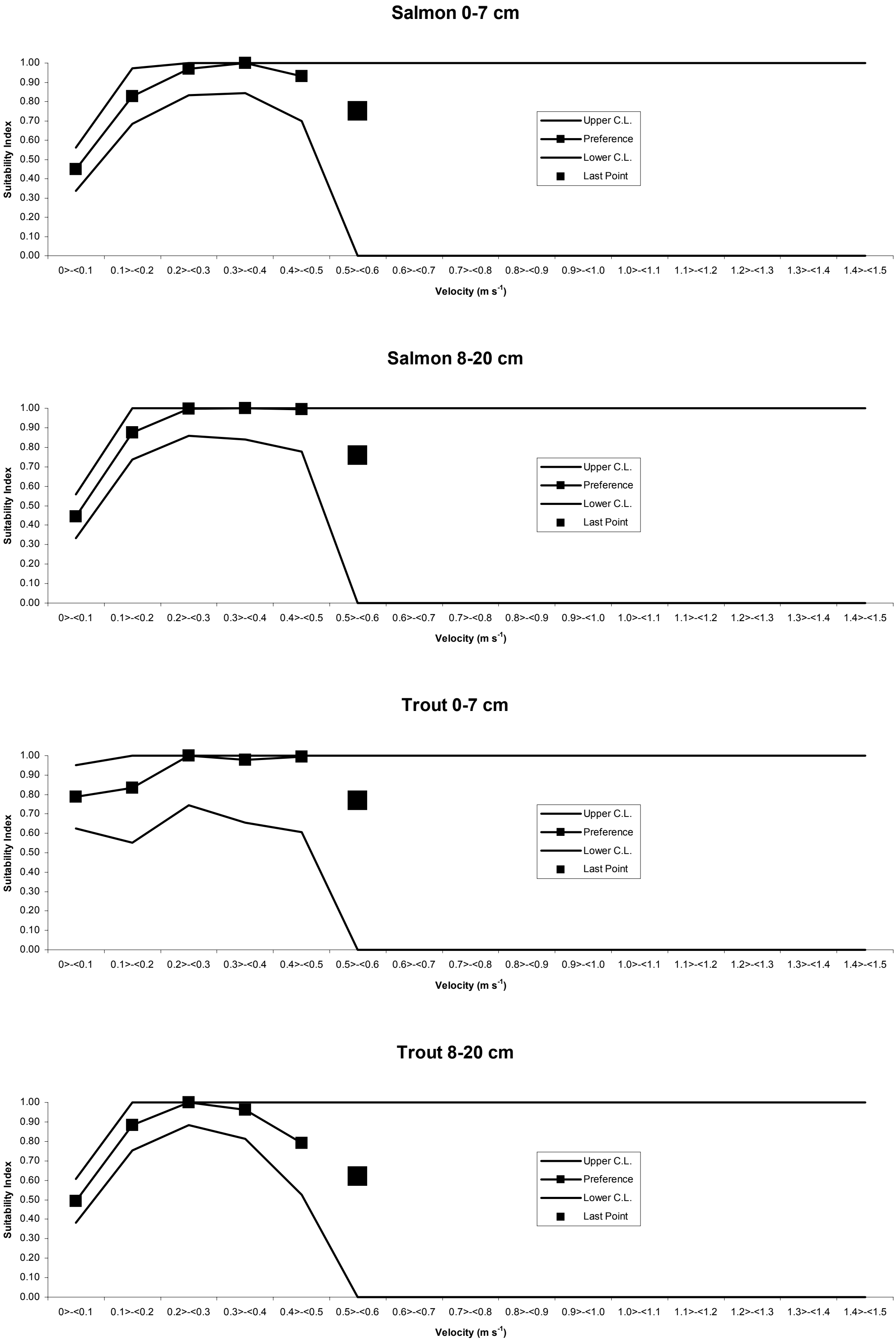


Figure 4.25: Suitability indices (with 95% C.L.) derived from preference for velocity use by two size groups of salmon and trout. Last point represents combined data for greater velocities.

4.5 Implications of HSI Selection and Confidence on PHABSIM Model Output

As part of this task, implication of choice of HSI was assessed in terms of the sensitivity of PHABSIM output.

Results are presented below for the two upland catchments. In general there was little difference in the shape of the responses generated using habitat use data from "catchment-specific" (ie Wales / Devon) vs "river-type" (ie upland). However the results using the "generic" preference-based HSIs (Section 4.6.8) were considerably different from results using habitat use data for catchment and river type.

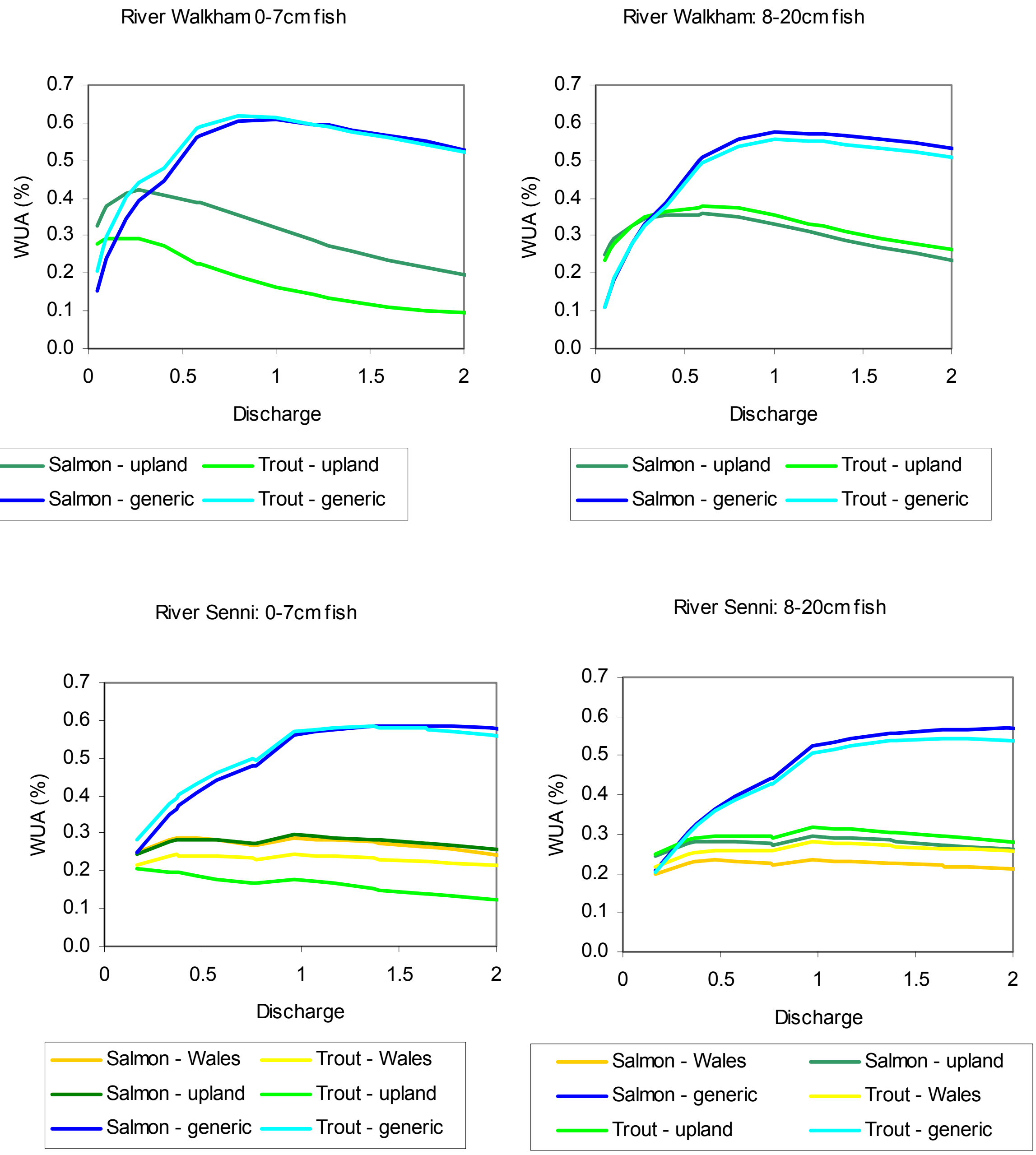


Figure 4.26: River Walkham and River Senni: implications of HSI selection on PHABSIM model output.

A theoretical pair of HSIs was created from the upper and lower confidence intervals for the depth and velocity HSIs for small (0-7cm) salmon and applied to the River Walkham and River Senni. These confidence intervals were estimated for expediency by using 2 times the standard error of the selectivity index assuming that the data had all come from one sample. Although this is an incorrect method as it takes no account of the fixed boundaries of the selectivity index (-1 to +1) and the fact that the data come from three separate measures on four study areas it was used to demonstrate the potential effect of error in HSIs on the WUA/discharge relationship.

On the River Walkham, in both cases the shapes of the relationship for upper and lower confidence limits are similar over the lower discharge values, however, at higher discharges this changes (Figure 4.27). The WUA/discharge relationship continues to increase for the upper confidence limit but decreases for the lower confidence limit once a certain discharge is reached. A similar effect occurs with the data for the river Senni except that the WUA/discharge relationship for the lower confidence limit is also generally very flat. In some applications of PHABSIM, concentrating on low flow habitat loss, using either the upper or lower confidence limit might result in the same overall conclusion being drawn. In other cases, if the relationship is required over the entire flow regime, there is clearly a great deal of potential for drawing different conclusions using these different relationships.

This demonstrates that uncertainty in the shape of the HSI needs further attention, both in determining its true shape and in seeking to reduce it. This is especially important in the context of applying a generic HSI to a new river. Although this study has not attempted to demonstrate the impact of uncertainty in the hydraulic predictions, there must also be a case for simulateously obtaining a greater understanding of the impacts of this error on the WUA/discharge relationship.

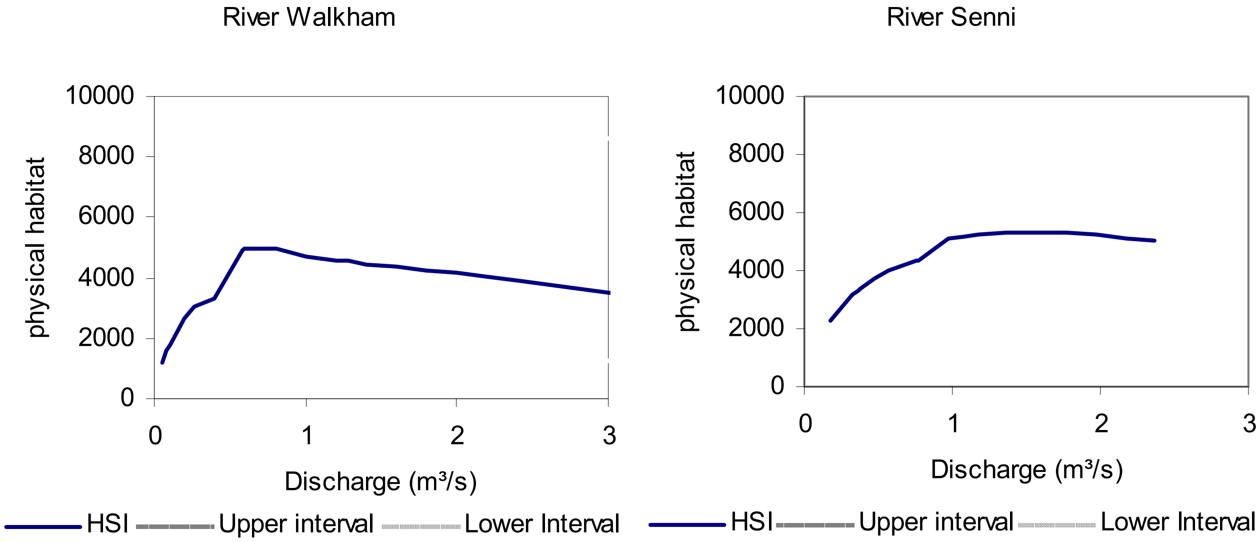


Figure 4.27: Rivers Walkham and Senni: WUA results from upper and lower "confidence interval HSIs"

4.6 Discussion

4.6.1 Habitat use by trout and salmon juveniles

Of the variables that were able to be tested, study area had the greatest effect on the habitat used by salmonid juveniles. Habitat use was different between all the study areas. This reflected the difference in the habitat available in each of the study areas, particularly in the case of depth and indicated a strong influence on habitat use by habitat availability. Of the other factors, size group and species also had significant effects, size group being more important than species. That is, salmon between the sizes of 8 and 20 cm were more similar to trout in the same size group in their habitat use than to salmon less than 8 cm in length.

Across all the study areas small trout (0-7 cm) tended to use shallower depths than salmon for their respective sizes. However, by the time they enter the larger size group (8-20 cm), this situation reversed and with the exception of the Frome trout were using deeper, slower habitats than the salmon. These differences will be partly due to the differing sources of data for salmon and trout. That is, some sites only contained trout and therefore the influence of habitat available on this site will have a bearing on the habitats used. However, the observations for the larger size groups (8-20 cm) do fit previous observations that trout use deeper and slower flowing velocities than salmon (Kennedy & Strange 1982). Nevertheless, comparative habitat use by these two species within sites was variable, on some occasions trout were observed using deeper habitats than salmon and on other occasions it was reversed. A similar situation occurred with velocities. This suggests that the classical view of habitat segregation by these two species is not necessarily stable and demonstrates how the selection of sites will have an influence on the shape of HSIs derived from observations of habitat use.

This principle, that the shape of HSIs based on habitat use are heavily biased by when and where the data are collected, is further demonstrated by the observations of habitat use within each study area. Both site and season had strong influences on the habitat used by salmon and trout juveniles in each study area. Again, this reflected the influence of habitat availability that varied between sites and changed within sites at different times of year due to differing discharge levels and growth of weed stands.

4.6.2 Preferential selection of habitats by salmon and trout juveniles

Differences between the habitat that was available and the habitat used in all study areas indicate that despite the influence of availability there was some selection of preferred habitats by the salmon and trout juveniles. Obvious differences between the use of habitat and preference for habitat emerged when the preference indices were calculated. In particular, in the upland study areas (Devon and Wales) the lowest class of velocities was most frequently used. However, taking account of the availability, this class of velocities was not the preferred habitat in these study areas, that in general being between 20-40 cm s^{-1}. The preference for these velocities in upland salmonids co-incides well with the observed preference for velocities in the two chalk river study areas. The one exception to this were the smaller size group of trout (0-7 cm) in upland river type, where habitat preference was also for the lowest velocities. However, this result can be traced to only two sites in Devon and the numbers of small trout observed was low in comparison to the other species/size groups. This afforded less confidence in that one observation and this is reflected in the wide confidence limits in the preference indices for the small trout group. Notwithstanding the observations of different preferences amongst small trout there was reasonable consistency in the preference for velocities across study areas. Although they are not identical their rough shape is similar and they tend to peak in the same habitat classes.

Preferences for depths are even more consistent across study areas, particularly over the shallower depths. Interestingly, use of depth habitats declines for all groups of fish beyond about 0.4m. However the preferences indicate that the fish are constantly selecting for greater depths, suggesting that even for small fish deep water is preferred to shallow water. This tends to contradict some views that deep water is limiting for small fish (Chaveroche & Sabaton 1989). The most commonly stated reason for this is that these fish are prone to predation from large fish and avoid this pressure by using shallow water. In this study it was observed that the small fish use shallower water than the large fish, whilst still selecting for deeper water. One explanation is that the small fish are making a trade-off between avoiding large fish that select the deep areas and selecting deep water that does not coincide with habitat use by the larger fish. There is a good body of evidence to suggest that small fish are prone to predation by large fish (Fuiman & Magurran 1994). Therefore it is recommended in depths greater than 0.4m, that depth should become unusable (i.e. given a suitability of 0) unless it is within 0.5m of cover for all the species/size groups considered in this study.

Most of the water sampled in this study was below 0.7m in depth and the amount of habitat available deeper than this was too low to give much confidence in the suitability of greater depths to juvenile trout and salmon in this study. Therefore there is still a question mark over the quality of this type of habitat.

4.6.3 Site-specific HSIs

The conclusions from the above discussion is that HSIs derived from habitat use are heavily biased by where and when the data are collected. This makes the use of site specific HSIs derived from habitat use problematic. This is because the habitats present at the time of observation have a large influence on the suitability index value ascribed to different classes of depths and velocities. For example, by taking the simplest river which only has one depth of 30 cm. All fish will be using this depth and therefore it will be ascribed a high value in any HSI developed in this river. However, if discharge is either increased or decreased the depth will change from 30 cm and the habitat will be valued as useless. Although few rivers are this simple the principle still applies. The variation in habitat available in each site and over changing seasons, together with the expense and often impracticality of collecting data leads us to conclude that site-specific HSIs are not the most appropriate way forward.

4.6.4 River type or regionalised HSIs

In the introduction we list a wide range of variables that have been shown under certain circumstances to affect the habitat use, and thus in most cases preference, by juvenile salmon and trout. To take account of these influences in defining river types, it would be necessary to place rivers into groups with similar characteristics across the list of influences. Even if only 6 of these influences are considered to be important in defining habitat use and only 2 levels are attributed to each of those 6 influences, it would require there to be 2^6 groups of rivers for which it would be necessary to develop specific HSIs. In truth the situation is more extreme than this as most of the influences would have many more than 2 levels.

This study started with an over-simplified classification of rivers into upland and lowland hoping that HSIs developed in the two lowland rivers would be the same and the ones developed in the upland rivers would be the same and between river types they would be different. Even within our abilities to place study areas into river types (i.e. upland and chalk), the habitat availability and use also varied. Thus the prognosis for our abilities to place rivers into river types are not good. Habitat use and availability are different in the four study areas and it would be difficult to have only two levels for many of the other variables, even if it were possible to collect the information which enables rivers to be assigned to a group. Therefore it has to be concluded that development of HSIs based on river type is too impractical to consider.

4.6.5 Biological response curves

HSIs would be better treated as biological response curves. For any physical variable an organism will have a tolerance range within which it can survive, grow, live and reproduce and within that range there will be variations in response to that variable. The response can be measured by growth, length of survival, reproductive success or any other appropriate biological response. Typically these response curves will look bell shaped. A good example and one that is easy to understand and where there are data for brown trout, (Elliott, 1976) is temperature. Using controlled experimental procedures he showed how brown trout would grow under different temperature regimes both whilst being fed maximum rations and less than maximum rations. This is a classic case of a biological response to a physical variable.

Fish, in this case juvenile salmon and trout, will have a biological response to depth and velocity, although these are likely to be heavily modified by interactions with other variables. Since the objective of a PHABSIM application is to determine the quality and quantity of habitat available to the fish under varying discharge conditions it would make sense to develop HSIs that are the equivalent of biological response curves. This argument is given further strength by the fact that a brown trout found in one river tends to be very similar to a brown trout found in another river. That is, if a brown trout is taken from a chalk stream and put in an upland stream it will behave in the same way as the trout already living in the upland stream when it comes to selecting habitat to live in. Indeed this study gives encouraging results in this direction by demonstrating that the preferential use of habitat is more consistent between study areas than habitat use is between study areas. Similar results were found by Beecher *et al*. (1995) for steelhead parr. Where he observed preferences for habitat types to remain stable between flows. He goes on to perform a simulation of estimating suitability with observations of habitat use and preference and found that the preference indices were better at predicting fish distribution (Beecher 1995). Although there are differences in the habitat preference exhibited between study areas, the confidence limits of these are wide and most of the observations of habitat preference within one study area fall within the confidence limits of the other study area. In other words, the data do not say that preferential habitat use is different between study areas. The only exception to this may the lowest velocity class for the small (0-7 cm) trout. However, as previously stated this was the species/size group where data was the fewest and observations were not made across a large number of sites and times.

Intuitively, therefore there ought to be just one single HSI for each physical variable for each fish species and life stage/size that can be applied in all rivers. In this way the suitability index would be seen as representing the biological response. Unfortunately, these biological responses have not been measured rigorously and are for most purposes unknown: the only place from which they can be derive for the moment is from the relationship between habitat use and habitat availability across a wide range of rivers. The only exception to this is the small amount of published literature on the limits of swimming capabilities of salmonids (Brett & Glass 1973). Unfortunately it is difficult to incorporate this into the application of PHABSIM because of the complicated relationship between substratum particle size and velocity profiles in the water column; the common use of velocities close to the substratum by salmonid juveniles; and the preponderance to use mean column velocities in PHABSIM. However, there is encouragement for the concept of using generic HSIs from other studies where these have been shown to perform well and often more realistically than site specific HSIs (Hardy & Addley 2001, Jowett 1990).

This leads to the belief that the best approach to developing HSIs would be to use generic HSIs based on good quality habitat preference data from a wide range of rivers. A huge advantage of this approach which is rarely, if ever, mentioned is that generic HSIs are independent of any PHABSIM application. Site specific HSIs are not independent of the PHABSIM application. That is they are developed on site under particular discharge conditions and these will determine the shape of the HSI. This report presents good evidence for this in the change in habitat use as habitat availability changes with season. This discharge dependent HSI is not an independent assessment of the WUA/discharge relationship. Conversely the generic HSI makes an assessment of habitat quality independently of the study, affording much greater confidence in the WUA/discharge relationship.

4.6.6 Binary HSIs

Binary HSIs have been suggested as a way of removing the contentious issue of assigning a quality to each part of a biological response curve or HSI. The case for using them is that our information on the response of juvenile salmon and trout to changes in depths and velocities are not well understood and therefore we are not capable of saying any more than a habitat is suitable or not suitable. However, despite the wide confidence limits exhibited by the preference data, in most cases, it is possible to see that the preferences lie between 0 and 1 of the suitability index and therefore have some intermediate value. This suggests that some assessment can be made of the quality of different depths and velocities to juvenile salmonids and we conclude that we should do so.

4.6.7 Other life stages and species

The conclusion of this study is that PHABSIM should make use of generic HSIs derived as much as possible from habitat preference data when considering juvenile salmonids. There is a question of whether this principle should also be carried forward to other life stages, for example adults and spawning. Currently the only factor that may limit this is the amount of data available, especially for adult trout. Most published HSIs for adults are based entirely on habitat use. There is not much information on availability and this would make estimates of preference difficult from current data sets. An interim solution to this could be the combination of HSIs based on use from a large number of sites. However, now the principle ofusing preference data has been established it would be advisable to attempt to look for or collect the necessary data for adults and other species likely to be important in PHABSIM applications. The requirement for this is given special importance when the differences in the WUA/discharge relationships derived from habitat use data are compared with those derived from habitat preference data.

4.6.8 Deriving generic HSIs from this study

Where the quantity of habitat availability was sufficient to calculate preference data at the lower depths and velocities, these have been used to derive the generic HSIs for the two size groups of salmon and trout (Fig. 4.26 & 4.27). In the case of small (0-7 cm) trout the level of uncertainty within this region was higher than for the other species/size groups and this is expressed in the figure as a dotted line.

Beyond the peak of the HSIs it was not possible to use preference data effectively as the amount of available habitat in this region was too low to estimate preference with confidence. Therefore beyond this point there is again uncertainty over the shape of the HSI. However, some suggestions can be made as to the likely shape of this relationship beyond this point.

For depth the composite habitat preference combining all data for depths deeper than 0.6m suggest that deeper water is still preferred (last point in Fig. 4.24). Therefore it is not possible to suggest that the suitability of depths falls once it reaches the maximum (Fig. 4.26). Operationally, in the application of PHABSIM in UK, the exact shape of this HSI in greater depths may not be important as the number of rivers containing large amounts of deep water are quite rare. However, because the likely relationship with depth may be predator related in the case of these small fish it is suggested that a cover criteria is added so that depths beyond 0.6m are considered useless unless there is sufficient cover within 0.5m.

Conversely for velocities the composite habitat preference combining all data for velocities greater than 0.5 m s^{-1} suggest that higher velocities are less suitable (last point in Fig. 4.25). Therefore one would expect to see a decline in suitability of velocities from this point onwards. In this study it is suggested that the HSI for velocity at greater velocities should represent an envelope over the observed use of velocities by these species/size groups from our study.

The high level of uncertainty about these generic HSIs leads to a high level of uncertainty surrounding the shapes of the WUA/discharge relationship. This would suggest that some effort needs to be put into improving the certainty of the shape of the generic HSIs.

4.6.9 Comparisons of the HSIs developed in this study with other published HSIs

The habitat suitability indices developed in this study have been derived from a mixture of habitat preference and the drawing of an envelope over observed use where there was not sufficient data to derive preference. The data was collected from 15 sites in four study areas. If these HSIs were correct in their assessment of habitat quality across a broad range of rivers then comparisons with habitat use in other rivers should fit with this assessment. In making these comparisons it would be normal to expect that habitat judged as suitable in this study is not always used by fish in other rivers as those habitats may not be available in them. However, we would not expect habitats judged as unsuitable in this study to be used extensively by fish in other studies. This essentially refers to the upper limits of the velocity HSIs as this is the only habitat that has been assessed as unsuitable in this study. Published studies by Bovee (1978), Belaud *et al*. (1989), Heggenes (1990), (1991), (1996), Heggenes & Saltveit (1990), Heggenes *et al*. (1991), Lambert (1994), Lambert & Hanson (1989), Raleigh *et al*. (1982) and Scruton & Gibson (1993) all show habitat use by these groups of fish, although sizes are frequently not given in these publications, to fall to zero at about 1 m s^{-1} for velocity, which is in good agreement with our generic HSI.

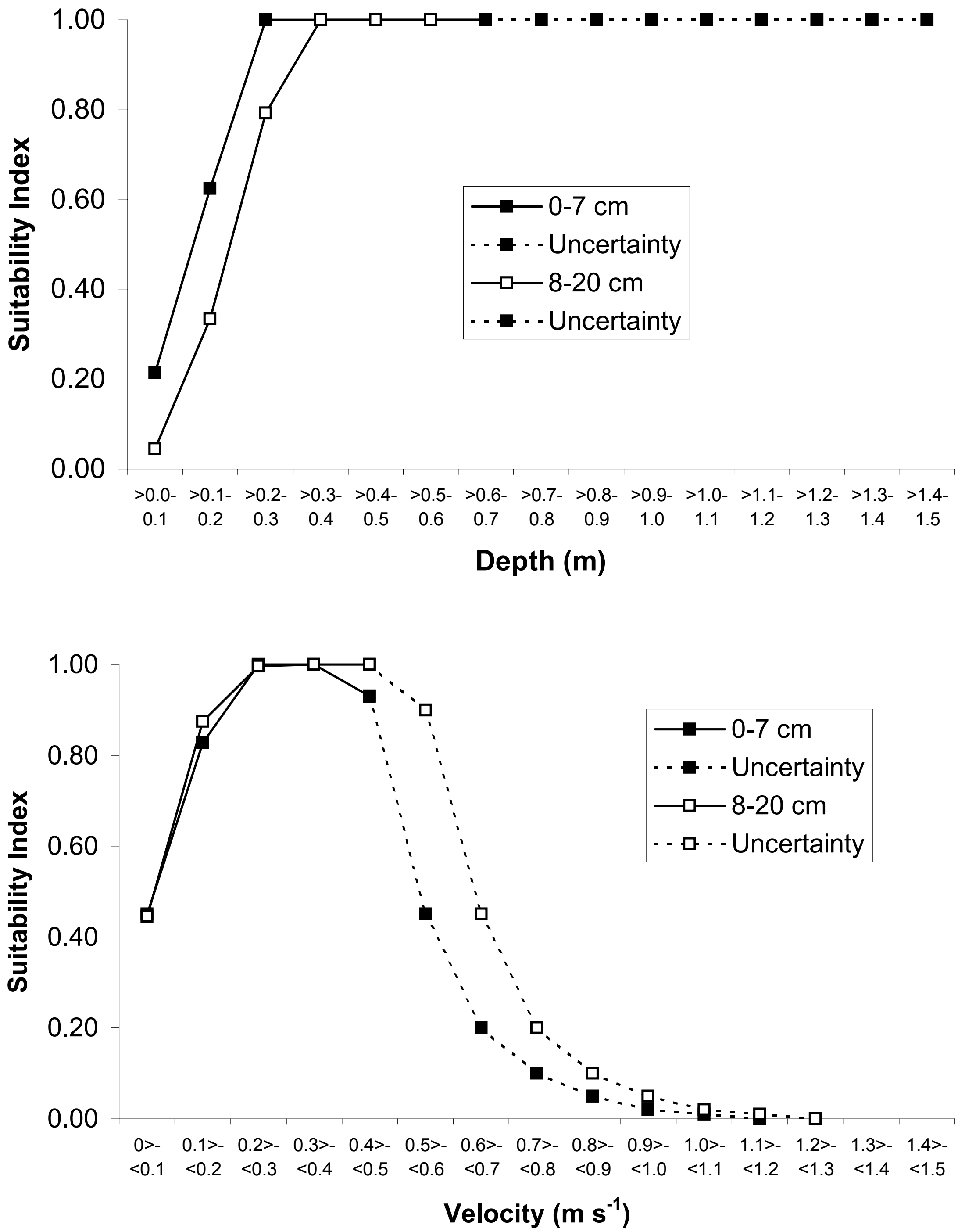


Figure 4.28: Generic HSIs for two size groups of juvenile salmon.

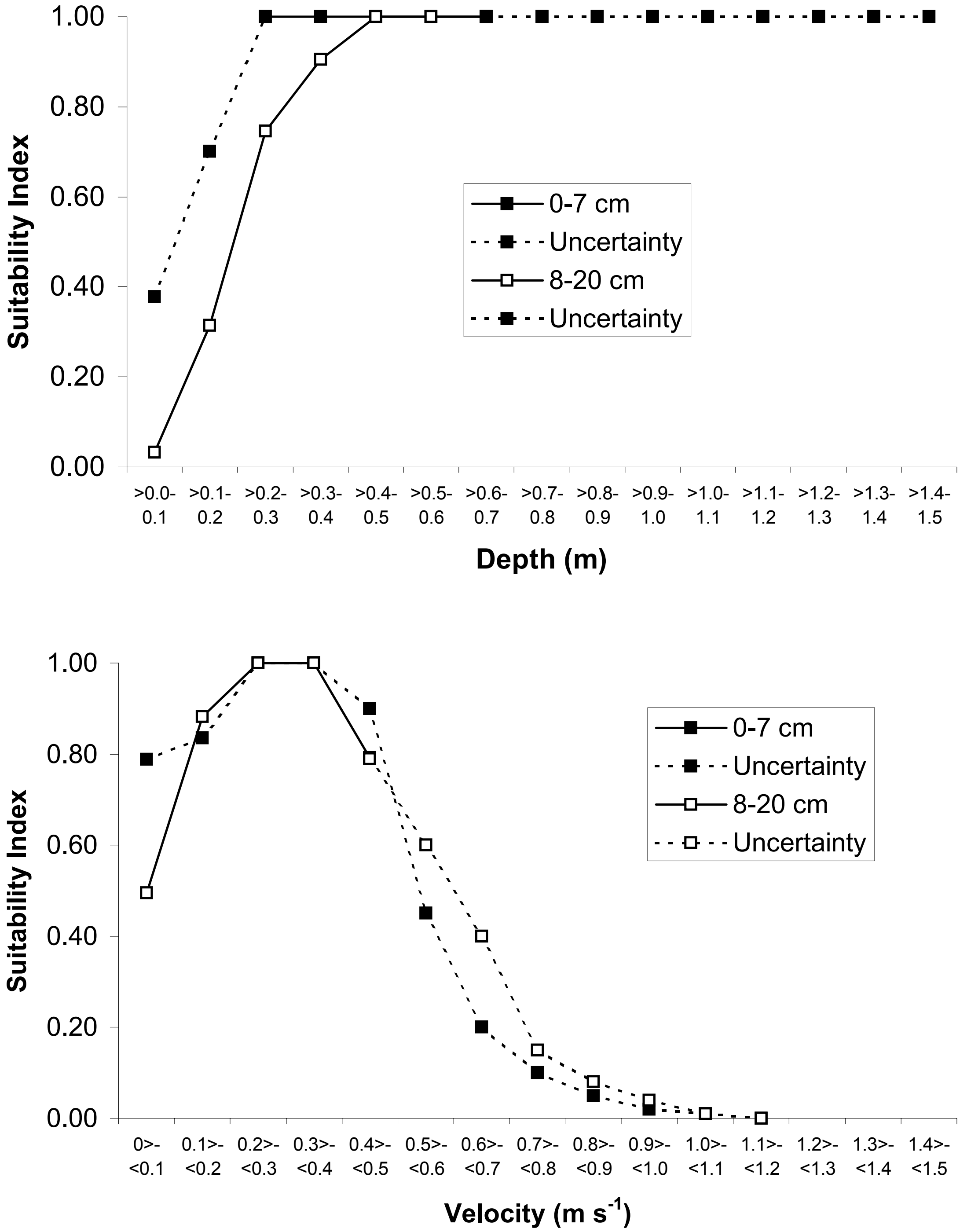


Figure 4.29: Generic HSIs for two size groups of juvenile trout.

4.6.10 Treatment of ecological data in PHABSIM and water resource decision making processes generally

Bi-variate and multi-variate factors

PHABSIM currently treats depth and velocity separately and this report has done the same to answer current operational questions. Clearly, the habitats experienced by fish consist of a mixture of a large number of variables, each of which interacts with the others to produce habitat quality. The most important of these factors for juvenile salmonids probably include food supply, temperature and water quality as well as depth and velocity. To treat each of these separately and to ignore others is biologically unrealistic and the development of multi-variate indices needs to be considered. In this study the use of velocity across different depths is clearly different (Fig. 4.28). The use of bi-variate (depth and velocity indices) HSIs within PHABSIM would be a considerable advance.

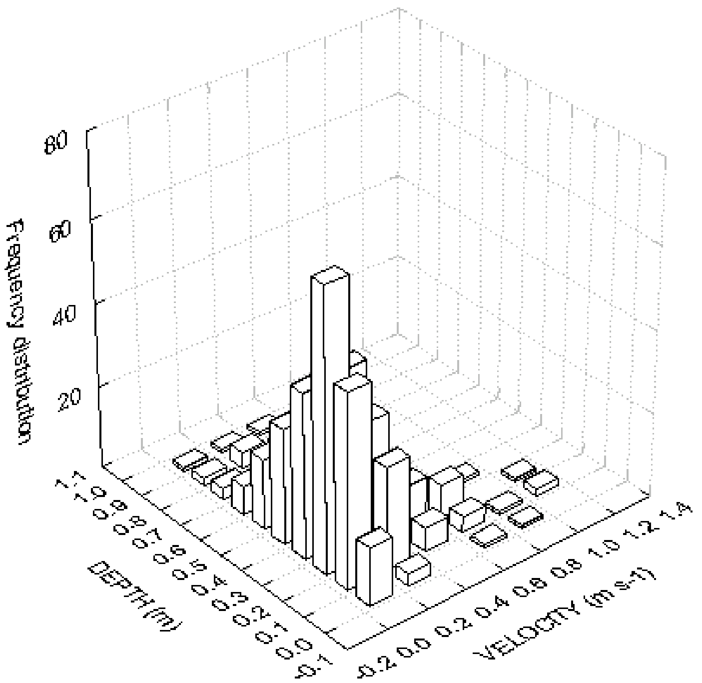


Figure 4.30: Bi-variate depth and velocity use by all sizes of active salmon during daylight hours in the Devon study area.

The importance of depth and velocity in determining habitat value.

The institutional use of PHABSIM tends to concentrate on a number of simple physical variables assuming that these are the important ones in determining habitat use and habitat quality and quantity. This assumption is rarely tested and evidence from this report suggests that the use of some of these variables may be incidental. Depth is the best example of this. Although there are obvious preferences for depths, tolerance for this variable is also great and its use appears to follow its availability very strongly. This would suggest that it is not important in determining habitat quality and quantity, but that there is a large element of coincidence in depth use as fish respond to other factors.

Multiplication of probabilities

PHABSIM requires that habitat requirements are fitted between a probability value of 0 and 1. The lack of realism of this is compounded by the habit of multiplying together the suitabilities for each of the factors being used. Clearly, such an exercise states that each factor i.e. depth and velocity has equal weighting in determining habitat value and that there are no interactions between factors. This is too simple statistically. With more extensive use of statistical techniques variables can be given more realistic weightings in respect to one another within habitat models.

Review of the use of ecology in water resource decision making processes.

There is no doubt that PHABSIM was 'state of the art' when it was developed nearly 30 years ago. However, whilst it has evolved within itself the principles behind it essentially remain the same as when it was first developed. At the same time other disciplines of ecology have developed and applied habitat models to deal with habitat modification questions without resorting to a common model such as PHABSIM. In the fisheries discipline, work on alternative methods for incorporating ecological data into water resource decision-making processes is at an advanced stage (Nislow *et al*. 2000; Van Winkle *et al*. 1998). All alternative methods make use of more sophisticated statistical techniques and more realistically important physical factors together with their interactions. In some areas of ecology behavioural and physiological attributes of animals are being used to determine the impacts of habitat modification on mortality and population levels (e.g. Stillman *et al*. 2000). Despite constant evolution and improvement to PHABSIM it is unlikely to be achieve similar outputs.

There is obviously a need for hydraulic modelling where flows are being manipulated. However, the techniques by which ecological data are treated in other ecological disciplines where habitat modification is an issue, is leaving PHABSIM behind. And in the fisheries discipline alternative approaches are now readily found in the literature. In some cases these have been incorporated into a PHABSIM framework (e.g. Braaten *et al*. 1997). Recently there have been some excellent reviews of methods for setting River Flow Objectives (e.g. Dunbar *et al* 1998). However, there has not been a comprehensive review of how ecological data are and could be incorporated into the water resource decisions of the future. This is a timely moment to suggest that an appropriate review is undertaken.

4.6.11 Periodic review of generic HSIs

Although the generic HSIs produced in this report now represent current knowledge, there will undoubtedly be further work in this field. In particular it is expected that HSI developed from fish behavioural and physiological attributes will available in the near future. It is, also, a recommendation of this report that the uncertainty in the shape of the generic HSIs is quantified and that there may need to be efforts to reduce these especially in deep and fast flowing water conditions. Thus it would make sense to periodically review and maintain definitive versions of these. A regular three year period is suggested with quantification of the uncertainty of the current generic HSI being the first such review.

5. PHABSIM MODELLING AND AVAILABILITY DATA COLLECTION

Work to achieve this objective has been undertaken under Tasks 1 and 2.

5.1 Introduction

PHABSIM data were collected at four sites, one in each study area: River Walkham at Ward Bridge (Devon), Piddle at Higher Hyde (Dorset), South Winterbourne at West Stafford (Frome - Dorset) and Senni at Abersenni (Usk – Wales).

Habitat mapping was undertaken and full PHABSIM data were collected at each site. The techniques outlined in Environment Agency R&D Reports W20 and W34 were applied. These are summarised in Appendix E in this report.

PHABSIM models were calibrated for each site, the details are documented below.

Two forms of PHABSIM outpfut data have been used in further analysis. Firstly relationships between weighted useable area and discharge were used for two purposes: assessment of the implications of different forms of habitat suitability curve on final PHABSIM output, and secondly for the testing of possible relationships between physical habitat and fish populations. These are documented in Sections 4 and 7 respectively. The main purpose for the PHABSIM modelling though, has been the testing of PHABSIM hydraulics. Collection of availability data for PHABSIM testing is documented in this section, and the testing procedure itself is covered in Section 6 below.

5.2 Data Collection and PHABSIM Model Calibration

5.2.1 Data collection methodology

Habitat mapping
The method followed that undertaken by Maddock (1996) on the River Kennet study, which has also been applied on the River Tavy (Maddock and Bird, 1998), Rivers Ebble and Exe (Dunbar *et al.*, 1997), and several other operational PHABSIM studies. The only modification was that two visual habitat classification systems were used. The first was that adopted in the above mentioned studies (mesohabitat mapping), while the second method concentrated on individual surface flow types, as in River Habitat Survey (RHS) (Table 5.1). A combination of the methods was used to select PHABSIM transects in most cases.

The following data were recorded at significant changes in habitat, or at intervals of either 50m (River Walkham) or 10m (River Piddle, South Winterbourne, Senni)

- distance downstream
- channel and water width
- % of water width in each substrate class
- max depth and velocity
- instream and overhanging vegetation %
- whether the habitat was situated on a hydraulic control
- habitat type, recorded according to the following definitions

System 1: (mesohabitats)
A single classification of each river cross section in terms of:
- Slack,
- Shallow Glide (max depth < 0.5m),
- Deep Glide (max depth >0.5m),
- Riffle,
- Rapids / Cascade,
- Chute.

System 2: (surface flow types) (Table 5.1.)

Table 5.1: Surface flow types.

Code	Flow type	Common name	Notes
FF	Free fall	waterfall	clearly separated from back wall
CH	Chute		low curving fall in contact with substrate
BW	Broken standing wave	Rapids	white water tumbling wave must be present
UW	Unbroken standing wave	Riffle	Upstream-facing wavelets, not broken
RP	Rippled	Run	no waves but general flow direction is downstream with disturbed rippled surface
SM	Smooth	Glide	Perceptible downstream movement is smooth (no eddies)
UP	Upwelling	Boil	Heaving water as upwelling breaks the surface
NP	No perceptible flow	pool, ponding, marginal deadwater	no net downstream flow

PHABSIM data collection methods
The methodology for the selection of representative PHABSIM transects, and the subsequent data collection followed that recommended in Elliott *et al.* (1996), the standard reference for application of the PHABSIM in England and Wales. At each site, transects were marked with “Anchormark” permanent marker pegs. Cross-section profiles and relative marker peg elevations were measured with an optical level. On each subsequent survey, repeat measurements of water surface level were taken at each cross section, mean water column velocity and depth, substrate and cover were measured at each cross section survey point. Occasionally it was not possible to current

meter all cross sections, in which case at least one cross section was current metered to provide an estimation of discharge on site.

Habitat availability data collection methods

In order to provide a dataset against which to test the transect-based PHABSIM model, a sampling procedure was devised to collect an unbiased inventory of the physical habitat present in a length of river. This procedure was implemented at each of the main sites (for PHABSIM testing and fish study) plus each of the subsidiary sites (for fish study only).

PHABSIM uses existing, well-proven hydraulic modelling techniques in order to make predictions of physical habitat availability across a range of discharges. Calibration data are used in the modelling process, collected during field surveys of representative reaches on three or more occasions. The hydraulic modelling techniques require data to be collected across fixed transects, chosen to represent the mesohabitat types present in a length of river (the sector) which is usually longer than that which contains the PHABSIM study reach. This requirement for transect sampling imposes a degree of subjectivity on the selection of transects that represent the mesohabitat types.

The physical habitat sampling procedure used here has been designed to be point-based rather than transect-based, to avoid any subjectivity in data collection. It covers the entire river sector which the PHABSIM site is intended to represent. The procedure adopts a fixed-interval approach in the longitudinal dimension, and a random sampling approach in the transverse dimension. An example of the calculation is presented below, as is a graphical representation of the sampling density at Ward Bridge in Figure 5.1. The protocol is as follows:

1. Collate river width measurements from habitat mapping survey, calculate mean (MeanW) and maximum (MaxW) width, and total target area length (TL),
2. Based on past experience, calculate required number of sample points in river (RSP),
3. Calculate RSP * (MaxW/MeanW) to give total number of potential sample points required (TSP),
4. Calculate TSP / TL to give sampling intensity per metre (SI),
5. Round SI down to a manageable number,
6. Calculate a series of TSP random numbers between zero and MaxW. These are distances across the river (DistAC),
7. Create survey sheets with distance upstream (DistUS, in multiples of SI) and DistAC, plus space for all observed data to be written in,
8. Undertake survey, collecting data at each point defined by DistUS, DistAC, measured using tape measures.

Example: Ward Bridge Site
MaxW = 15.4, MeanW = 9.8
TL = 300m
RSP = 300
TSP = 480
SI = one point every 0.6 m of river

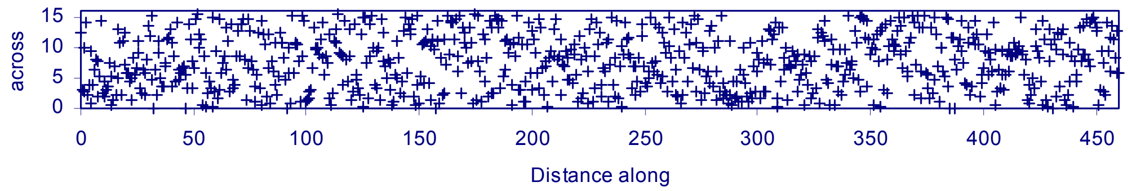


Figure 5.1: Example of pre-selected data points for collection of habitat availability data collection

5.2.2 River Walkham

Habitat mapping

On April 12-13 1999, a habitat mapping survey was undertaken on the Walkham in the vicinity of Ward Bridge. This extended from c.2km upstream to c.1km downstream of the bridge. Proportions of the mesohabitat types present are illustrated in Figure 5.5. Daily mean flows on the Walkham at the Horrabridge gauge were recorded as follows:
Day 1: 12/4/1999 1.93 m^3/sec ~ Q30
Day 2: 13/4/1999 1.52 m^3/sec ~ Q39

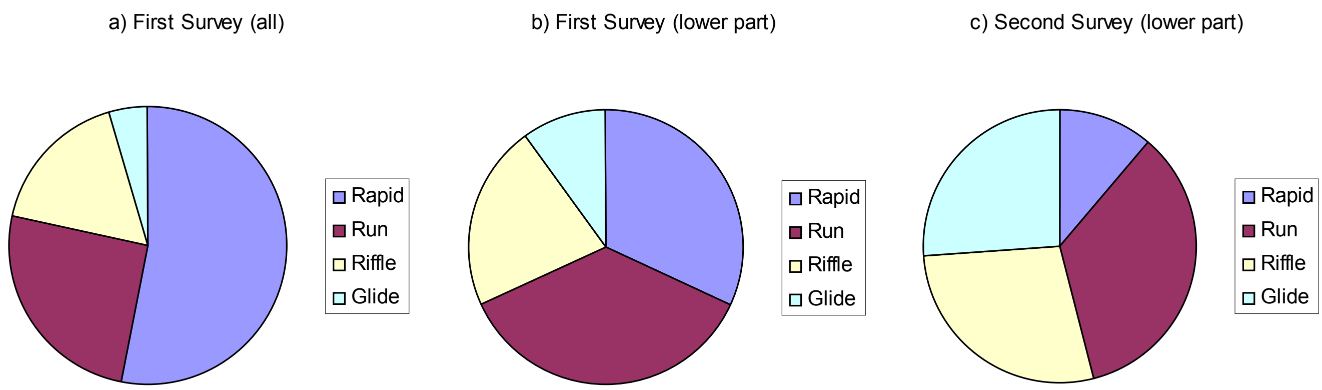


Figure 5.2: a,b,c River Walkham: distribution of mesohabitat types

The initial survey demonstrated that beyond 500m upstream of Ward Bridge, the river was too torrential for either PHABSIM surveys or snorkelling. Thus it was decided to focus on the section of the river from 500m upstream of the bridge to 200m downstream of the bridge. On 20 May, the site was re-visited, and this shorter section of river was habitat mapped in more detail (proportions illustrated in Figure 5.2c. The daily mean flow was 0.93 m^3/sec (Q59). This is a considerably lower flow than when the initial habitat mapping was undertaken. The combination of the lower flow, and the exclusion of a continuous stretch of torrential river, indicated that proportions of run, riffle, glide and rapid were actually much more even.

PHABSIM data collection

Initial selection and marking of candidate PHABSIM transects took place on 23 June 1999. A main representative reach with eight hydraulically-linked transects was selected together with a second "mini" reach with two transects. The attributes of each transect are shown in Appendix C, information on the repeat survey is in Table 5.2., and the surveyed water surface profiles in Figure 5.6. On the week beginning 27 September 1999, each transect was marked permanently and the cross section profiles surveyed. The first PHABSIM hydraulic survey took place on 26 October 1999. At each site a water surface profile was surveyed and all transects were current metered. The second PHABSIM survey took place on 30 November 1999. Seven cross sections were current metered, a full water surface profile for all cross sections was surveyed. A third PHABSIM hydraulic survey took place on 18 January 2000. All ten cross sections were current metered and a full water surface profile was surveyed. This was followed ten days later with a fourth PHABSIM hydraulic survey in order to obtain a low flow survey, however the flow was not as low as anticipated (given up to date gauged discharge and a weather forecast). All ten cross sections were current metered and a full water surface profile was again surveyed. A final PHABSIM survey was undertaken on 26 June 2000, at a flow of 0.54 m^3/s at Horrabridge, corresponding to Q78.

The graph in Figure 5.3 illustrates historical flows on the Walkham at Horrabridge during 1999-2000.

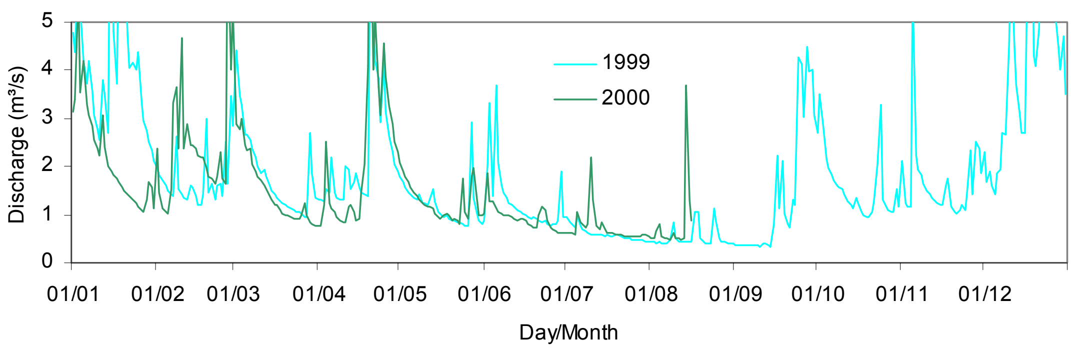


Figure 5.3: River Walkham: gauged historical discharge in 1999-2000

Table 5.2: River Walkham: PHABSIM calibration flows and gauged flows at Horrabridge

Survey ref	Model cal set	Velocity set	Date	Discharge (m^3/s) *	Horrabridge gauge (m^3/s)	Horrabridge Q
1	2		26-27/10/1999	0.82	1.155	Q51
2			30/11/1999		1.846	Q32
3	4	1,3	18/01/2000	1.20	1.689	Q35
4	3		28/01/2000	0.92	1.330	Q44
5	1	2	26/7/2000	0.37	0.530	Q79

* discharge was calculated using the mean flows from four cross sections (2/4/5/7) assessed as most suitable for this purpose.

Habitat availability data collection

Collection of habitat availability data proceeded concurrently with the observations of fish microhabitat use. The dates of the surveys, the discharges at the Horrabridge gauge, and the numbers of data points collected are given in Table 5.3. Figure A1.1 illustrates the lengths of river surveyed each day on each visit.

Table 5.3: River Walkham: discharge and habitat availability survey data.

Survey	Date	Discharge	Discharge at site*	Number of habitat survey points
1	22-23/06/99	0.871 (G) Q62	0.580	303
2	26-28/07/99	0.469 (G) Q84	0.270	291
3	5-6+8/10/99	1.800 (G) Q32	1.280	298

** calculated from regression between gauge and site*

PHABSIM calibration

Water Surface levels

Separate WSP models were created for the lower two cross sections and the upper eight. Tables C1.3 and C1.4 illustrate the models used and the calibration parameters.

Velocities

Figure 5.4 illustrates the velocity models used for different cross sections and dischages. The velocity set numbers are cross referenced to the surveys in Table 5.4. A combination of low and high velocity calibration sets was used, for cross sections 9 and 10 the high set without mass-balancing enabled (Table C1.5).

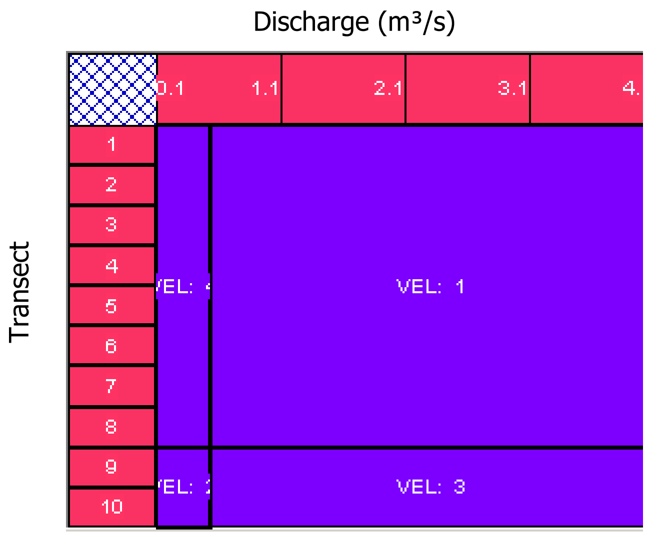


Figure 5.4: River Walkham: velocity modelling sets

Figure 5.5: River Walkham (main site): simulated water surface levels.

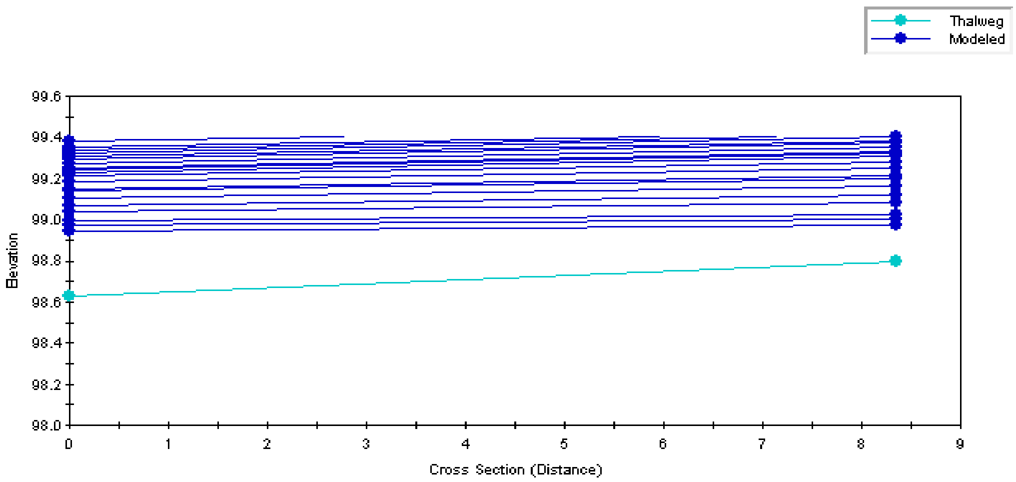


Figure 5.6: River Walkham (lower site): simulated water surface levels.

Table 5.4 summarises the overall fit of the water surface level model. Figures 5.5 and 5.6 illustrate the range of modelled water surface levels. The aberrant level at cross section 8 at the lowest flow was not used for habitat modelling, a water level was fitted by eye.

Table 5.4: River Walkham: errors in water surface level calibration

CS	Max +ve error (m)	Max –ve error (m)
1	+0.03	0
2	+0.03	0
3	+0.01	0
4	+0.03	0
5	+0.02	-0.02
6	+0.02	0
7	-0.02	+0.02
8	+0.03	-0.01
9	+0.03	-0.02
10	0	-0.07*

* probable WSL survey error

5.2.2 River Piddle

Habitat mapping

A habitat mapping survey of the River Piddle and Bere Stream at Higher Hyde was undertaken on 9th August. The sector comprised c.400m of the Piddle downstream of the confluence, 300m of the Piddle upstream of the confluence, and 400m of the Bere Stream. Flows at the Baggs Mill gauge were around 1.3 m^3/s, corresponding to approximately Q65. Results from this survey showed that the Bere Stream was too shallow in this area to provide a sufficient test for the PHABSIM model. In addition, there were outstanding issues relating to repeated access to the Piddle upstream of the confluence, thus the decision was taken to concentrate PHABSIM studies on the Piddle downstream of its confluence with the Bere.

The proportion of the three different mesohabitat types present is illustrated in Figure 5.7.

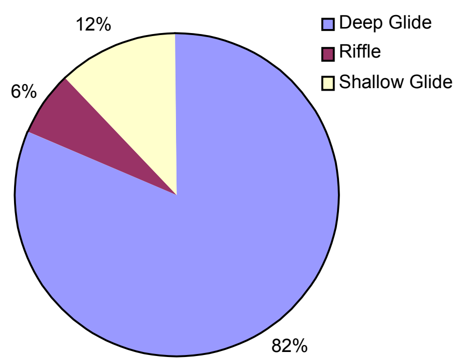


Figure 5.7: River Piddle: distribution of mesohabitat types

PHABSIM data collection

A PHABSIM representative reach was selected, located downstream of the confluence with the Bere Stream. Within this reach, eleven hydraulically-linked PHABSIM transects were established to represent the sector of river. Transects were selected on a mesohabitat basis, in rough proportion to the areas of the mesohabitat types measured in the habitat mapping. Water depth (and width) was used to provide additional discrimination of the deep glide habitat type (Figure 5.9). A conscious decision was made to chose a reach that was first and foremost representative of the river conditions at low flows. The sector contained a range of channel types: the downstream and upstream areas had mainly vertical banks, while the middle section had a vegetated berm along one side that was dry at low flows but would likely be covered at higher flows. It was decided that this might be an issue at high flows, but was not important for the testing of PHABSIM at lower flows.

Transects were marked and surveyed on 10-11th August, and an initial, complete current metering / water surface levels survey was undertaken on 12th August. A second complete survey took place on the 1st December 1999. The final survey took place on the 11th January 2000. The river was running very high and fast, so current meter measurements were taken only on a single cross section, a full water surface profile survey was completed. The river flow was about 4.6 m^3/sec (Q5) at Baggs Mill. Water surface levels for each survey are presented in Appendix C.

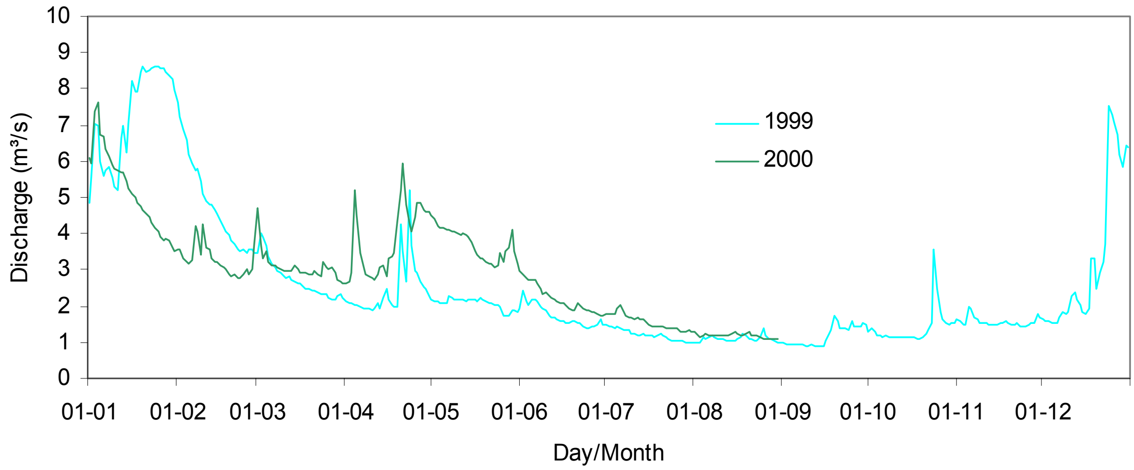


Figure 5.8: Historical flows on the Piddle at Baggs Mill.

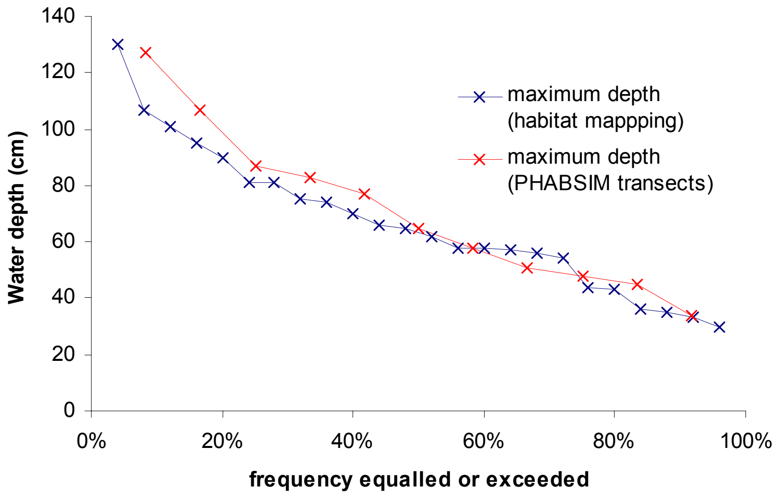


Figure 5.9: River Piddle: comparison of maximum depths of PHABSIM transects and habitat mapping data.

Table 5.5: River Piddle: PHABSIM calibration flows and gauged flows.

Date	Discharge at site (m³/s) *	Briantspuddle discharge (m³/s)	Briants-puddle Q	Baggs Mill discharge (m³/s)	Baggs Mill Q
19/8/99	0.970	0.400	Q69	1.190	Q71
1/12/99	1.466	0.701	Q57	1.616	Q56
11/1/00	4.611	4.913	Q7	5.747	Q5

* discharge was calculated using the mean flows from three cross sections (c/s 3/6/11 for first two flows and c/s 5 for the high flow): assessed as those most suitable for this purpose.

Habitat availability data collection

Three surveys of habitat availability were undertaken on the Piddle in order to provide a reference dataset with which to compare the PHABSIM model output. They are summarised in Table 5.6.

Table 5.6: River Piddle: habitat availability surveys

Survey	Date	Discharge at site (m^3/s)	Number of survey points	Date	Baggs Mill discharge (m^3/s)	BaggsMill Q
1	11-17/8/99	0.906/0.977	435	11/16-17/9/99	1.107	Q76
2	21/09/99	1.229	423	14/17/9/99	1.073	Q78
3	5-9,12-14/6/00	2.094	413	5-9,12-14/6/00	2.373	Q38

It was only possible to undertaken two surveys on the River Piddle in the 1999 field season, the early summer survey being postponed until 2000. We undertook a completely successful early summer survey from 17th-26th June, in parallel with the first Frome survey.

PHABSIM calibration

Water Surface Levels

Various alternative model calibrations were compared:

- WSP calibrated to the 1.47 flow with STGQ4 (IFG4) for downstream cross section
- WSP calibrated to the 4.6 flow with STGQ4 (IFG4) for downstream cross section
- Two WSP models: cross sections 1-6 and cross sections 7-11, each separately calibrated to the 1.47 flow, with STGQ4 (IFG4) for cross sections 1 (linear stage-discharge) and 7 (log-log stage discharge)

The third option was chosen as giving the best overall fit, however the fit was not as good as had been hoped. A range of flows below the highest calibration flow (Q5: 4.61m^3/s) was added down to an estimate of the Q95 flow.

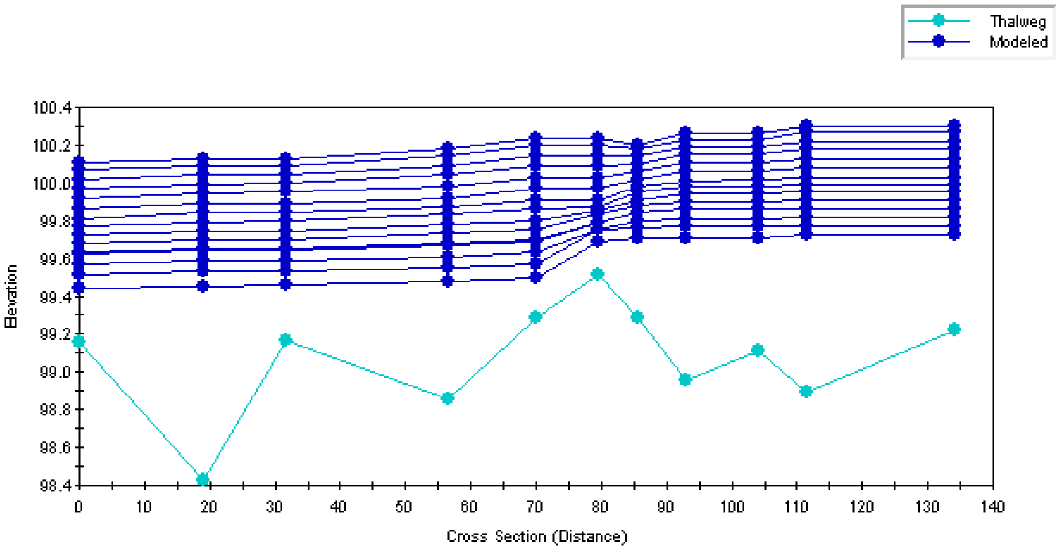


Figure 5.10: River Piddle: simulated water surface levels.

Table 5.7 summarises the overall fit of the water surface level model for the Piddle, and Figure 5.10 the longitudinal variation in water level with discharge.

Table 5.7: River Piddle: errors in water surface level calibration

CS	Max +ve error (m)	Max –ve error (m)
1	0	-0.02
2	+0.02	-0.02
3	+0.01	-0.05
4	0	-0.03
5	0	-0.02
6	-0.01	-0.07
7	0	-0.01
8	+0.01	0
9	+0.01	-0.01
10	+0.05*	+0.01
11	+0.01	-0.03

* probable WSL survey error

5.2.3 River Senni

A habitat mapping survey of the River Senni around Abersenny was undertaken on 24th June 2000. The proportions of the habitats surveyed are illustrated in Figure 5.11. Flows at Pont-Hen-Hafod were around 0.5 m^3/s corresponding to approximately Q53. The sector started 1.5km upstream (SN932259) and finished 1km downstream (SN927275) of Abersenny (SN930268).

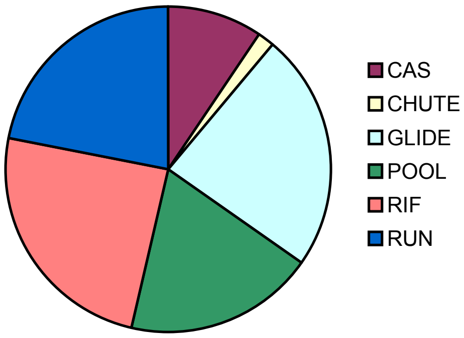


Figure 5.11: River Senni: distribution of mesohabitat types.

PHABSIM data collection

A PHABSIM representative reach was selected within the study area chosen for fish habitat / available habitat study, downstream of Abersenny bridge. Within this reach, 12 hydraulically linked transects for PHABSIM modelling were chosen. Between 14-16 August 2000, cross sections were marked using Anchormark permanent marker pegs, cross sections and a levelling loop were surveyed, and substrate and cover characteristics noted. The first PHABSIM hydraulic survey took place on 15th September. Due to high flows and the deep water at cross-sections 1-5 only transects 7-12 were current metered, a full water surface profile was surveyed. A second survey was undertaken on 18th October 2000 but again due to high river levels we were unable to current meter any of the transects; a full water surface profile was surveyed. The third survey was carried out on 17th January 2001. All cross sections were current metered and a full water surface profile was surveyed. Flows during this period are illustrated in Figure 5.12. and surveyed flows in Table 5.8.

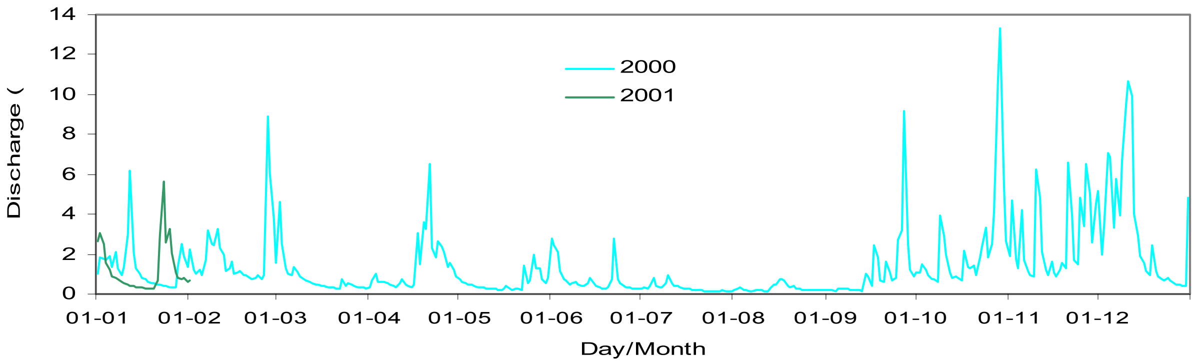


Figure 5.12: River Senni: Flows at Pont-Hen-Hafod during 2000-1.

Table 5.8: River Senni: PHABSIM calibration flows and gauged flows at Pont-Hen-Hafod.

Survey	Date	Discharge at Pont-hen-Hafod(m^3/s)	Discharge at Site (m^3/s)*
1	15/9/2000	1.08	0.869
2	18/10/2000	1.64	1.391
3	17/1/2001	0.47	0.302

* Discharge was calculated using the mean flows from two cross sections: assessed as those most suitable for this purpose (c/s 9/10). In the case of survey 2 it was estimated using a regression relationship between gauge and site

Habitat availability data collection

The first two habitat availability surveys took place between the 20-24 June and 31 July – 5 August 2000 respectively. Both were completed successfully. The third survey which took place between 11-13 September was partially successful, towards the end of the three days heavy rain meant that flows had considerably changed when we returned on the 14 September to completed the survey. The final survey which was scheduled for the 16-20 October was abandoned after two days due to heavy rain. Table 5.9 summarises the data collected.

Table 5.9: River Senni: discharge and habitat availability survey data

Survey	Date	Discharge at site (m^3/s) *	Number of habitat survey points
1	20-24/6/00	0.878	398
2	31/7-5/8/00	0.397	330
3	11-13/9/00	0.330	285
4	16-17/10/00	1.660	207

* discharge estimated using regression equation between gauged flows and site spot gaugings

PHABSIM calibration

Water Surface Levels

The STGQ4 (IFG4) model was found to predict water surface levels satisfactorily for all calibration flows. In addition there were no discrepancies when levels were simulated outside the calibration range. Table 5.10 illustrates the errors for each cross section. Cross section 4 (which exhibits the greatest error) plus cross section 1 were included in the model simply to ensure representation of water slope should the WSP (step-backwater) model be required. Neither have been used in the habitat calculations.

Table 5.10: River Senni: errors in water surface level calibration

CS	Max +ve error (m)	Max –ve error (m)
1	+0.01	0
2	+0.01	-0.01
3	+0.02	-0.01
4	+0.03	-0.01
5	+0.02	-0.01
6	+0.01	0
7	0	-0.01
8	0	-0.01
9	+0.02	0
10	+0.02	-0.01
11	+0.01	-0.01
12	+0.01	-0.01

Velocities

The uneven bed topography, combined with the presence of numerous riffle and cascade areas made velocity modelling complex. For cross sections 1-6 a single velocity calibration set was used, for cross sections 5 and 6 mass balancing (VAFs) was switched off. For sections 8 and 12, both available velocity sets were used where appropriate, again with VAFs switched off. Finally the higher velocity set was used across the whole discharge range with mass balancing enabled. The split between the different velocity models is summarised in Figure 5.13.

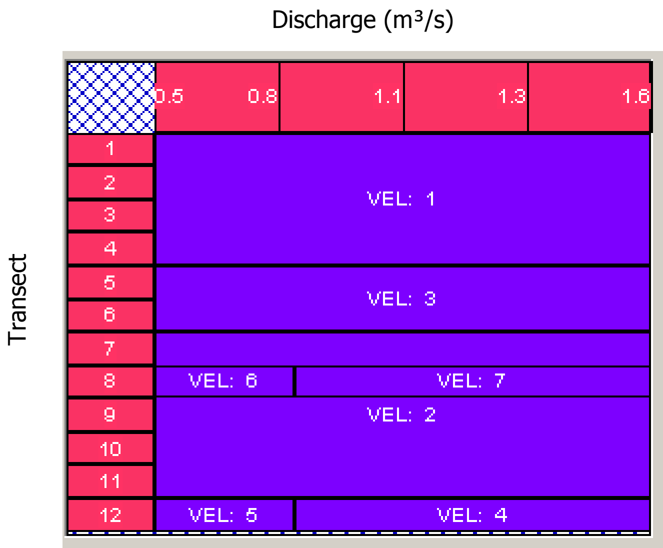


Figure 5.13: River Senni: Velocity model summary

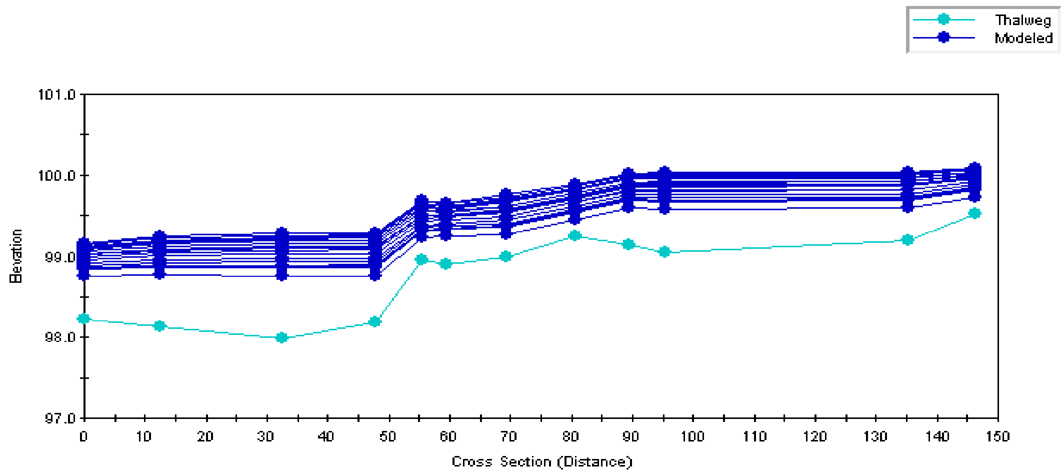


Figure 5.14: River Senni: simulation water surface levels.

5.2.4 South Winterbourne

Habitat mapping

The South Winterbourne at West Stafford (NGR SY726897), and the Carrier which feeds into it were habitat mapped on the 21st – 22nd August 2000. The river was predominantly shallow glide, with some deep glide and riffle. The sector comprised of c.120m downstream of the bridge and c.67m upstream and c.200m of the carrier. Proportions of the mesohabitat types present are illustrated in Figure 5.15

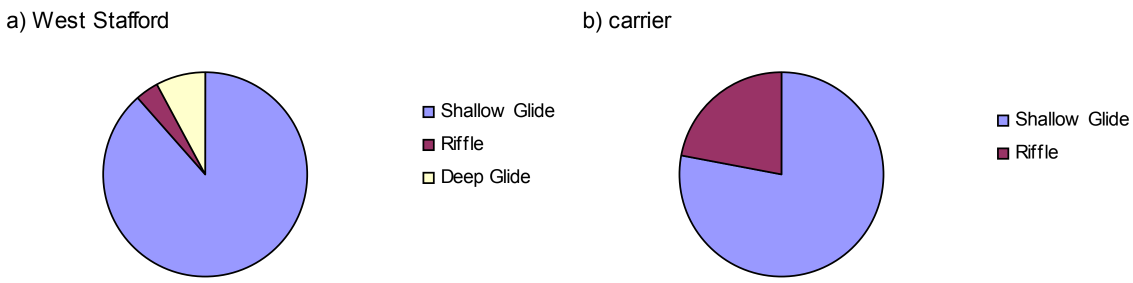


Figure 5.15a,b: South Winterbourne and carrier: distribution of mesohabitat types.

PHABSIM data collection

Eleven transects were selected for PHABSIM modelling, on the basis of water depth, habitat type (riffle or glide), channel width and macrophyte cover. Seven hydraulically linked transects were located on the South Winterbourne itself downstream of the road bridge just outside West Stafford. Four linked transects were located on the carrier. On the 22nd August 2000 all transects were marked out using Anchormark permanent marker pegs, bed elevations were then surveyed across each transect and pegs levelled relative to each other. Substrate and cover characteristics were also recorded. On the 6th September 2000 all cross sections on both sites were current metered and a water surface profile was surveyed. The second PHABSIM survey took place on the 3rd October 2000. All cross sections were current metered and a full water surface profile was surveyed for both sites. A third PHABSIM survey took place on the 9th October 2000 where just a water surface profile was surveyed for both sites. Due to heavy rain during this period that removed all instream vegetation on the South Winterbourne site on the evening of the 9th October a fourth PHABSIM survey was carried out on the 10th October 2000. All cross sections were current metered and a full water surface profile was surveyed. Calibration discharges are detailed in Table 5.11 and 5.12.

Table 5.11: South Winterbourne Main Site: PHABSIM calibration flows

Date	Discharge at site (m^3/s)	Mill Channel discharge (m^3/s)
06/09/2000	0.19	0.196
03/10/2000	0.24	0.302
10/10/2000	0.42	0.659

* Discharge was calculated using the mean flow from cross sections 1,2 and 7

Table 5.12: South Winterbourne Carrier: PHABSIM calibration flows

Date	Discharge at site (m³/s)*	Mill Channel discharge (m³/s)
06/09/2000	0.143	0.196
03/10/2000	0.231	0.302
10/10/2000	0.316	0.602

* Discharge was calculated using the mean flow from cross sections 2-4.

Habitat availability data collection

Each habitat survey consisted of two survey samples over the same reach of river. The first survey sampled one point every 1m and the second survey sampled every 0.5m. The initial survey took place on the South Winterbourne / Carrier between the 22 – 23 May 2000 where one point every 1m was surveyed. We returned on the 15 June and successfully completed the survey. These surveys have been referred to as 1A and 1B. The second full survey took place between the 17 – 20 July 2000 and was completed successfully. The third and final survey was planned to take place between the 2-11 October 2000 but had to be abandoned due to flooding. The details of the surveys are summarised in Tables 5.11 and 5.12.

Table 5.13: South Winterbourne Main Site: discharge and habitat availability survey data

Survey	Date	Number of habitat survey points
1A	22-23/5/2000	161
1B	15/6/2000	155
2	17-19/7/2000	285

Table 5.14: South Winterbourne Carrier: discharge and habitat availability survey data

Survey	Date	Discharge (m³/s)	Number of habitat survey points
1	23/5/00	*0.461	140
2	20/7/00	* 0.198	126

* Estimated using the gauge for the Mill Channel from Loudsmill gauging station

PHABSIM calibration

Water surface levels

The West Stafford and Carrier sites proved to be the most difficult model calibrations. This was likely due to the extensive in-channel macrophyte growth and overhanging vegetation close to the water. For the West Stafford site, a MANSQ model was fitted to cross section 1, IFG4 to cross section 2, and WSP / step-backwater to the remaining cross sections. Problems were experienced modelling water levels at cross sections 6 and 7, which were shallow fast-flowing transects with woody debris in the channel.

However this may partly be due to water surface survey errors, which are highlighted in the longitudinal profile in Figure C4.2.

For the Carrier the MANSQ model was used for cross section 1 (a riffle) and the STGQ4 (IFG4) model for the remainder of the cross-sections. Final differences between measured and modelled data are shown in Table 5.15.

Table 5.15: South Winterbourne / Carrier. Water surface level errors.

CS	Max +ve error (m)	Max –ve error (m)
Main Channel		
1	+0.02	-0.01
2	0	0
3	0	0
4	0	0
5	0	0
6	+0.07	0
7	+0.04	-0.01
Carrier		
1	+0.02	-0.03
2	+0.01	-0.02
3	0	-0.01
4	0	-0.01

Velocities

For the main site calibration set 2 (0.24m^3/s) was used to model velocities for all cross sections. This represented a condition with summer weed growth which had had little management, but still contained significant areas of clear gravels. For cross section 6 (a riffle), which had a calculated discharge much higher than the other cross sections, mass balancing had to be turned off.

A mixed model approach was taken to model velocities on the Carrier site. The low flow calibration set was used up to a discharge of 0.15 m^3/s, and the high flow calibration set above this. For cross section 4, there was a considerable variation in velocity across the cross section, caused by upstream macrophyte growth. In order to model realistic velocities across the flow range 0.15 to 0.3 m^3/s, VAFs were not applied for this cross section only. This is summarised in Figure 5.16.

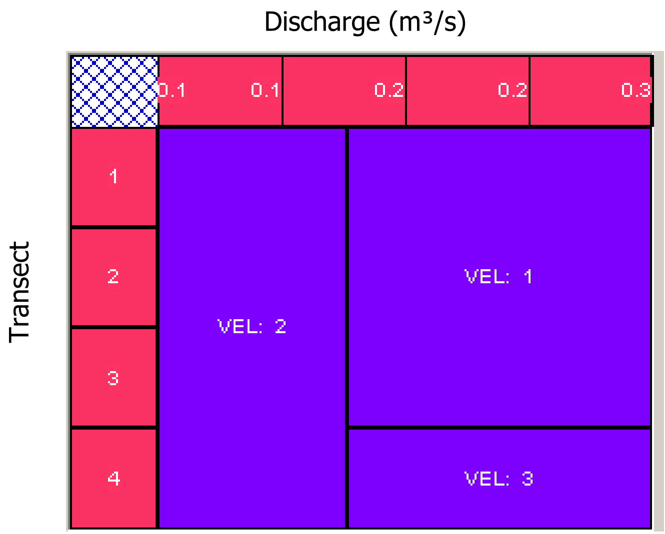


Figure 5.16: South Winterbourne Carrier: velocity models used.

6. TESTING THE ROBUSTNESS OF THE PHABSIM HYDRAULIC MODEL

6.1. Introduction

Following PHABSIM model calibration, output data (water depths and velocities) were collated for the discharges at which the availability surveys were undertaken. Considerable use was made of the calibration and output capabilities of the new Windows version of PHABSIM. In particular, the revised form of model output was essential for the preparation of tables of water depths and velocities over a range of discharges: this could not have been achieved using the existing Institute of Hydrology / Environment Agency version of PHABSIM.

Various tests, both visual and numerical, were undertaken in order to quantify the differences between measured and modelled data. In some cases a hypothesis-testing approach was applied (ie the null hypothesis that there is no significant difference between predictions of physical habitat availability taken from the PHABSIM model, and measurements of physical habitat availability taken by an unbiased sampling approach). Initial work concentrated on univariate statistical approaches, such as the Kolmogorov-Smirnov test. Following work in collaboration with Utah State University, including discussion with statisticians, an alternative, bivariate approach, based on chi-squared testing principles[2] was adopted as this could take into account situations where the proportions of habitats within the PHABSIM site did not exactly match the proportions of habitats in the study sector.

6.2 Methods

The overall process for hydraulic testing can be outlined as follows

Stage	Activity
1	Survey hydraulic habitat availability in river sector three times using un-biased sampling approach. Ensure discharge is known for each survey.
2	Select PHABSIM transects to represent river sector, collect PHABSIM calibration data.
3	Calibrate PHABSIM for a range of discharges including the discharges on the dates of the habitat availability surveys
4	Run PHABSIM for model calibration and availability survey discharges
5	Re-scale PHABSIM model outputs to sector scale if required

[2] We do not describe it as a chi-squared test as it does not compare two sets of data sampled in the same manner, rather it tests a measurement protocol with a different protocol and a model which should give equivalent results

6	Collate model output as water depths and velocities
Tests 1 (verification)	Compare PHABSIM measured depths and velocities with model output data at calibration flows (reach scale)
Tests 2 (validation)	Compare PHABSIM measured depths and velocities (scaled using habitat mapping data) with habitat availability measurements (sector-scale)

For Tests 1, the null hypothesis was that there is no significant difference between depths and velocities measured at the PHABSIM calibration discharges, and the PHABSIM model output at those discharges. The analytical approaches used were:

- paired-sample t-test (univariate: comparing point-for-point)
- Chi-square test for depth and velocity categories (bivariate)

For Tests 2, a variety of approaches was taken. Firstly the approach based upon chi-squared testing principles was employed, comparing the availability data ("expected") with PHABSIM model output ("observed"). Secondly, a more pragmatic approach, based primarily on visual interpretation of differences in measured physical habitat (measured by WUA) and modelled WUA using a standard set of HSIs for Atlantic salmon.

For the chi-squared testing, the null hypothesis was that for the discharges when the habitat availability surveys were undertaken, there was no significant difference between the availability depths and velocities (measured over the river sector) and those from the PHABSIM model (measured at transects over the PHABSIM reach) run at the same discharge.

The advantage of an approach based on chi-squared testing is that firstly it allows PHABSIM point measurements and transects to be re-weighted (this is explained below), and secondly it allows a simple bivariate approach to be adopted. Thus the chi-squared categories were split by both depth and velocity into a two-way matrix design. This approach is considered vitally important as ultimately physical habitat is calculated from at-a-point combinations of water depth and velocity. The assumption being tested is illustrated in a stylised fashion in Figure 6.1 below.

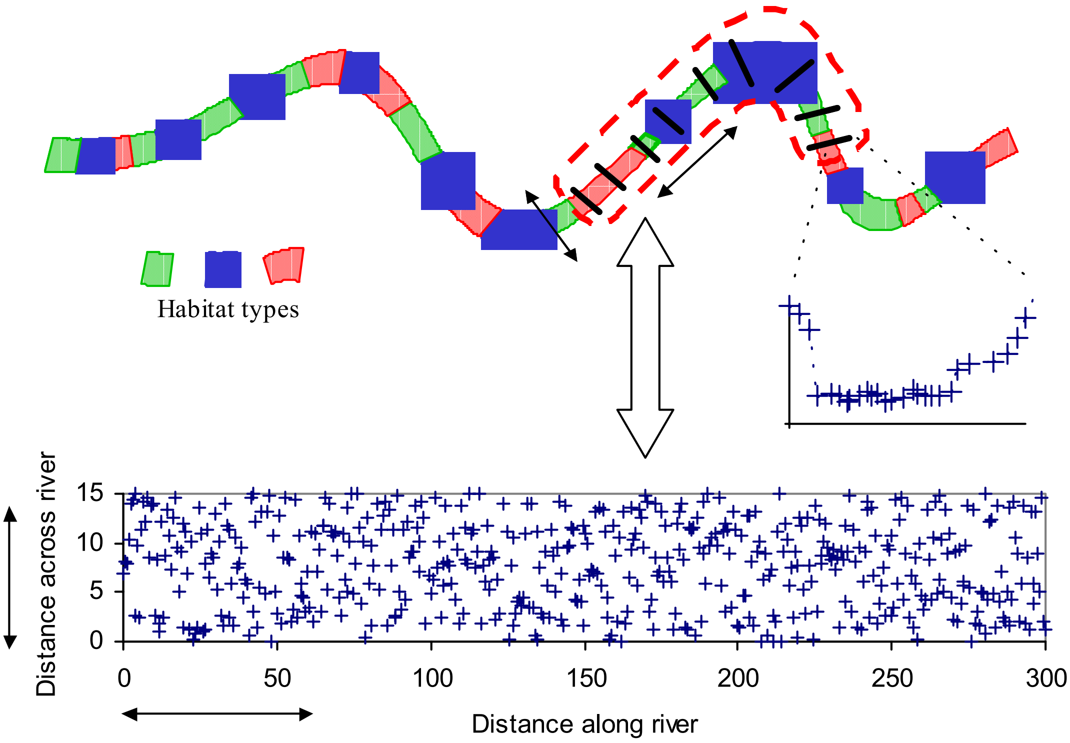


Figure 6.1: Comparison of PHABSIM reach model and sector scale habitat availability

Re-weighting

Re-weighting of PHABSIM points and transects is important to allow a true comparison with the unbiased, point sampled habitat availability datasets. In the latter set, each point is of equal weight. However each point in a PHABSIM dataset is not of equal weight, for two reasons:

a. All cells are not the same width as they are surveyed to take into account breaks in slope and also to reflect local habitat heterogeneity (e.g. cells tend to be narrower in the zones near the bank where velocity changes). Thus model cells need to be re-weighted as they represent different areas of river.

b. It may not be possible to choose a set of PHABSIM transects so that the overall proportions of the habitat types in the PHABSIM reach exactly match the proportions in the sector one is trying to represent. Thus each transect may need to be re-weighted.

When the re-weighting is undertaken, the sum of all the weights is equal to the total number of points measured, so no alteration of degrees of freedom occurs in any following statistical test.

Chi-square testing

For both the availability and PHABSIM model results, it is possible to produce a matrix of the number of points in a series of depth and velocity classes. In the case of the PHABSIM model results, the numbers of points in each class will take into account the weightings described above. Table 6.1 illustrates an example of the category boundaries used:

Table 6.1: Example of classification categories for depth and velocity

Category	Depth class interval (m)	Velocity class interval (m/s)
3	<0.03 (ignored)	0-0.02
4	0.03-0.1	0.02-0.1
5	0.1-0.2	0.1-0.2
6	0.2-0.3	0.2-0.5
7	0.3-0.4	0.5-0.8
8	0.4-0.8	0.8+
9	0.8+	

As the number of PHABSIM points surveyed was always less than the number of habitat availability points measured, a final down-weighting of the counts of availability points needed to be undertaken, so that the final degrees of freedom for both sets of data to be compared would be equal.

As some of the categories contained counts less than five, some merging of categories had to be undertaken. Merging was undertaken for each test separately by eye, using common sense to ensure that the merged categories still contained realistic/relevant categories. An example pair of tables is illustrated in Table 6.2, the colours indicate the merged categories used in that case.

Table 6.2: River Senni: example of bivariate contingency tables for habitat availability and PHABSIM output

Reweighted PHABSIM model results

		1	**2**	**3**	**4**	**5**	**6**	
	2		6	6	6	4		
	3		12	5	8	7	4	
	4		17	6	7	19	9	
	5		12	13	21	10	4	
	6		2	2	5			
Total								184

Reweighted availability survey data

		1	**2**	**3**	**4**	**5**	**6**	
	2	1	5	3	1	2		
	3	1	10	6	6	6	4	
	4	0	14	9	15	22	7	
	5		12	13	25	8	3	
	6		2	2	4	0		
Total								184

(total number of categories n = 16)
(The bold numbers indicate the categories as illustrated in Table xx).

A test statistic, X^2 is then calculated from the results from this cross-classification table (with categories merged where necessary).

$$X^2 = \sum \frac{(O-E)^2}{E}$$

(O = “Observed” data, E = “Expected” data)
X^2 approximately follows a chi-squared distribution. The availability survey data represent the “expected” values, the PHABSIM model results the “observed” values.

Quantification of uncertainty in PHABSIM results

For a chi-squared statistic, a probability value may then be calculated for the statistic, with n-1 degrees of freedom. However as the test does not compare like-with-like, as outlined in the section introduction, we do not emphasise set probabilities, instead we recommend that the results be used to give more detailed information as to how the model is performing. In the real world, this must be considered against the relative suitabilities of the categories of PHABSIM results that contribute to failure.

To investigate this, the Tests 2 procedure used percentage useable habitat both for the PHABSIM site (with transects correctly weighted) and the river sector. These results can themselves be presented visually, and if required, by calculating the percentage differences between them. The latter is purely illustrative in that as for the chi-squared approach, the results being compared are derived in slightly different ways.

The question as to what difference is acceptable is clearly subjective. Common sense suggests it should depend on the steepness of the WUA against discharge function: as a general guide, if the function is steep then a greater percentage difference would be acceptable compared to a shallow curve – this is illustrated in Figure 6.2.

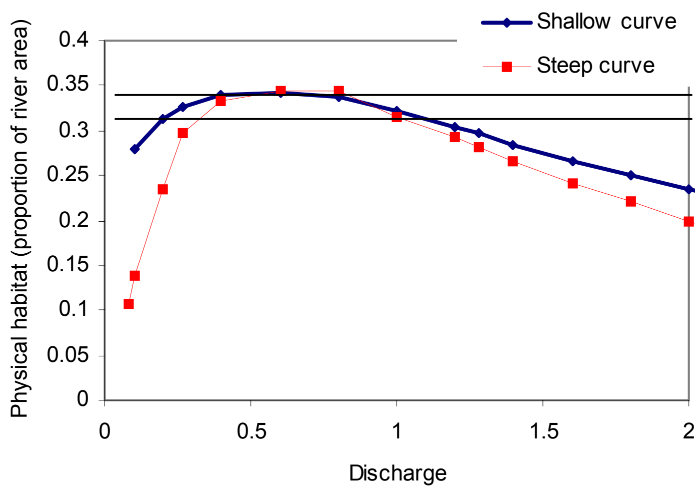


Figure 6.2: Illustration of relative importance of hypothetical 2.5% habitat discrepancy for contrasting habitat-discharge relationships

Substrate data

Testing of whether the distribution of substrates within the PHABSIM reach was a true representation of the substrates present in the broader river sector was also undertaken. Chi-square testing was the analytical technique used.

Presentation of results

Key data are presented in tables in this section, while supporting data are presented in Appendices A and D. In this section, for each site, the first table presents the distributional parameters for the tested flows, the second table presents the results of the tests based on chi-squared methodology, both for verification and validation tests. Included are the number of wetted points from the PHABSIM model output (n), the degrees of freedom of the test (number of categories minus 1) and the associated test P-value. The third table presents the results of the paired sample tests for verification, while the fourth table presents percentage of river useable (calculated from salmon HSIs) for each flow, to indicate whether to what extent hydraulic discrepancies are reflected in habitat discrepancies. The fifth table illustrates substrate for sector and PHABSIM reach, while the sixth table expands on the second and third tables to illustrate which hydraulic categories are contributing most to overall discrepancy between measured and modelled habitat.

6.2 Results

6.2.1 River Walkham

The Walkham PHABSIM output hydraulic data were verified against the high and low calibration set, and validated against three sets of habitat availability data. A comparison of modelled means and variances is presented in Table 6.3., results for chi-squared tests are presented in Table 6.4, for paired t-tests in Table 6.5, and for calculated habitat for salmon in Table 6.6. Discrepancies between measured and modelled data are presented graphically in Figure 6.4.

Overall, the PHABSIM model passed the verification tests at the calibration discharges. It passed the validation test for one out of the three discharges (0.58 m^3/s). This indicates that the PHABSIM reach is capable of representing the sector, but that there are problems at lower and higher discharges.

At the lower discharge (0.27 m^3/s) the contingency table indicates that there are problems with only two categories: high velocities and low velocity habitat between 0.2-0.3m deep. At the higher discharge (1.28m^3/s), there is a major discrepancy in the representation of deeper (>0.4m) medium velocity habitat.

Table 6.3: River Walkham: comparison of distribution parameters

Survey ref	Discharge (m^3/s)	Survey type	Mean Depth	Variance of Depth	Mean Velocity	Variance of velocity
1	0.58	Measured habitat availability	0.28	0.031	0.32	0.095
		PHABSIM (modelled)	0.28	0.026	0.28	0.059
2	0.27	Measured habitat availability	0.25	0.021	0.23	0.073
		PHABSIM (modelled)	0.23	0.021	0.16	0.02
3	1.28	Measured habitat availability	0.34	0.035	0.43	0.124
		PHABSIM (modelled)	0.35	0.036	0.40	0.103

Table 6.4: River Walkham: results of chi-squared tests for verification and validation

	Discharge (m^3/s)	n	df	P-value	Pass / Fail
Verification	1.2	169	11	0.088	Pass
	0.37	141	10	0.146	Pass
Validation	0.58	149	15	0.176	
	0.27	136	11	0.035	
	1.28	176	14	0.000	

Table 6.5: River Walkham: results of paired t-tests for verification.

Discharge (m^3/s)	Mean depth difference (m)	P-value	Mean velocity difference (m/s)	P-value
1.2	-0.01	0.02	0.04	0.00
0.37	0.00	0.69	-0.02	0.05

When physical habitat is calculated (using the generic salmon HSIs) at each discharge (Table 6.6), it appeared that while the discrepancies at the 0.27 m^3/s discharge do not produce serious discrepancies between measured and modelled habitat, at both the 0.58 and 1.28 m^3/s discharges, the differences are likely to be highly significant, with PHABSIM consistently over-estimating the physical habitat in the reach. However it may be that this consistent bias would not be important in an operational context: when considering relative differences in habitat.

Table 6.6: River Walkham: calculated habitat (generic HSIs) for salmon at availability discharges.

Discharge	Salmon 0-7 % useable			Salmon 8-20 % useable		
(m^3/s)	Availability	Modelled	% difference	Availability	Modelled	% difference
0.58	43%	50%	+18%	37%	45%	+22%
0.27	35%	38%	+7%	28%	31%	+8%
1.28	43%	55%	+28%	42%	55%	+29%

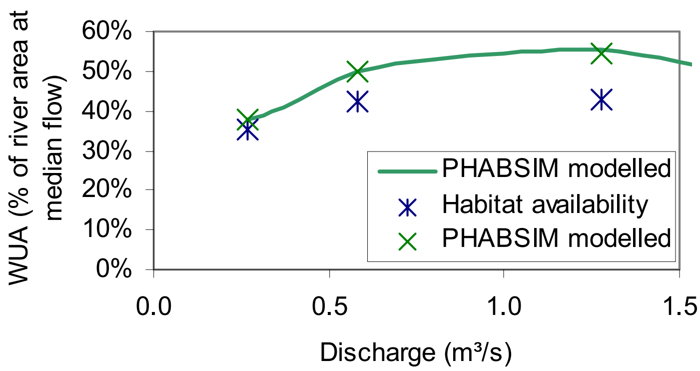


Figure 6.3: River Walkham calculated habitat (generic HSIs) for salmon at availability discharges.

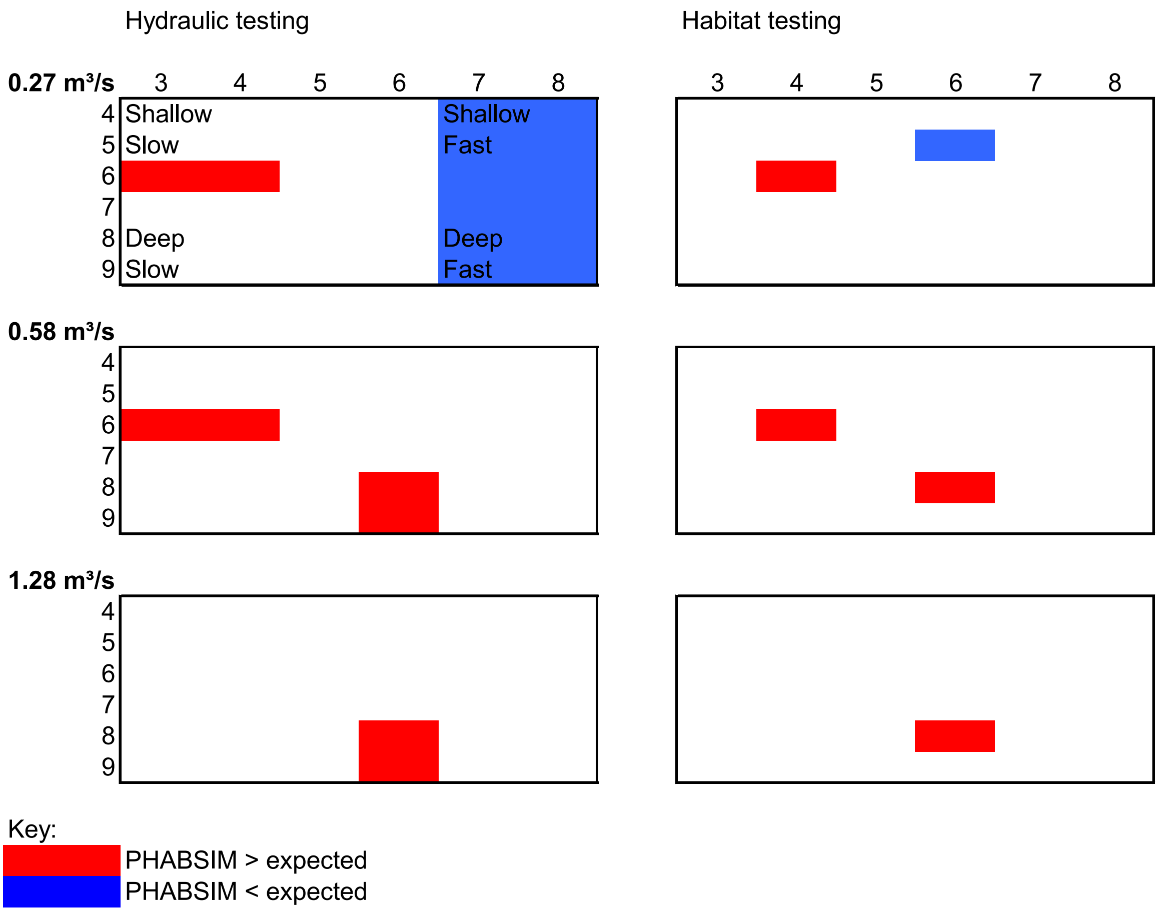


Figure 6.4: River Walkham: graphical illustration of differences between modelled and expected habitat

For substrate the test failed for the sand, bedrock and boulder categories. The PHABSIM site had too much sand and bedrock and not enough boulder when compared to the reach as a whole.

Table 6.7: River Walkham: proportions of substrate in PHABSIM reach and sector

Category	PHABSIM	Availability
Sand	11%	3%
Fine gravel	8%	9%
Coarse gravel	13%	13%
Fine cobble	13%	15%
Coarse cobble	23%	26%
Boulder	19%	31%
Bedrock	13%	4%

The 0.58m³/s discharge passed the hydraulic validation test, yet it fails to represent the habitat by visual inspection. Conversely, at 0.27 m³/s, the hydraulic test fails (but not by much), yet there is little difference in habitat between measured and modelled. Further details of how this can be possible are illustrated in Table 6.8. Units are differences between modelled and measured habitat, expressed as percentages of total available

habitat at that discharge. At 0.58m³/s, over-estimation of categories 6/8 and 4/8 in the PHABSIM model (figures highlighted in bold) along with relatively accurate prediction of all other categories leads to overall over-estimation of habitat. For the 0.27m³/s discharge, general under and over-estimation of habitat across all categories balances out, so the modelled and measured data give similar overall physical habitat.

Table 6.8: River Walkham: habitat discrepancies at two discharges

Discharge of 0.58 m³/s

Depth category	Velocity category 3	4	5	6	7	8
4	0.00	0.00	-0.15	-0.36	0.01	0.00
5	0.00	0.54	-0.52	-1.14	0.07	0.00
6	0.00	**2.72**	0.19	-0.26	-0.15	0.00
7	0.00	0.19	0.51	-0.04	0.27	0.00
8	0.00	1.85	1.23	**4.98**	-0.01	0.00
9	0.00	0.00	-0.27	-0.97	-0.07	0.00

Discharge of 0.27 m³/s

Depth category	Velocity category 3	4	5	6	7	8
4	0.00	0.03	0.03	0.49	-0.03	0.00
5	0.00	-0.04	0.53	-2.03	0.23	0.00
6	0.00	2.78	-1.22	-1.37	-0.29	0.00
7	0.00	0.70	0.96	-1.59	-0.25	0.00
8	0.00	1.24	2.48	1.16	-0.39	0.00
9	0.00	0.00	-0.38	0.00	0.00	0.00

6.2.2 River Piddle

The Piddle PHABSIM output hydraulic data were verified against two calibration discharges: 0.97 and 1.46 m³/s, and were validated against three sets of habitat availability data. A comparison of the means and variances of observed and modelled data is given in Table 6.9. Results for chi-squared tests are presented in Table 6.10 and for paired t-tests in Table 6.11. Discrepancies between measured and modelled data are presented graphically in Figure 6.7. An additional Table, 6.12, illustrates the frequencies of depths in different categories at different flows, used in the later discussion.

The tables illustrate that PHABSIM struggles to model conditions in the sector at all flows where availability was measured. In general for each test, 20-25% (ie 2-3) of the categories contribute over 60% of the total chi-squared statistic. This could indicate that the representation of the reach by the selected transects is not good.

Table 6.9: River Piddle: comparison of distribution parameters

Survey no.	Survey type	Mean Depth	Variance of Depth	Mean Velocity	Variance of velocity
1	Measured habitat availability	0.52	0.068	0.24	0.035
	PHABSIM (measured)	0.44	0.070	0.25	0.042
	PHABSIM (modelled)	0.42	0.070	0.24	0.040
2	Measured habitat availability	0.50	0.071	0.24	0.038
	PHABSIM (modelled)	0.44	0.075	0.26	0.050
3	Measured habitat availability	0.70	0.054	0.31	0.038
	PHABSIM (modelled)	0.52	0.089	0.40	0.11

Table 6.10: River Piddle: results of chi-squared tests for verification and validation.

	Discharge (m^3/s)	n	df	P-value	Pass / Fail
Verification	0.97	230	14	0.213	Pass
	1.46	250	13	0.598	Pass
Validation	0.94	225	12	0.000	
	1.23	242	12	0.000	
	2.1	270	8	0.000	

Table 6.11: River Piddle: results of paired t-tests for verification.

Flow	Mean depth difference (m)	P-value	Mean velocity difference (m/s)	P-value
0.97	0.02	0.00	0.00	0.34
1.46	-0.04	0.00	-0.01	0.00

Table 6.12: River Piddle: proportions of depths in different categories at availability discharges

Depth	0.94 m^3/s		1.23 m^3/s		2.1 m^3/s	
Category (m)	Availability	Modelled	Availability	Modelled	Availability	Modelled
0.04-0.099	2%	4%	4%	5%	0%	7%
0.1-0.199	8%	7%	9%	9%	2%	6%
0.2-0.399	27%	31%	26%	29%	5%	18%
0.5-0.799	45%	45%	45%	46%	54%	50%
0.8+	18%	12%	16%	12%	38%	19%

When considering univariate depth distributions at each of the discharges, for the lower two discharges (0.94 and 1.23 m^3/s), the PHABSIM reach does generally represent the sector (at 1.23 m^3/s $p=0.40$ for chi-squared, at 0.94 m^3/s $p=0.022$, however the latter statistic only fails due to a lack of deep water (>0.8m). However at the higher discharge, the PHABSIM reach contains far more shallow habitat than the sector overall. Potential reasons for this include a change in the weed cover between availability survey and PHABISM survey, a possible under-estimate of the discharge for the availability survey and a failure of the habitat mapping procedure to describe sufficiently high flow conditions.

Possible discharge under-estimation was tested by comparing the availability data with habitat at discharges of 2.5 m³/s (20% greater) and 3 m³/s (40% greater) from the PHABSIM model. Results (Figure 6.5) indicate that although increasing the discharge clearly reduces the amount of shallow habitat, overall it does not improve the overall fit.

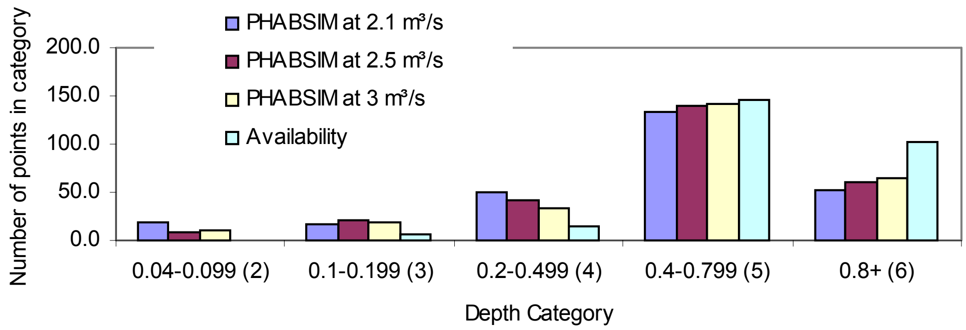


Figure 6.5: River Piddle: sensitivity to discharge estimation for availability survey 3

For velocity, at the lower two discharges, there is inadequate sampling of the low velocity class (0.02-0.099 m/s) and over-sampling of the 0.1-0.2 m/s class in the PHABSIM reach. A similar effect is seen at the higher discharge, with the 0.1-0.2 m/s class being inadequately represented and the 0.2-0.4 m/s class being over-represented. It is difficult to tell whether this is directly due to inadequate representation of the sector or modelling inaccuracies. However, as the two verification tests both passed, it does suggest that the procedure of habitat mapping and characterisation by habitat type and maximum depth has been inadequate in this case, particularly for high flows.

When the impacts of these noted discrepancies are assessed in terms of calculated physical habitat (Table 6.14), a slightly different picture emerges. Firstly, it appears that the practical importance of the discrepancies described above may not be that great at the 0.93 m³/s discharge. At the other two discharges, the discrepancies appear to have a greater effect.

When the details of these calculations are examined (Appendix C and example in Table 6.15), it is clear that as was the case on the Walkham at 0.27m³/s, although individual categories are under or over-predicted, the overall bias is fairly neutral. In particular, over-prediction by PHABSIM in the 6/8 class is balanced by under-prediction in the 5/9 class. Overall the question must be asked whether a small discrepancy (or even no discrepancy) in calculated habitat is important if it is the product of significant individual positive and negative discrepancies which mostly cancel each other out. For the 2.1 m³/s discharge, measured and modelled habitat is quite different. There are three possible reasons for this. Firstly, the highest PHABSIM velocity calibration set was collected at a discharge of 1.5 m³/s, so to model at 2.1 m³/s involves calibration upwards. Secondly, and crucially, the availability dataset was collected in early summer the year after the velocity calibration set. The latter was collected in late summer and winter. It is possible that this seasonal difference meant that a late summer velocity calibration set was not valid for the prediction of habitat earlier in the year. Finally, as mentioned above, the mapping procedure may not have been valid at the higher flows.

Table 6.13: River Piddle: calculated habitat (generic HSIs) for salmon at availability discharges

Discharge	Salmon 0-7 % useable			Salmon 8-20 % useable		
(m³/s)	Availability	Modelled	% difference	Availability	Modelled	% difference
0.94	61%	59%	-4%	60%	58%	-3%
1.23	65%	58%	-11%	63%	57%	-9%
2.1	74%	50%	-31%	76%	52%	-31%

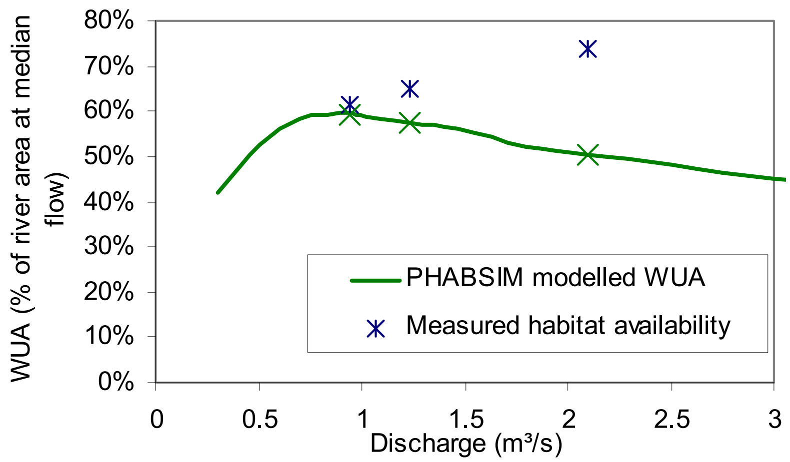


Figure 6.6: River Piddle: calculated habitat (generic HSIs) for salmon at availability discharges

Discharge of 0.94 m³/s

Depth category	Velocity category 3	4	5	6	7	8
4	0.0	0.1	0.0	0.0	0.0	0.0
5	0.0	0.3	-0.1	-0.9	-0.1	0.0
6	0.0	0.9	0.1	-1.5	0.1	0.0
7	0.0	1.3	0.4	-3.1	0.1	0.0
8	0.0	-1.1	-1.0	6.3	0.0	0.0
9	0.0	-0.7	-5.8	2.4	0.0	0.0

Table 6.14: River Piddle: habitat discrepancies
(units are differences in weighted usable "points" for measured and modelled categories – the total number of points at this flow was 225).

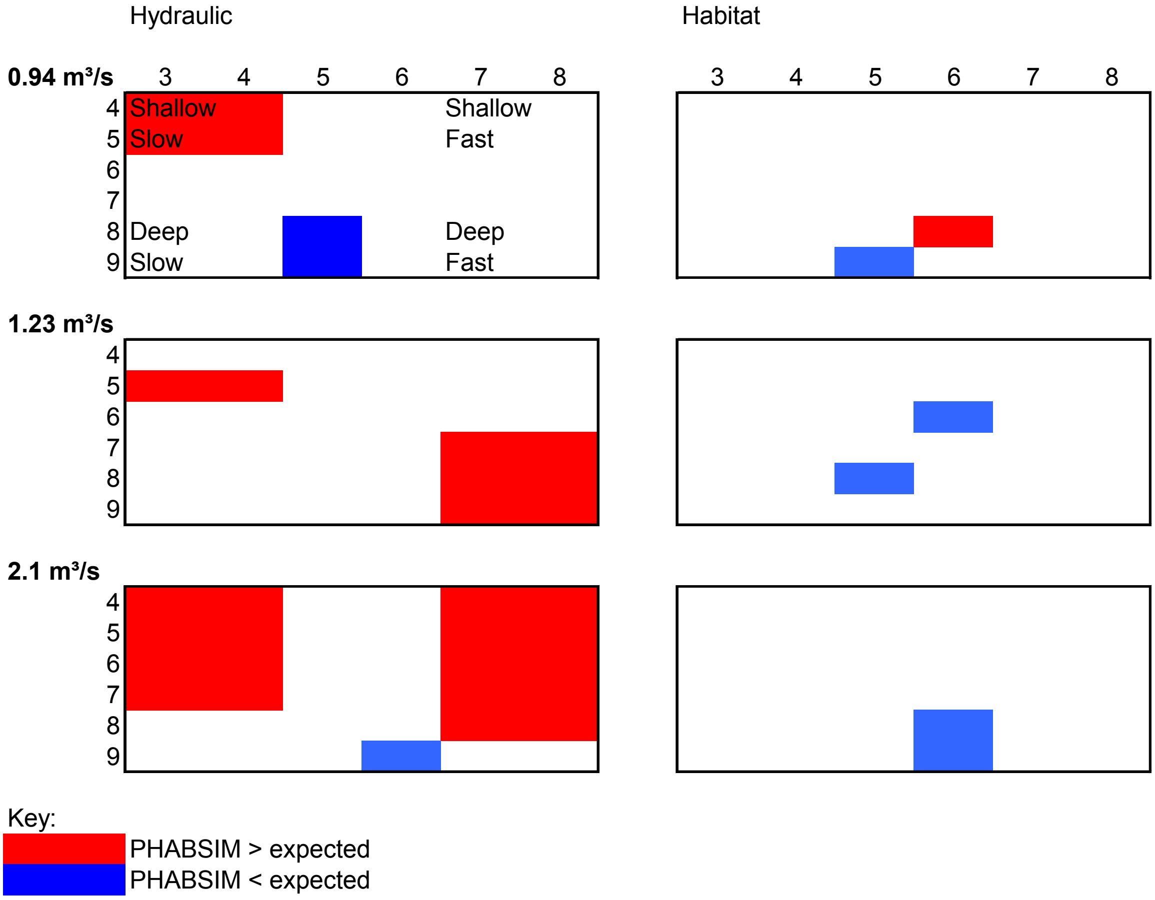


Figure 6.7: River Piddle: graphical illustration of differences between modelled and expected habitat

The chi-square test for substrate in the reach and sector is just significant at p=0.05 (Table 6.16). However, on a practical level, one would probably accept that the PHABSIM reach did acceptably represent the sector for substrate.

Table 6.15: River Piddle: proportions of substrate in PHABSIM reach and sector

Category	PHABSIM	Availability
Silt	26%	24%
Sand	27%	21%
Fine Gravel	18%	21%
Coarse Gravel	24%	30%
Fine Cobble	4%	3%

6.2.3 River Senni

The Senni PHABSIM output hydraulic data were verified against a single calibration discharge and a further partial data set: 0.47 and 1.08 m³/s respectively. The model results were then validated against two sets of habitat availability data. Table 6.16 summarises the distribution parameters for modelled and measured data. Results for chi-squared tests are presented in Table 6.17, for paired t-tests in Table 6.18, and for calculated habitat for salmon in Table 6.19. Discrepancies between measured and modelled data are presented graphically in Figure 6.9.

The results indicate that there was some difference between PHABSIM reach and sector at the lower discharge (0.38 m^3/s), but that at the higher discharge (0.78 m^3/s) the modelled and measured data were very similar. For the lower discharge, a univariate comparison of depths reveals that the 0-0.1 m depth category is over-estimated by PHABSIM and the 0.1-0.2 m depths under-estimated by a similar amount. Thus if it were valid to merge these two categories, the overall distribution of depths would be similar. This highlights issues with cross sections with shallow edges which is discussed later. For velocity, PHABSIM over-estimates the 0.1-0.2 m/s and 0.4-0.8 velocity categories, and under-estimates the <0.1 m/s velocity categories.

Table 6.16: River Senni: comparison of distribution parameters

Survey no.	Discharge (m^3/s)	Survey type	Mean Depth	Variance of Depth	Mean Velocity	Variance of velocity
1	0.76	Measured habitat availability	0.36	0.049	0.31	0.076
		PHABSIM (modelled)	0.36	0.050	0.32	0.100
2	0.38	Measured habitat availability	0.27	0.037	0.19	0.099
		PHABSIM (modelled)	0.30	0.041	0.22	0.060

Table 6.17: River Senni: results of chi-squared tests for verification and validation.

	Discharge (m^3/s)	n	df	P-value	Pass / Fail
Verification	0.47	220	16	0.281	Pass
	1.08	129	8	0.037	Fail*
Validation	0.76	184	15	0.233	
	0.38	146	11	0.000	

* only 6/12 cross sections current metered

Table 6.18: River Senni: results of paired t-tests for verification.

Flow	Mean depth difference (m)	P-value	Mean velocity difference (m/s)	P-value
0.47	-0.02	0.00	0.02	0.07
1.08	-0.04	0.00	0.07	0.00

When expressed in terms of salmon habitat, the calculated values for the 0.76 m^3/s discharge are fairly close, as one would hope given the closeness of the distributions of the raw variables (Table 6.19). However, the habitat values for the comparison at the 0.38 m^3/s discharge are also equally close. The measured availability data suggest a rather steeper response of physical habitat to discharge, and it is this, rather than the magnitudes of individual differences which is probably most important.

Table 6.19: River Senni: calculated habitat (generic HSIs) for salmon at availability discharges.

Discharge	Salmon 0-7 % useable			Salmon 8-20 % useable		
(m^3/s)	Availability	Modelled	% difference	Availability	Modelled	% difference
0.76	53%	49%		47%	46%	
0.38	35%	38%		31%	34%	

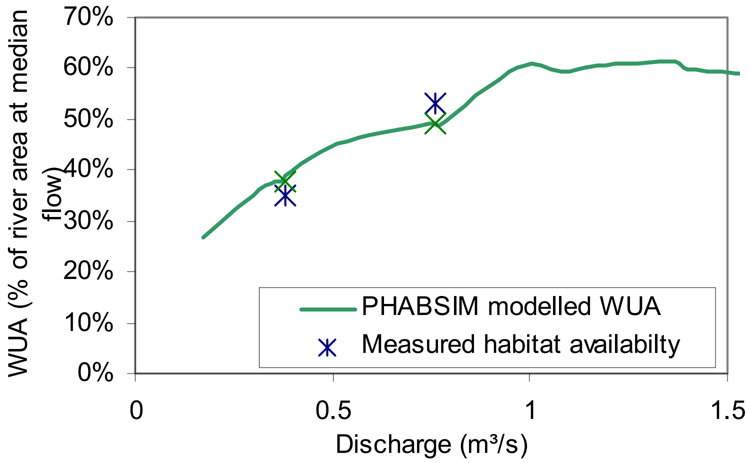


Figure 6.8: River Senni: calculated habitat (generic HSIs) for salmon at availability discharges.

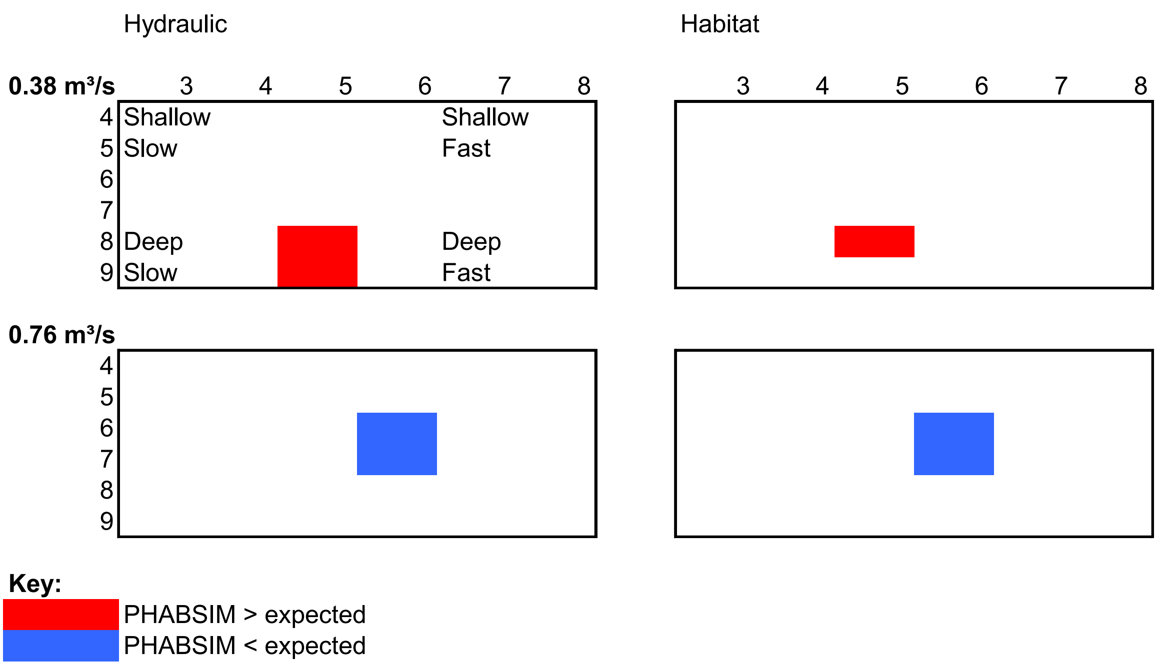


Figure 6.9: River Senni: graphical illustration of differences between modelled and expected habitat

For substrate, there appears to have been some confusion between fieldworkers between coarse cobble and boulder, a single merged category would have similar proportions. In addition, there appears not to have been sufficient coarse gravel in the PHABSIM reach (2% vs 8%) (Table 6.20).

Table 6.20: River Senni: proportions of substrate in PHABSIM reach and sector

Category	PHABSIM	Availability
Silt	2%	4%
Sand	1%	2%
Fine Gravel	0%	2%
Coarse Gravel	2%	8%
Fine Cobble	10%	9%
Coarse Cobble	14%	27%
Boulder	39%	21%

6.2.4 River Frome

Two PHABSIM hydraulic models were created for the Frome, firstly on the main South Winterbourne and secondly on the carrier (from the main Frome at Loud's Mill) that feeds it. PHABSIM output hydraulic data were verified against a calibration discharge of 0.19 m^3/s for the main site and 0.13 m^3/s for the carrier, and in both cases, passed the chi-squared test. Each PHABSIM model was then validated against two sets of habitat availability data: 0.5 and 0.24 m^3/s for the main site and 0.29 and 0.15 m^3/s for the carrier. Table 6.21 and 6.22 summarise the distribution parameters for modelled and measured data. Results for chi-squared tests are presented in Table 6.23 and for paired t-tests in Table 6.24. Comparison of measured and modelled habitat is presented in Table 6.25.

Table 6.21: River Frome: main site comparison of distribution parameters

Survey no.	Discharge (m^3/s)	Survey type	Mean depth	Variance of depth	Mean Velocity	Variance of velocity
1	0.50	Measured habitat availability	0.42	0.020	0.22	0.036
		PHABSIM (modelled)	0.37	0.025	0.22	0.069
2	0.24	Measured habitat availability	0.24	0.009	0.14	0.028
		PHABSIM (modelled)	0.27	0.020	0.15	0.030

Table 6.22: River Frome: carrier site comparison of distribution parameters

Survey no.	Discharge (m^3/s)	Survey type	Mean depth	Variance of depth	Mean Velocity	Variance of velocity
1	0.29	Measured habitat availability	0.31	0.012	0.38	0.066
		PHABSIM (modelled)	0.26	0.012	0.30	0085
2	0.15	Measured habitat availability	0.21	0.008	0.28	0.064
		PHABSIM (modelled)	0.24	0.010	0.21	0.044

Table 6.23: River Frome: results of chi-squared tests for verification and validation

Test	Site	Discharge (m^3/s)	N	Df	P-value	Pass / Fail
Verification	Main	0.19	125	11	0.505	Pass
	Carrier	0.13	67	7	0.992	Pass
Validation	Main	0.5	139	8	0.000	
	Main	0.24	130	6	0.054	
	Carrier	0.29	68	NA	0.000	
	Carrier	0.15	69	6	0.089	

Table 6.24: River Frome: results of paired t-tests for verification

	Flow	Mean depth difference (m)	P-value	Mean velocity difference (m/s)	P-value
Main	0.19	-0.01	0.00	-0.02	0.08
Carrier	0.13	-0.01	0.05	0.01	0.05

Table 6.25: River Frome: calculated habitat (generic HSIs) for salmon at availability discharges

Site	Discharge (m^3/s)	Salmon 0-7 % useable			Salmon 8-20 % useable		
		Availability	Modelled	% difference	Availability	Modelled	% difference
Main	0.5	36%	38%	+6%	20%	21%	+5%
Main	0.24	43%	37%	-14%	24%	19%	-26%
Carrier	0.29	39%	34%	-12%	36%	25%	-30%
Carrier	0.15	33%	38%	+15%	17%	19%	+11%

In each case, the PHABSIM model did much better at representing the habitat for the lower discharge. On the carrier, in particular failure was due to a lack of deep water in the PHABSIM reach. This may in turn be related to:

- problems obtaining a satisfactory model stage-discharge relationship,
- possible errors in ascribing a discharge to the flow when habitat availability was measured,

- a failure in the habitat mapping (which was undertaken at a low discharge) to identify adequately deeper areas of water on the carrier. In particular, it is thought that as discharge increases, weed growth and marginal vegetation caused a more rapid increase in depth in parts of the channel that were already deep.

Again on the main site, the high habitat availability discharge data were collected in early summer (May 2000), while the high flow PHABSIM calibration discharge was collected in October. It is likely that the patterns of vegetation growth were significantly different at these times of year.

The results for substrate (Table 6.26) indicate that there was a significant difference between PHABSIM reach and sector, for both sites. In particular, in the PHABSIM reach, cobble was inadequately represented and silt over-represented.

Table 6.26: River Frome: proportions of substrate in PHABSIM reach and sector

	Main channel		Carrier	
Category	**PHABSIM**	**Availability**	**PHABSIM**	**Availability**
Silt	41%	30%	34%	24%
Sand	1%	3%	4%	3%
Fine Gravel	22%	15%	16%	6%
Coarse Gravel	34%	35%	44%	36%
Fine Cobble	3%	13%	1%	26%
Coarse Cobble	0%	3%	0%	5%

6.3 Discussion

6.3.1 Introduction

A toolbox of techniques has been developed to provide a simple numerical assessment of the hydraulic capabilities of the PHABSIM hydraulic model. In particular, this study used these techniques to assess the ability of a PHABSIM representative reach to describe, over a range of discharges the physical habitat over a broader river sector.

Assessments have also been made of the calibrations of the PHABSIM models by comparison to the calibration data, and where available, to velocity data not used in the calibration process. Results for this element of verification have shown that for the upland sites surveyed, it was possible to produce acceptable calibrations of the PHABSIM models. On the Chalk stream sites, results were more variable, calibrations were acceptable on the River Piddle, but only partially acceptable on the South Winterbourne sites.

PHABSIM model results were compared with the sector-scale measurements of habitat availability, both in terms of raw hydraulic variables (depth and velocity) and calculated physical habitat for salmon. A test, based on chi-squared comparison of modelled and measured data was used. This test is informative and has great potential to be useful as a model calibration tool, but it was felt that this should not be used in this context to give definitive probability values for any hypothesis concerning modelled and measured data.

For the calculated habitat comparisons, no direct significance test was available, instead it was preferable to rely on judgement, considering the steepness of the physical habitat-discharge relationship from PHABSIM itself. In several cases, these comparisons suggest that the hydraulic conditions that cause test failure are not important for calculated habitat, although this is not always the case. Table 6.27 summarises these results.

Table 6.27: All sites: summary of results.

River	Hydraulic conparison	Habitat comparison	Notes on further issues to be examined
Walkham	Model worked best at low discharges	Differences acceptable	Specific: low flow calibration General: low depth / high velocity modelling
Senni	Model worked best at intermediate discharges	Differences acceptable	Low flow calibration
Piddle	Model worked best at low discharges	Differences acceptable at low discharges	PHABSIM site does not represent sector at high discharges
South Winterbourne	Considerable problems with model	Differences acceptable at low discharges	Weed growth and mapping

The following issues have been raised through more detailed examination of the validation data.

6.3.2 Discharge measurement and survey

It is worth re-stating that probably the most important factor influencing the quality of PHABSIM output data is quality of PHABSIM input data. Of particular importance are accurately ascribing a discharge to a PHABSIM dataset: it cannot be stressed too highly that it is wise to consider discharge measurement independently of PHABSIM cross section current metering. If PHABSIM habitat transects happen to be suitable for gauging then they may be used, otherwise suitable gauging sections should be used. Measurement of water surface levels will always be problematic in turbulent water and when the water level varies across the cross section: this was experienced on the Senni and Walkham and also on the Piddle. If this occurs, it is vital to make field notes as to the likely best water level to use when PHABSIM modelling.

This project has relied on accurate estimation of discharge during the habitat availability surveys, discrepancies here could be a cause of error.

Finally it should be re-stated that significant extrapolation of PHABSIM model results is un-desirable. In practice, extrapolation has to happen as it is often not possible to collect the desired range of discharges. The problem is most acute for velocity modelling in transects with shallow gradient banks.

6.3.3 PHABSIM velocity modelling

This topic can be divided into firstly model calibration and extrapolation issues, and secondly issues related to the basic workings of the PHABSIM velocity model.

Model extrapolation at high / low flows
The results from the River Senni, and to some extent the Walkham highlight problems that can occur when extrapolating velocity distributions beyond the low and high calibration velocity sets.

Previous experience had highlighted that care had to be taken when modelling higher than the high calibration set in order to ensure sensible velocities at points which were dry at the calibration discharge. This may be done by careful inspection of the model output, and the manual editing of cell 'n' values.

However, by comparison with independent habitat availability data, this work has shown that while it is possible for a model to be valid at an intermediate discharge, this is not necessarily the case at low discharges. This is thought to arise because of the reverse of the high flow process outlined above. The effect is only apparent in V-shaped cross sections where as discharge falls, water concentrates in a narrower part of the channel. The model cells that are close to the new water's edge will have roughness values which do not account for edge effects, and consequently, modelled velocities, without manual adjustment, will be too high.

Another reason for velocity errors at higher discharges arises when cross-section velocity profiles are uneven due to upstream obstructions, such as weed or boulders. Accurate simulation of higher discharges can be assisted by manual assignment of 'n' values to mid-channel points of low velocity. However this is often not realistic if discharge is much higher than the calibration discharge.

Assumptions of the velocity modelling process
Finally the process that PHABSIM uses to model velocities and ensure mass balance is often defeated by shallow, fast flowing water and deep, slow flowing water. The logical

way around this is to use as much velocity calibration data as possible, spanning as much of the flow regime as possible.

6.3.4 Capability of habitat mapping and habitat representation in Chalk streams

This study has highlighted the limitations of existing habitat mapping procedures in chalk streams. This is highlighted by experiences in this project that there are subtle changes in topography, in both longitudinal and transverse directions which influence habitat availability, but which are not picked up by existing techniques. This may in part be related to the fact that historically, chalk streams have been subjected to piecemeal artificial channel alterations. It may be that without improved habitat mapping procedures, chalk streams may need more cross sections than more diverse upland streams.

Another issue is that in chalk streams, often long sections are subject to channel control: where there are subtle changes in hydraulic control with discharge. In upland streams hydraulic controls are often clearer and the processes simpler.

A further issue is that when in the field it is proving difficult to select a perfect representative reach, a decision can be made to chose a reach that is representative for an acceptable portion of the low flow regime, but that may not be adequate for habitat modelling at high discharges. This is the situation encountered on the River Piddle.

Thus in some more demanding circumstances it may be that a representative reach approach is never going to be acceptable unless the complete reach is characterised. Perhaps under these conditions the only way to model a representative reach from a hydraulics perspective is to measure it in its entirety and use a 2D/3D hydraulic approach.

6.3.5 Weed growth in Chalk streams

Results from the South Winterbourne have indicated that seasonal weed growth can cause a valid model to be invalid for un-measured discharge / weed growth conditions. Commonly in Chalk streams, hydraulic roughness increases significantly as discharge drops during the year.

PHABSIM water surface modelling can cope with this, however it cannot cope with a complete reversal of the stage-discharge relationship where discharge falls yet water level rises. This is a particular issue on carrier channels whose discharge is determined by sluices, but can also be important on main river channels. An example of this had been at the River Piddle site, where the greatest discrepancy was noticed for the occasion for the set of availability data which were collected in the year following the PHABSIM calibration data.

It is worth noting that the problems experienced may be in part related to the sites surveyed and the discharges experienced. Other recent work (Dangerfield, 2000) on the River Kennet at Manton has suggested that with a clear downstream hydraulic control and four sets of PHABSIM calibration data (collected at specific times of year), it was possible to model water levels as macrophytes grew and then declined.

Previous work (Hearne *et al.* 1994) proposed an algorithm for improving the accuracy of PHABSIM water surface models in weedy channels. This requires the collection of data at varying levels of both discharge and weed growth and the construction of a composite function relating roughness both to discharge and macrophyte biomass ($n_i=f(b_i,Q)$, where i represents individual transects). Unfortunately, there are a number of practical issues that they do not consider:

- The number of different surveys required in theory, and the practicality of obtaining them in a reasonable time frame
- The requirement to measure biomass, this is not easy, there is often no clear relationship between surface cover and macrophyte biomass
- The requirement for modifications to the PHABSIM hydraulic models to handle such a composite function
- Issues surrounding the effects of macrophyte growth on velocity
- For time series analysis, the requirement have historical or modelled time series of macrophyte biomass for the procedure to work.

It is thus not immediately obvious how the work of Hearne *et al.* can be used in an operational context without considerable effort, and whether the detail required would provide sufficient accuracy.

Another option is to adopt a far more simple approach to chalk stream habitat hydraulics, however such approaches could be in danger of being even more empirical than PHABSIM. The fact noted above that most chalk streams are historically engineered channels means that whatever approach to determine their instream flows is adopted in the future, it must be based around some numerical consideration of channel form / hydraulics.

7. ASSESSING THE RELATIONSHIP BETWEEN PHYSICAL HABITAT AND POPULATION DATA

7.1 Overview

As noted in Section 4.1 there are many factors that control the population of salmonids, with physical habitat being just one. It was never intended that PHABSIM predictions of physical habitat would in themselves determine population levels in a river. Thus comparisons of fish population data and physical habitat (measured by WUA) time series should not be used as a test of PHABSIM performance (unless it could be shown, perhaps experimentally, that all factors apart from flow have remained constant over the period of record). Indeed, the concept behind the method is to isolate out the impacts of changing flow regime, from amongst the impacts of other factors. However, some researchers have discovered relationships between WUA and species occurrence or density. For example, Gore *et al* (1998) found a significant correlation between PHABSIM based predictions of habitat and actual benthic community diversity in a river rehabilitation project involving the addition of artificial riffles. Gallgher and Gard (1999) found that WUA was significantly correlated with spawning density of chinook salmon. Jowett (1992) demonstrated that in a large multi-river dataset, modelled WUA expained most variation in brown trout abundance.

Whilst it is not intended as a test of the utility of WUA outputs, it was felt that some investigations of the relationships between WUA time series and fish population data would be interesting, as these would indicate that physical habitat was a major controlling variable in the rivers under study.

As documented in the previous section, PHABSIM models were calibrated for the River Walkham at Ward Bridge, the South Winterbourne Carrier at West Stafford and the Senni at Abersenny. In each case, the PHABSIM habitat model was run using both river-type and generic HSIs. Flow time series were generated for the sites using regression relationship between gauged flows and site spot gaugings.

Fish population data were obtained from the Environment Agency by CEH Dorset. It should be noted that the only data available were given as fish densities. This will in turn be related to the area of river (in turn arising from the discharges) at the time of sampling. This can potentially bring a further level of uncertainty as river area itself varies with discharge.

7.2 Data collection / collation

7.2.1. River Walkham

Fish population data

Fish population data for two age classes of trout and salmon were obtained from the Environment Agency via CEH Dorset. The period covered is 1975 to 1998, with a total of nine years of discontinuous data. Densities are illustrated in Table 7.1. and Figure 7.1.

Table 7.1: Ward Bridge: fish densities

	1975	1976	1980	1983	1989	1992	1995	1996	1998
Salmon 0+	0.0	0.0	3.6	92.7	122.1	19.5	167.2	81.9	56.0
Salmon 1+	2.2	2.2	6.8	37.3	24.1	11.7	17.3	18.2	19.1
Trout 0+	0.3	0.0	7.9	35.7	8.4	5.7	25.3	13.5	15.5
Trout 1+	4.5	3.9	7.2	26.1	13.9	9.4	12.2	9.0	8.0

Densities expressed as n/100m²

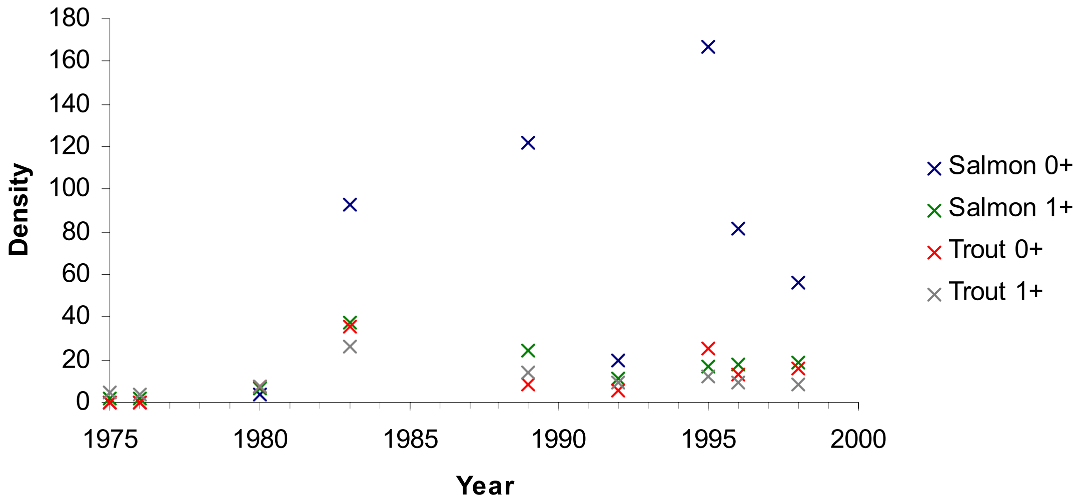


Figure 7.1: Ward Bridge: fish densities between 1975 and 1998.

Discharge data

Historical daily mean flow data have been obtained from the Environment Agency's gauging station at Horrabridge via the National Water Archive (Reference 47014). The period of record is 1976-present. These flows have been transferred to the Ward Bridge site using a regression relationship obtained from spot gauging records, as illustrated in Figure 7.2:

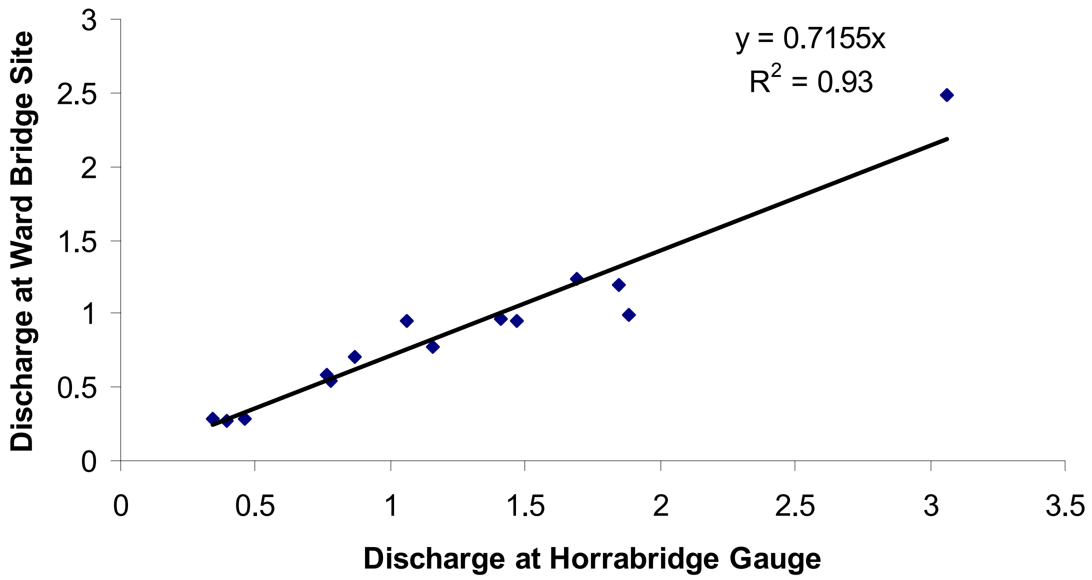


Figure 7.2: Regression relationship between discharge at Horrabridge (continuously-gauged) and at Ward Bridge (spot-gaugings)

PHABSIM data

Collection of PHABSIM data, and PHABSIM hydraulic modelling has already been described under Section 5 above. For the purposes of Objective 3, data from the PHABSIM hydraulic model were combined with the HSIs developed as part of this study, to produce relationships between weighted usable area and flow for each of the four target life stages considered.

7.2.2 River Senni

Fish population data

Fish population data for two age classes of trout and salmon were obtained from the Environment Agency. The period covered is 1975 to 1998, with a total of nine years of discontinuous data. Densities are illustrated in Table 7.2. and Figure 7.3.

Table 7.2: Senni at Abersenny: fish densities

Date	Salmon 0+	Salmon >0+	Trout 0+	Trout > 0+
04/08/1986	1	3.4	0.8	2.6
15/07/1987	31	9.8	7.3	7.5
20/08/1988	8.9	9.7	11.3	3.3
11/07/1989	18.4	4.7	0.9	7.4
23/07/1990	51.7	7.8	1.3	4.8
30/07/1991	12.1	13.4	2.8	4.3
05/07/1993	0.9	9.6	2	8.5
25/08/1994	96.7	7.5	8.9	6.1
05/09/1995	76.9	17.6	5.1	10
06/08/1996	55.9	6.4	13.5	2.36

Densities expressed as n/100m²

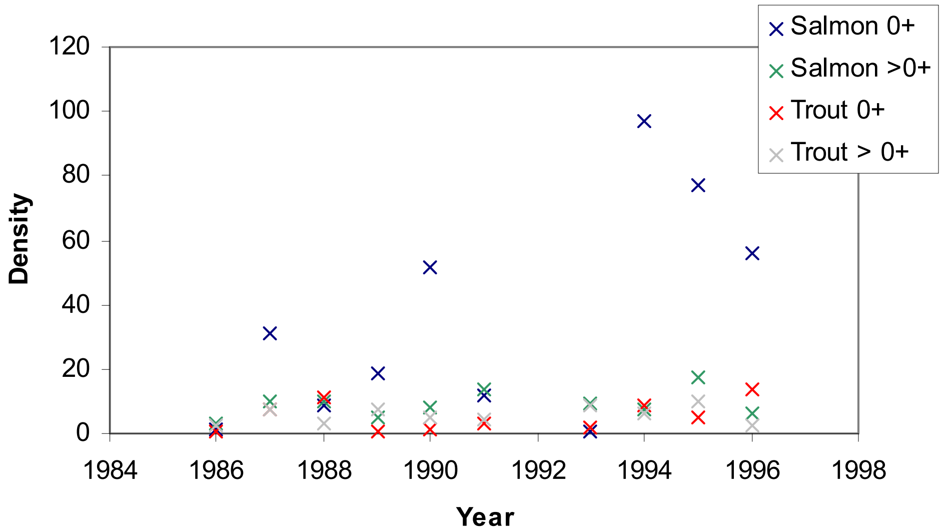


Figure 7.3: Senni: fish densities between 1986 and 1996.

Discharge data

Historical daily mean flow data were obtained from the Environment Agency's gauging station at Pont-hen-Haford via the National Water Archive. The period of record is 1980-present. These flows were transferred to the Abersenny site using a linear regression relationship obtained from spot gauging records, as illustrated in Figure 7.4:

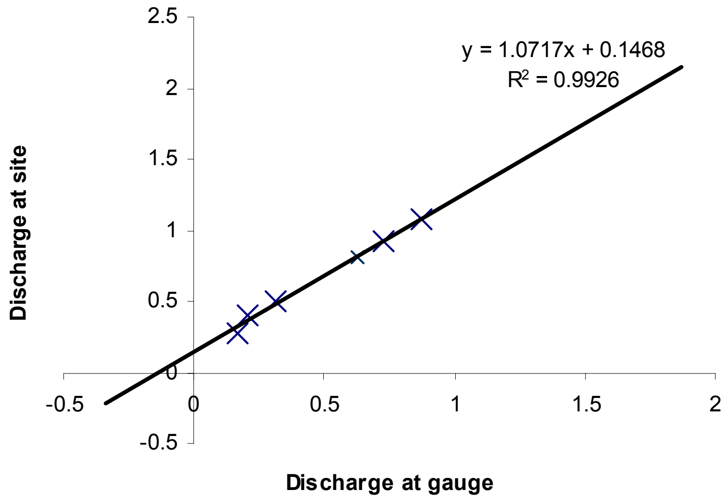


Figure 7.4: Regression relationship between discharge at Pont-hen-Hafod (continuously-gauged) and at Abersenny (spot-gaugings)

PHABSIM data

Collection of PHABSIM data, and PHABSIM hydraulic modelling has already been described under Section 5 above. For the purposes of Objective 3, data from the PHABSIM hydraulic model were combined with the HSIs developed as part of this study, to produce relationships between weighted usable area and flow for each of the four target life stages considered.

7.2.3 Carrier at West Stafford

There were serious problems in creating a valid PHABSIM hydraulic model for this site, as documented in Section 5. For this reason, plus the fact that there were only five years of fish population data available (Table 7.3), comparison of habitat and fish densities for this site would not be productive.

Table 7.3: South Winterbourne Carrier: historical fish densities

Year	Salmon 0+	Salmon 1+	Salmon>1+	Trout 0+	Trout 1+	Trout>1+
1988	7.24	0.59	0	19.35	1.03	0.3
1989	1.86	0	0	5.4	1.17	1.17
1990	36.05	0	0	7.36	0.39	2.03
1991	24.7	0	0	5.24	3.05	1.22
1992	19.16	2.4	0	5.79	4.39	0.6

7.3 Analytical Approach

The main approach adopted to fulfil this objective has been to hindcast values of physical habitat back throughout the period of record for the fish population data. For each target life stage, times series of annual aggregate indices of physical habitat were be constructed, of the following form:

- mean value in months preceding fish survey (summer and year-round),
- duration under various thresholds (summer and year round),
- minimum value in months preceding fish survey.

7.4 Results

In general, virtually all the simple indices of physical habitat showed no relationship with fish densities. Examples of the results obtained are illustrated in Figures 7.5 and 7.6.

For the River Walkham site, probably the only exception to this was that there was some relationship between the minimum summer monthly mean physical habitat value for the 0-7cm size class and the density of 8-20cm fish the following summer. In this case, the relationship is strongly influenced by two outlying points, and given the general lack of available data, there is little that can be satisfactorily concluded from this work. Results using the generic HSI curves based on preference were less promising than those using the “river type” or catchment-specific HSI curves based on habitat use.

Given the multitude of factors that can affect fish densities (particularly for anadromous fish such as salmon, and sea trout, it is perhaps not surprising that no obvious correlations have been obtained from a simplistic approach such as this. It is also clear that routine fish population monitoring data are not collected and stored in a form that is useful for determining if such relationships do exist.

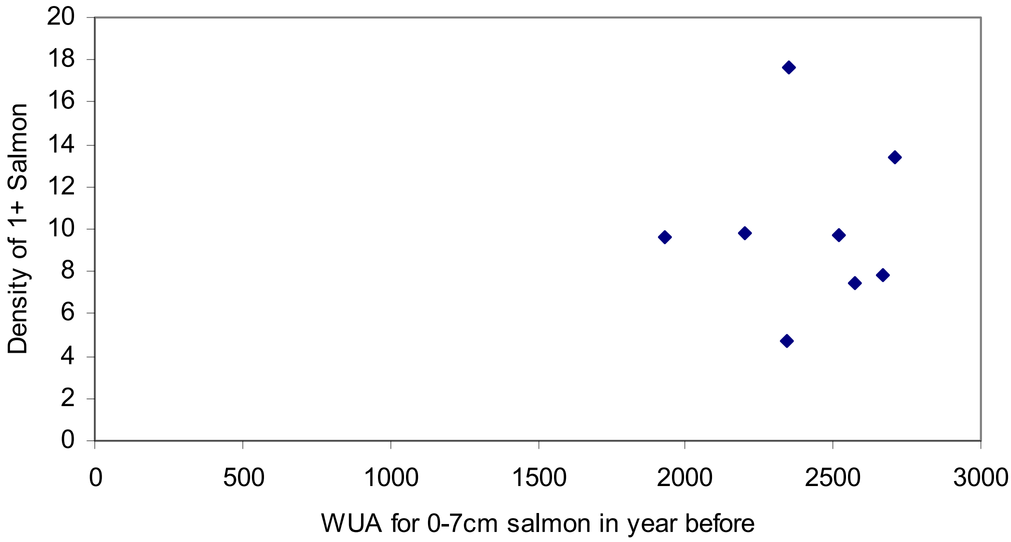


Figure 7.5: River Senni: example relationship between physical habitat and discharge

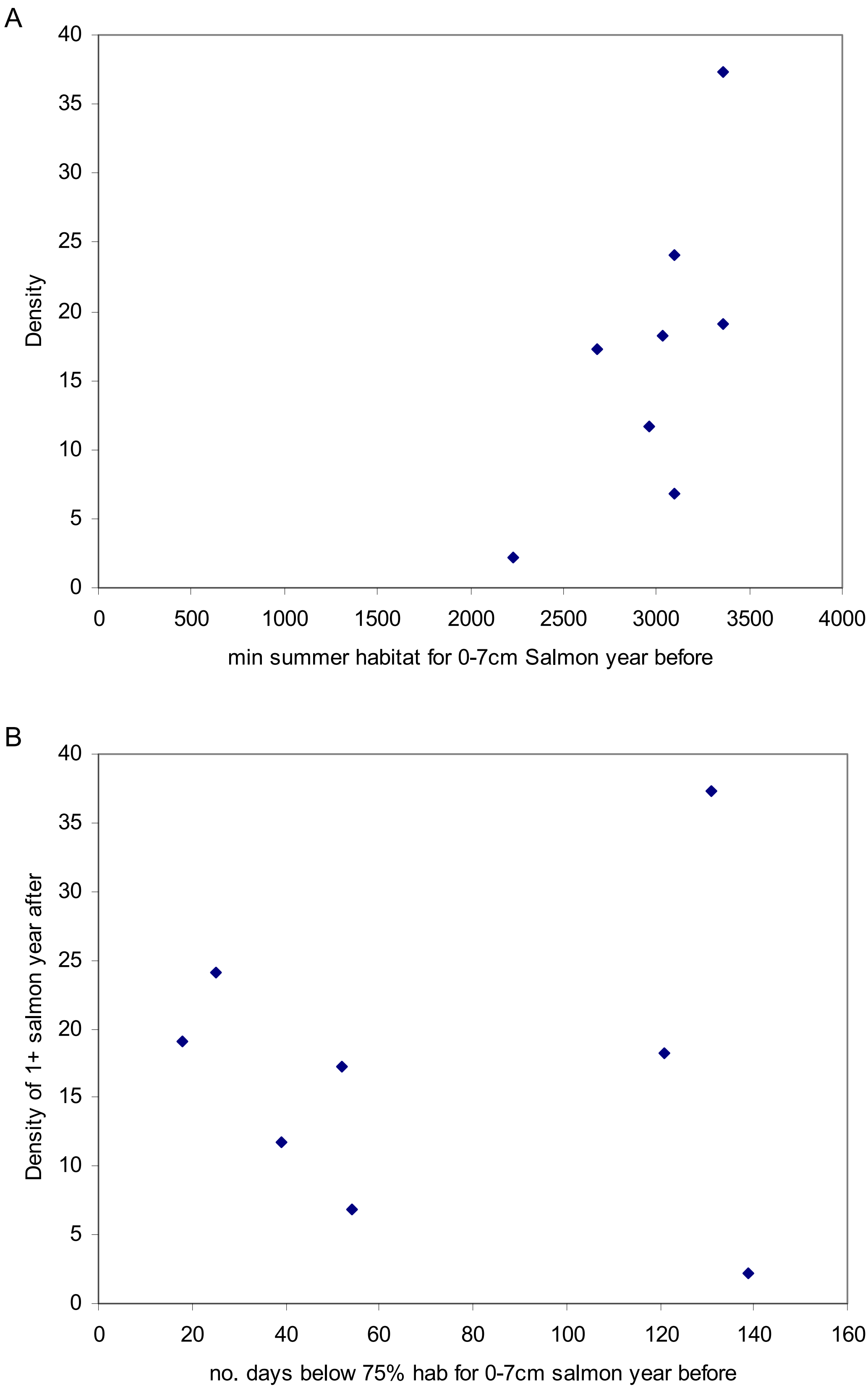


Figure 7.6: River Walkham: relationships between physical habitat and discharge

8. CONCLUSIONS

8.1 Evaluation of HSIs

Of the variables that we were able to test, study area had the greatest effect on the habitat used by salmon and trout juveniles. Habitat use was different between all the study areas. This reflected the difference in the habitat available in each of the study areas, particularly in the case of depth and indicated a strong influence on habitat use by habitat availability. Of the other factors size group and species also had significant effects, size group being more important than species. That is salmon between the sizes of 8 and 20 cm were more similar to trout in the same size group in their habitat use than to salmon less than 8 cm in length.

Within study areas, both site and season had strong influences on the habitat used by salmon and trout juveniles. Again this reflected the influence of habitat availability that varied between sites and changed within sites at different times of year due to differing discharge levels and growth of weed stands. These observations establish a principle that the shape of HSIs based on habitat use are heavily biased by when and where the data are collected and the habitat available at the time. The variation in habitat available in each site and over changing seasons, together with the expense and often impracticality of collecting data leads us to conclude that site-specific HSIs based on habitat use are not the most appropriate way forward.

There are a wide range of variables that have been shown in this and other studies to affect the habitat use, by juvenile salmon and trout. To take account of these influences in defining river types, it would be necessary to place rivers into groups with similar characteristics across the list of influences. Even if you only consider 6 of these influences to be important in defining habitat use and you only attribute 2 levels to each of those 6 influences, it would require there to be 2^6 groups of rivers for which it would be necessary to develop specific HSIs. In truth the situation is much worse than this as most of the influences would have many more than 2 levels. For example, even our attempt to place rivers into two types based on channel form failed suggesting there may be many levels for the influence of availability.

Despite the influence of availability, selection was shown to influence habitat use. Apart from the lowest velocity class for small trout for which there was the least amount of data there was good consistency in the preference for depths and velocities across study areas. Although not identical, their rough shape was similar, they lay within the confidence intervals of each other and they tended to peak in the same depth and velocity classes.

Therefore we suggest that HSIs should be treated as reflecting an unspecified biological response curve, which is stable between rivers. This is given further strength by demonstrating that the preferential use of habitat is more consistent between study areas than habitat use is between study areas. We conclude that the best approach to developing HSIs would be to use generic HSIs based on good quality, habitat preference data from a wide range of rivers. A great advantage of this approach, rarely mentioned elsewhere, is that generic HSIs are independent of any PHABSIM application. Site specific HSIs are not independent of the PHABSIM application. That is they are developed on site under particular discharge conditions and these will determine the shape of the HSI. This report presents good evidence for this in the change in habitat use as habitat availability changes with season. This discharge dependent HSI is not an independent assessment of the WUA/discharge relationship. Conversely the generic HSI makes an assessment of habitat quality independently of the study, affording much greater confidence in the WUA/discharge relationship.

With the quality of data we have for juvenile salmon and trout these generic HSIs should not be binary in shape but as far as is practical should assign varying values to different depth classes of depth and velocity. The same principles for developing generic HSIs should apply to other life stages and species.

Using a combination of preferential habitat use and observed habitat use both from this study and other published studies we have derived generic HSIs for two size groups of salmon and trout juveniles (Figures 4.28 and 4.29). These should be applied in future PHABSIM applications in England and Wales under the following boundary conditions.

- In time series analysis these generic HSIs should not be used outside the period May to September and
- neither should it be applied in cold climates (<12^{o}C) as habitat use by these fish is very temperature sensitive.

The level of uncertainty about these HSIs has not yet been properly quantified. Uncertainty and risk have become more important recently in the management of eco-systems and therefore it should form part of future applications of PHABSIM beginning with the proper estimation of uncertainty around the current generic HSIs. Once this has been quantified any work required to reduce it, especially at the upper limits of the HSIs i.e. for deep and fast flowing water. However, we are currently able to make some suggestions as to the likely shape of the HSIs across the complete range of depths and velocities.

Periodically, the shape and uncertainty of the generic HSIs should be updated and definitive versions maintained at CEH Dorset.

We have concluded that once the value of habitat suitability reaches 1 for depth all deeper water should be given the same suitability as our study appeared to show an increasing preferential habitat use with increasing depth. Operationally, in the application of PHABSIM in UK, the exact shape of this HSI in greater depths may not be important as the number of rivers containing large amounts of deep water are quite rare. However, because the likely relationship with depth may be predator related in the case of these small fish it is suggested that a cover criteria is added so that depths beyond 0.6m are considered useless unless there is sufficient cover within 0.5m.

PHABSIM currently treats depth and velocity separately. Clearly, the habitats experienced by fish consist of a mixture of a large number of variables, each of which interacts with the others to produce habitat quality. To treat each of these separately and to ignore others is biologically unrealistic and the development of multi-variate indices needs to be considered. Such indices may also need to consider weighting varying importance to the variables used. This study indicate for example that the use of depth may have been largely incidental and thus of not much importance to defining habitat quality.

We conclude that this may be an opportune moment to review current and possible future techniques for incorporating ecological data into water resource planning. This would consider current techniques for resolving habitat modification issues in other ecological disciplines, the type of ecological data that could be collected even if it is not available presently and take account of current abilities in hydraulic modelling. This would complement and balance recent reviews on setting River Flow Objectives

8.2 Testing of PHABSIM Hydraulics

A toolbox of techniques has been developed to provide a simple statistical assessment of the hydraulic capabilities of the PHABSIM model. In particular, this study used these techniques to assess the ability of a PHABSIM representative reach to describe, over a range of discharges the physical habitat over a broader river sector. Assessments have also been made of the calibrations of the PHABSIM models by comparison to the calibration data, and where available, to velocity data not used in the calibration process.

Results have shown that for the upland sites surveyed, it was generally possible to produce acceptable calibrations of the PHABSIM models. On the Chalk stream sites, results were more variable, calibrations were acceptable on the River Piddle, but only partially acceptable on the South Winterbourne sites.

For the hydraulic comparisons, on the Piddle, none of the tests were passed. On the other rivers, some of the tests passed, some failed, with no river passing all tests. For the calculated habitat comparisons, no suitable statistical significance test was available, instead it was preferable to rely on judgment, considering the steepness of the physical habitat-discharge relationship from PHABSIM itself. In several cases, these comparisons suggest that the hydraulic conditions that cause test failure are not important for calculated habitat, although this is not always the case.

The following issues have been raised through more detailed examination of the validation failures:

Discharge measurement and survey
The most important factor influencing the quality of PHABSIM output data is quality of PHABSIM input data. Of particular importance are accurately ascribing a discharge to a PHABSIM dataset: it cannot be stressed too highly that it is wise to consider discharge measurement independently of PHABSIM cross section current metering. If PHABSIM habitat transects happen to be suitable for gauging then they may be used, otherwise suitable gauging sections should be used. Measurement of water surface levels will always be problematic in turbulent water and when the water level varies across the cross section. If this occurs, it is vital to make field notes as to the likely best water level to use when PHABSIM modelling.

Finally it should be re-stated that significant extrapolation of PHABSIM model results is un-desirable. In practice, extrapolation is commonly necessary as it is often not possible to collect the desired range of discharges. The problem is most acute for velocity modelling in transects with shallow gradient banks.

PHABSIM velocity modelling

Model extrapolation at high / low flows
The results from the River Senni, and to some extent the Walkham highlight problems that can occur when extrapolating velocity distributions beyond the low and high calibration velocity sets.

Previous experience had highlighted that care had to be taken when modelling higher than the high calibration set in order to ensure sensible velocities at points which were dry at the calibration discharge. However, by comparison with independent habitat availability data, this work has shown that while it is possible for a model to be valid at an intermediate discharge, this is not necessarily the case at low discharges. This is thought to arise because of the reverse of the high flow process outlined above. The effect is only apparent in V-shaped cross sections where as discharge falls, water concentrates in a narrower part of the channel. The model cells that are close to the new water’s edge will have roughness values which do not account for edge effects, and consequently, modelled velocities, without manual adjustment, will be too high.

Another reason for velocity errors at higher discharges arises when cross-section velocity profiles are uneven due to upstream obstructions, such as weed or boulders. Accurate simulation of higher discharges can be assisted by manual assignment of 'n' values to mid-channel points of low velocity. However this is often not realistic if discharge is much higher than the calibration discharge.

Assumptions of the velocity modelling process

Finally the process that PHABSIM uses to model velocities and ensure mass balance is often defeated by shallow, fast flowing water and deep, slow flowing water. The logical way around this is to use as much velocity calibration data as possible, spanning as much of the flow regime as possible. As particular problems exist in steep upland streams with exposed substrates, it is worthwhile investigating alternative methods for quantifying the physical habitat in these situations. Such approaches will need to be able to demonstrate the same robustness as the PHABSIM procedure, particularly with regards to showing a demonstrable link to fish habitat preference, and in quantifying that habitat across a range of discharges.

Capability of habitat mapping and habitat representation in Chalk streams

This study has highlighted the limitations of existing habitat mapping procedures in chalk streams. There are often subtle differences changes in topography, in both longitudinal and transverse directions which influence habitat availability, but which are not picked up by existing techniques. This may in part be related to the fact that historically, chalk streams have been subjected to piecemeal artificial channel alterations. It may be that without improved habitat mapping procedures, chalk streams may need more cross sections than more diverse upland streams.

Another issue is that in chalk streams, often long sections are subject to channel control: where there are subtle changes in hydraulic control with discharge. In upland streams hydraulic controls are often clearer and the processes simpler.

Thus in some more demanding circumstances it may be that a representative reach approach is never going to be acceptable unless the complete reach is characterised. Perhaps under these conditions the only way to model a representative reach from a hydraulics perspective is to measure it in its entirety and use a 2D/3D hydraulic approach.

Weed growth in Chalk streams

Seasonal weed growth can cause a valid model to be invalid for un-measured discharge / weed growth conditions. Commonly in Chalk streams, hydraulic roughness increases significantly as discharge drops during the year. PHABSIM water surface modelling can cope with this, however it cannot cope with a complete reversal of the stage-discharge relationship where discharge falls yet water level rises. This is a particular issue on carrier channels whose discharge is determined by sluices, but can also be important on main river channels. The procedures covered in Hearne *et al.* (1994) are potentially time

Another option is to adopt a far more simple approach to chalk stream habitat hydraulics, however such approaches could be in danger of being even more empirical than PHABSIM. The fact noted above that most chalk streams are historically engineered channels means that whatever approach to determine their instream flows is adopted in the future, it must be based around some numerical consideration of channel form / hydraulics / macrophyte growth.

8.3. Relationships between Physical Habitat and Population Data

As this study progressed, it became clear that to fulfil completely all three objectives of the project would be impossible. In particular, sites with good long-term time series of gauged flows and fish population data were very difficult to find. Thus sites had to be chosen to give the best chance of fulfilling the project objectives as a whole, and the data to fulfil objective three were less than ideal. In general this re-emphasises the point that demonstrating such relationships with routine monitoring data, expressed as density per unit area, is virtually impossible. The results from this simplistic analysis should not be viewed as surprising given the multitude of factors other than physical habitat that can affect anadromous fish densities.

In some cases (e.g. Jowett, 1992, Nehring, 1993, Railsback, 1993, Capra, 1995, Sabaton, 2002), relationships have been demonstrated which show the benefit of indexing physical habitat rather than discharge alone. However, those studies all involved targeted fish data collection across a large range of sites and multiple years, something that was not possible in this study.

It should be re-emphasised that demonstrating links between physical habitat and population will require more sophisticated analysis techniques, and either large field data sets or controlled experiments, for example in experimental channels.

9. RECOMMENDATIONS

Application of PHABSIM hydraulic models

1. In diverse rocky upland streams it is essential to collect at least two velocity sets (high and low), and to use the low velocity set for low flow modelling.
2. The recommended velocity modelling approach in all chalk and upland streams is to collect and use three velocity sets
3. In diverse rocky upland streams, for riffle and other channels with shallow banks, extrapolation down should not go beyond 0.9 times the lowest measured discharge.

Application of HSIs

1. HSIs should be treated and developed as though they were biological response curves. Generic HSIs are preferred over site specific and river type HSIs. This principle should be adopted wherever possible for all other life-stages and species. Those developed in this study for juvenile trout and salmon should be applied in future PHABSIM applications in England and Wales under the following boundary conditions.
   - In time series analysis these generic HSIs should not be used outside the period May to September and neither should it be applied in cold climates (<12°C) as habitat use by these fish is very temperature sensitive.
   - Where there is deep water (> 70 cm) the HSIs produced in this report for depth must have a cover criteria attached so that the habitat is counted as zero unless adequate cover is available to the fish within 50 cm.

2. There should be efforts to quantify and improve the level of uncertainty in the shape of the generic HSIs in preference to efforts to develop new site-specific or regional HSIs.

3. Periodic review (every 3 years) of the state-of-the-art HSIs for brown trout and salmon should be undertaken to incorporate additional data collection on these species. The first of these could represent a proper quantification of the uncertainty in the shape of the generic HSIs as described in 2 above. Updated and definitive versions should be maintained at CEH Dorset.

Future research

Issues of particular international (European) interest

1. Further quantification of uncertainty in habitat mapping and hydraulic sampling strategies, and comparison of hydraulic sampling strategies at a range of scales.

This should be undertaken against a definitive high-intensity spatial dataset of river morphology / velocity.

2. The quantification of uncertainty in the shape of the generic HSIs produced in this report. This should lead to a work programme for reducing this uncertainty, especially under deep water and fast flowing conditions.
3. A protocol should be developed to link uncertainty in HSIs and habitat typology to final WUA vs discharge output.
4. For upland streams: guidance materials should be produced on hydraulic modelling strategies, particularly comprising photographs at different flows, linked to diagrams etc.
5. For high gradient, rocky upland streams: investigation of alternative descriptions of habitat such as surface flow biotopes, which are less reliant on conventional hydraulic modelling.
6. More detailed investigation of the impact of spatially and temporally-varying hydrology on river communities. This should include work on selecting key flow indices, and also further controlled experimental investigation of physical habitat / population links.

Issues of particular interest for England and Wales

7. Further development of habitat classification / mapping on Chalk streams
8. Investigation of alternative habitat-hydraulic methods for Chalk streams, which can more explicitly take account of macrophyte growth
9. There should be a review of current and possible future techniques for incorporating ecological data into water resource planning. This would consider current techniques for resolving habitat modification issues in all other ecological disciplines, the type of ecological data that could be collected even if it is not available presently and take account of current abilities in hydraulic modelling.

Issues relating to software design

10. The treatment of HSIs within PHABSIM should be improved to take account of the varying importance of each variable, a greater number of variables and the interactions between variables.
11. To achieve the above, a UK PHABSIM habitat model should be developed. This would also allow correct weighting of cross sections in habitat calculations, easy comparison with point hydraulic validation data, and compatibility with other hydraulic models such as ISIS.

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APPENDICES

APPENDIX A:
DATA COLLECTED ON FISH / HABITAT AVAILABILITY SURVEYS

A1. Devon study area

Table A1.1: Devon sites: details of nearby gauging stations

River	Gauge	Grid Reference	NRFA reference	Period	Gauge area (km²) / Mean flow / Q95 (m³/s) / BFI
Plym	Carn Wood	SX522613	47011	71-81	79.2 / 2.28 / 0.30 / 0.48
Walkham	Horrabridge	SX513699	47014	76-	44.6 / 1.75 / 0.33 / 0.59
W.Dart	Dunnabridge	SX643742	46007	72-	47.9 / 2.53 / 0.31 / 0.42

Table A1.2: Devon sites: survey dates

Site	Survey 1	Survey 2	Survey 3
Ward Bridge	21-23/6/99	26-28/7/99	5-8/10/99
Crockern Tor	1-18/6/99	28-30/7/99	6/10/99
Ham	15-17/6/99	3-5/8/99	7/10/99
Dewerstone	14-18/6/99	2-4/8/99	28/9/99
Overall	14-23/6/99	26/7-5/8/99	28/9-8/10/99

Table A1.3: Devon sites: number of fish observations collected on each survey

	Survey 1		Survey 2		Survey 3	
Site	Trout	Salmon	Trout	Salmon	Trout	Salmon
Ward Bridge	160	123	155	200	58	43
Crockern Tor	75	27	92	56	61	36
Ham	55	73	34	106	32	94
Dewerstone	138	26	67	41	78	37
Total	428	249	348	403	229	210

Table A1.4: Devon sites: Total length (m) of river snorkelled

Site	Survey 1	Survey 2	Survey 3
Ward Bridge	292	306	308
Ham	132	100	170
Crockern Tor	146	256	298
Dewerstone	488	103	148

Table A1.5: Devon Sites: Number of habitat availability points collected on all surveys

Site	Survey 1	Survey 2	Survey 3
Ward Bridge	303	216	298
Crockern Tor	195	149	185
Ham	110	135	188
Dewerstone	143	127	75
Total	751	627	746

Table A1.6: Devon sites: Total length (m) of river surveyed for habitat availability

Site	Survey 1	Survey 2	Survey 3
Ward Bridge	335	300	359
Ham	150	131	151
Crockern Tor	310	310	300
Dewerstone	300	300	150

Table A1.7: River Walkham: gauged flows during habitat surveys

Site	Date	First survey	Date	Second survey	Date	Third survey
Ward Bridge	22-23/6/99	0.871 (G) Q	26-28/7/99	0.469 (G) Q	5-8/10/99	1.80 (G) Q

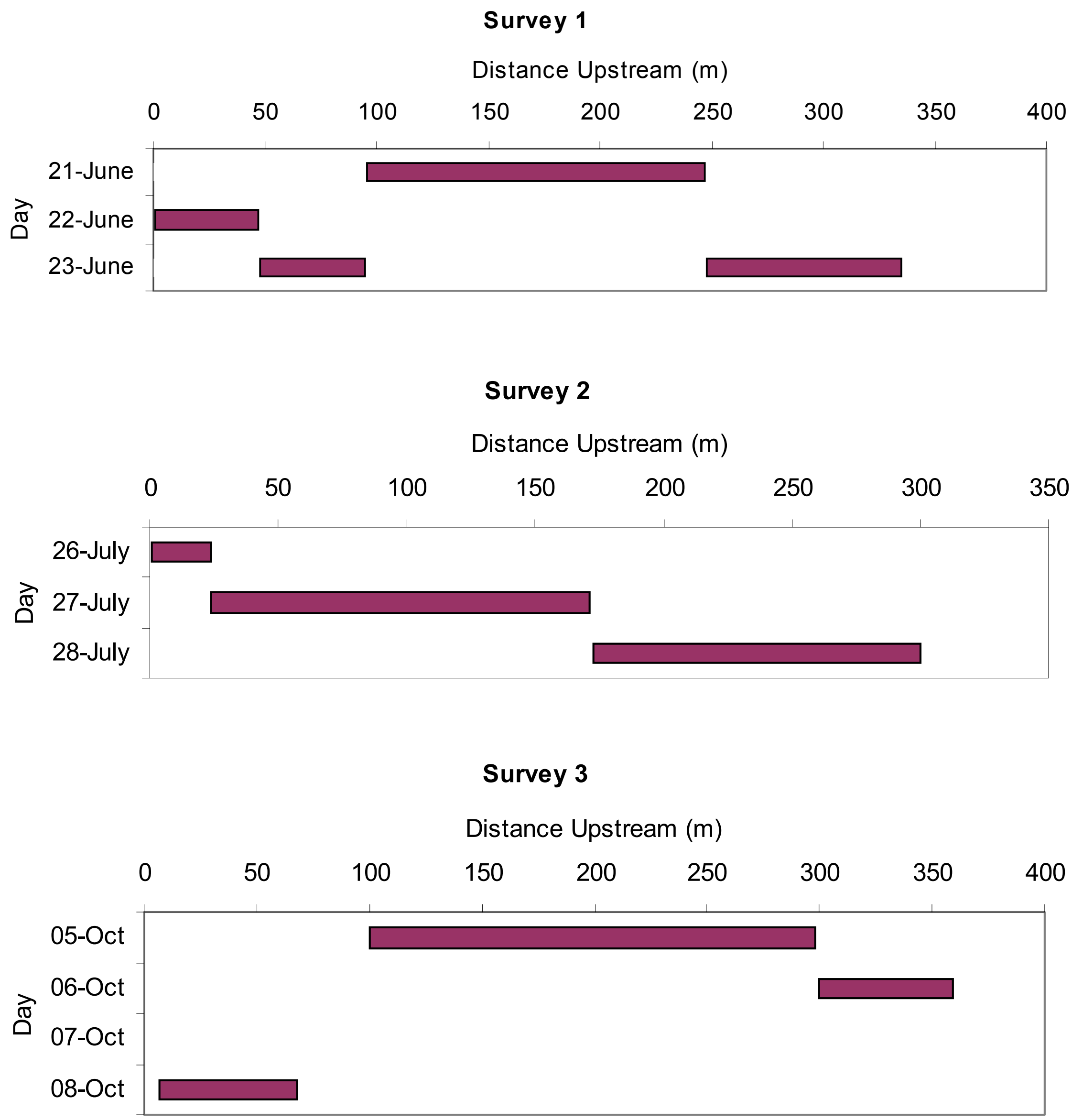


Figure A1.1: River Walkham: horizontal bar graphs of survey dates

A2. Piddle study area

Table A2.1: Piddle / Bere stream sites: details of nearby gauging stations

River	Gauge	NGR Gauge	NRFA Gauge ref	Gauge area / MF / Q95 / BFI
Piddle	Baggs Mill	SY913876	44002 63-	183.1 / 2.38 / 0.76 / 0.89
Piddle	Briantspuddle	SY82199347		116.6

Table A2.2: Piddle / Bere stream sites: survey dates

Site	Survey 1	Survey 2	Survey 3
Piddle Higher Hyde upstream	12-13/8/99	15-16/9/99	13-14/6/00
Piddle Higher Hyde downstream	10-17/8/99	13-17/9/99	5-14/6/00
Piddle Throop	16-18-/8/99	15-16/9/99	12/6/00
Bere Higher Hyde	10-12/8/99	13-15/9/99	5-7/6/00
Overall	10-18/8/99	13-17/9/99	5-14/6/00

Table A2.3: River Piddle / Bere stream: Number of fish observations collected on each survey

Site	Survey 1		Survey 2		Survey 3	
	Trout	Salmon	Trout	Salmon	Trout	Salmon
Piddle Higher Hyde upstream	85	81	66	112	124	145
Piddle Higher Hyde downstream	44	164	99	108	20	173
Piddle Throop	47	45	59	38	40	22
Bere Higher Hyde	75	68	65	82	140	57
Total	251	358	289	340	324	397

Table A2.4: Piddle / Bere stream sites: Total length (m) of river snorkelled.

Site	Survey 1	Survey 2	Survey 3
Piddle Higher Hyde upstream	197	213	233
Piddle Higher Hyde downstream	226	299	286
Piddle Throop	327	305	314
Bere Higher Hyde	345	346	339

Table A2.5: Piddle / Bere stream: Number of habitat availability points collected on all surveys

Site	Survey 1	Survey 2	Survey 3
Piddle Higher Hyde upstream	98	91	87
Piddle Higher Hyde downstream	435	546	560
Piddle Throop	129	124	134
Bere Higher Hyde	181	166	205

Table A2.6: Piddle / Bere stream sites: Total length (m) of river surveyed for habitat availability.

Site	Survey 1	Survey 2	Survey 3
Piddle Higher Hyde upstream	200	200	200
Piddle Higher Hyde downstream	260	260	260
Piddle Throop	318	318	318
Bere Higher Hyde	350	300	300

Table A2.7: River Piddle / Bere: Discharge measurements taken during habitat availability surveys

	Survey 1		Survey 2		Survey 3	
	Date	**Discharge**	**Date**	**Discharge**	**Date**	**Discharge**
Piddle Higher	11/8/99	0.906	21/9/99	1.229	5-9/6/00	2.094
Hyde	17/8/99	0.977			13-14/6/00	
Piddle Throop			16/9/99	0.227	12/6/00	1.391
Bere Higher Hyde	11/8/99	0.454			5-7/6/00	0.708

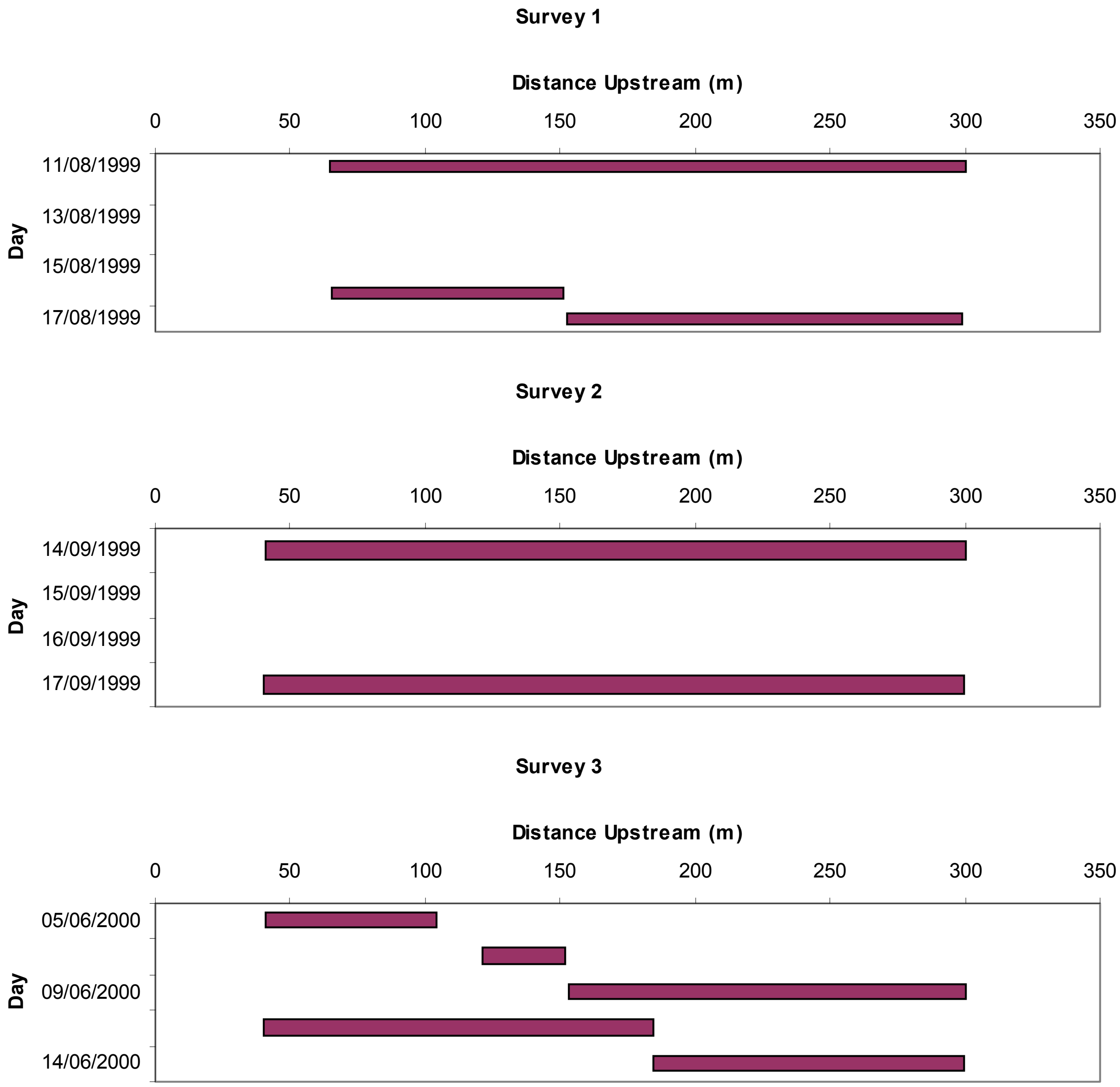


Figure A2.1: River Piddle Downstream: horizontal bar graphs of survey dates

A3. Wales study area

Table A3.1: Wales sites: details of nearby gauging stations.

River	*Gauge*	NGR Gauge	NRFA Gauge ref	Gauge area / MF / Q95 / BFI
Senni	Pont Hen Hafod	SN928255	56007 67-	19.9 / 1.00 / 0.1 / 0.37
Cilieni	None			
Yscir	Pontaryscir	SO003304	56013 72-	62.8 / 1.94 / 0.19 / 0.46

Table A3.2: Wales sites: survey dates

Site	Survey 1	Survey 2	Survey 3	Survey 4
Senni	20-24/6/00	31/7-5/8-/8/00	11-13/9/00	16-17/10/00
Yscir	24/6/00	3-6/8/00		
Cilieni	20-25/6/00	2-4/8/00	11-12/9/00	17-18/10/00
Overall	20-25/6/00	31/7/00-6/8/00	11-13/9/00	16-18/10/00

Table A3.3: Wales sites: number of fish observations collected on each survey

	Survey 1		Survey 2		Survey 3		Survey 4	
Site	Trout	Salmon	Trout	Salmon	Trout	Salmon	Trout	Salmon
Senni	47	302	98	513	38	474	15	33
Yscir	25	42	28	159	*	*	*	*
Cilieni	124	86	137	50	40	70	82	46
Total	196	430	263	722	78	544	97	79

**Survey 3/ 4 100m was snorkelled and no fish observed*

Table A3.4: Wales sites: Total length (m) of river snorkelled

.

Site	Survey 1	Survey 2	Survey 3	Survey 4
Senni	380	397	211	357
Yscir	190	196	100	100
Cilieni	151	160	68	174

Table A3.5: Wales Site: Number of habitat availability points collected on all surveys

Site	Survey 1	Survey 2	Survey 3	Survey 4
Senni	398	330	285	207
Yscir	91	87	*	*
Cilieni	78	77	65	87
Total	567	494	350	294

** Habitat availability survey abandoned due to abandoned fish survey.*

Table A3.6: Wales sites: Total length (m) of river surveyed (habitat availability).

Site	Survey 1	Survey 2	Survey 3	Survey 4
Senni	381	399	399	399
Yscir	190	199	0	0
Cilieni	159	159	159	159

Table A3.9: Wales Sites: Spot-gauged discharge measurements taken during habitat availability surveys on Cilieni

Survey	Date	Discharge
1	20/6/00	0.363
	25/6/00	0.445
3	12/9/00	0.136
4	17/10/00	0.853
	18/10/00	1.028

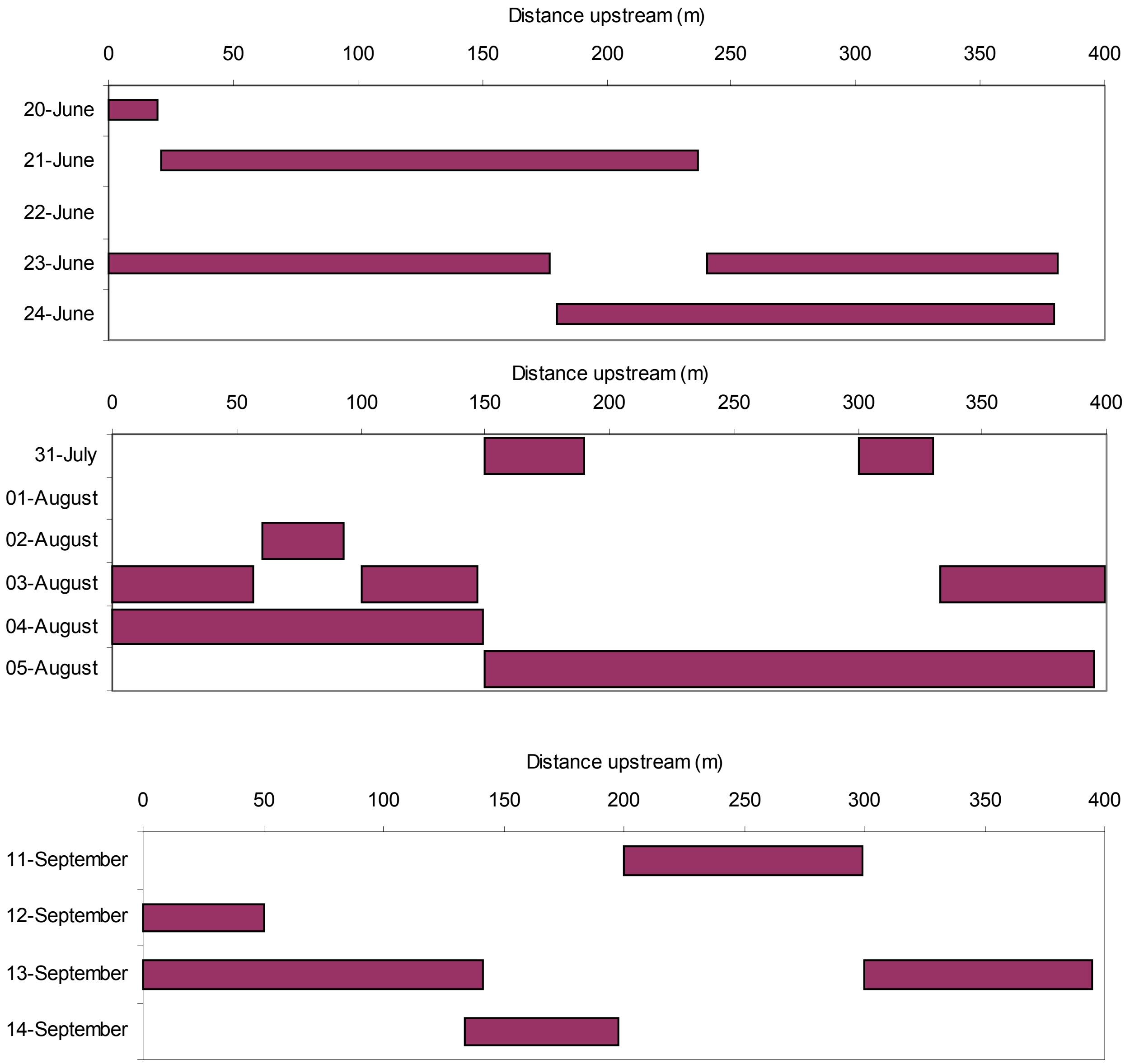


Figure A3.1: River Senni: horizontal bar graphs of survey dates

A4. Frome study area

Table A4.1: Dorset sites: details of nearby gauging stations.

River	Gauge	NGR Gauge	Gauge ref	Gauge area / MF / Q95 / BFI
South Winterbourne	Steepleton	SY62988976	44008 74-	19.9 / .1 / .01 / 0.88 /
Carrier	Mill Channel	SY708903	44004 71-	

Table A4.2: Dorset sites: survey dates

Site	Survey 1a	Survey 1b	Survey 2	Survey 3
West Stafford	22-23/5/00	15/6/00	17-20/7/00	9/10/00
Carrier	23/5/00		19-20/7/00	
East Burton		6-9/6/00	17-19/7/00	2-5/10/00
Manor House		15/6/00	20-24/7/00	4-5/10/00
Maiden Newton		12-/6/00		
Overall	22-23/5/00	6-15/6/00	17-24/7/00	2-9/10/00

Table A4.3: Frome sites: number of fish observations collected on each survey

Site	Survey 1		Survey 2		Survey 3	
	Trout	Salmon	Trout	Salmon	Trout	Salmon
West Stafford	47	4	103	163	*[3]	*[3]
Carrier	12	1	29	81	*[3]	*[3]
East Burton	11	337	5	412	2 *[2]	23 *[2]
Manor House	79	0	148	8	105	1
Maiden Newton	36	0	*[1]	*[1]	*[1]	*[1]
Total	185	342	285	664	107	24

*[1] *Site abandoned due to lack of fish*
*[2] *Only 75m snorkelled due poor visibility*
*[3] *Site not snorkelled due to poor visibility*

Table A4.4: Dorset sites: Total length (m) of river snorkelled.

Site	Survey 1	Survey 2	Survey 3
West Stafford	193	193	*
Carrier	115	197	*
East Burton	329	365	68
Manor House	289	293	284
Maiden Newton	95	0	0

** Sites not snorkelled due to flooding / poor visibility.*

Table A4.5: RiverFrome: Number of habitat availability points collected on all surveys

Site	Survey 1a	Survey 1b	Survey 2	Survey 3
West Stafford	161	155	285	*[3]
Carrier	140		126	*[3]
East Burton		205	193	43 *[2]
Manor House		116	222	191
Maiden Newton		93	*[1]	*[1]
Total	445	826		235

*[1] *Site abandoned due to lack of fish*
*[2] *Only 75m snorkelled due poor visibility therefore only 75m of habitat availability*
*[3] *Site not snorkelled due to poor visibility therefore no habitat availability survey*

Table A4.6: Dorset sites: Total length (m) of river surveyed for habitat availability.

Site	Survey 1	Survey 2	Survey 3
West Stafford	198	188	5
Carrier	159	199	0
East Burton	340	340	80
Manor House	300	300	300

* Sites not snorkelled due to flooding / poor visibility.

Table A4.9: PHABSIM calibration flows and gauged flows at Steepleton

S. Winterbourne	Discharge *	Mill Channel
06/09/00	0.179	0.196
03/10/00	0.257	0.302
10/10/00	0.384	0.602

* Discharge was calculated using the mean flow from one cross section: assessed as the most suitable for this purpose (c/s 7)

Table A4.10: PHABSIM calibration flows and gauged flows

Carrier	Discharge *	Mill Channel
06/09/00	.143	0.196
03/10/00	.231	0.302
10/10/00	.316	0.602

* Discharge was calculated using the mean flow from all four cross sections.

Table A4.11: Frome sites: discharge measurements taken during habitat availability surveys

Site	Survey 1	Survey 2	Survey 3
West Stafford	0.495	0.230 / 0.242	0.17
Carrier	0.45/0.320	0.200	
East Burton	0.411	0.185	
Manor House	0.240	0.172	0.199 / 0.166

Carrier: estimated using the gauge for the Mill Channel from Loudsmill gauging station

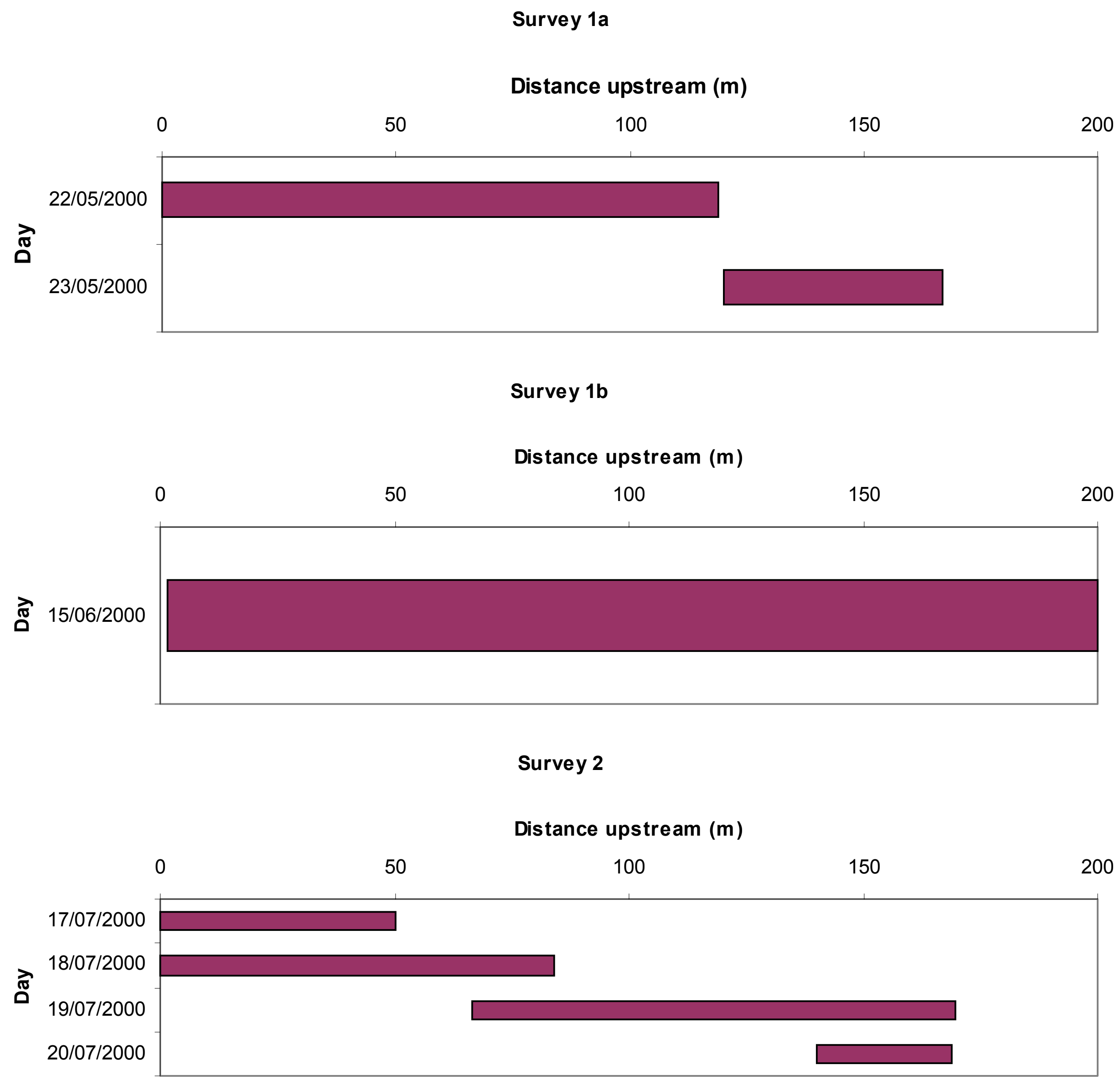


Figure A4.1. South Winterbourne main site: horizontal bar graphs of survey dates

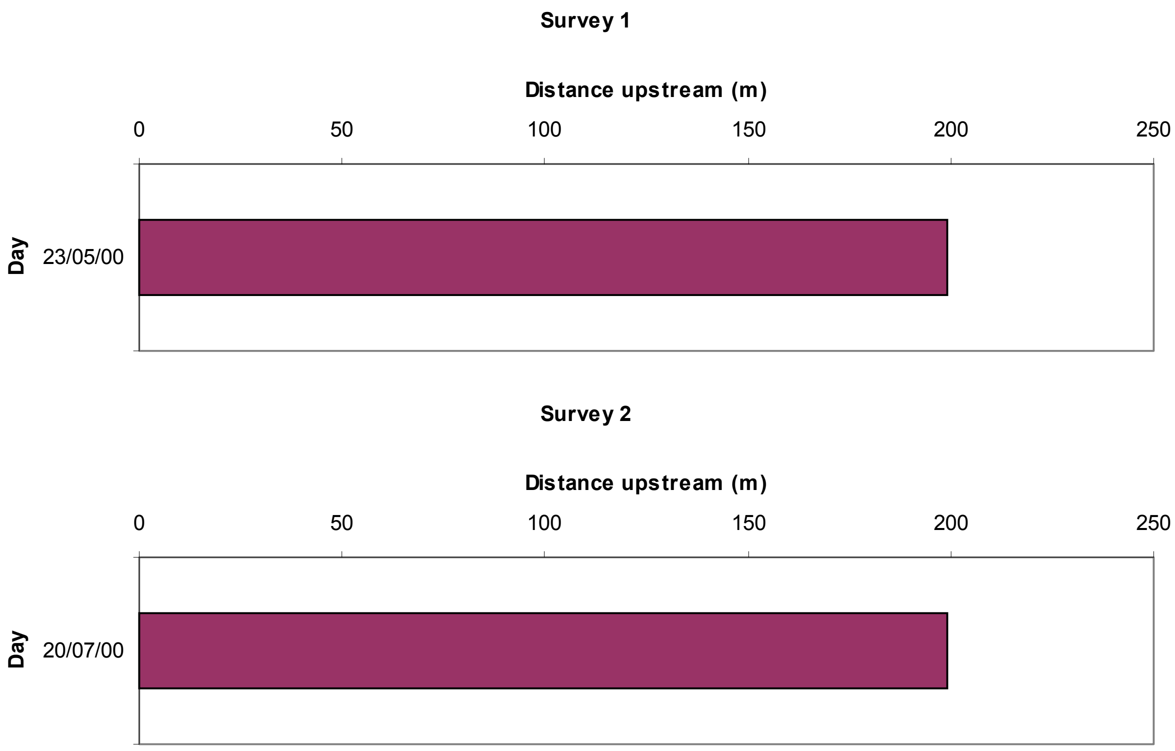


Figure A4.2: South Winterbourne Carrier: horizontal bar graphs of survey dates

APPENDIX B:
ELECTRIC FISHING AND HABSCORE SURVEYS

Introduction

Over the summer months of 1999 and 2000 four sites on Dartmoor and the River Piddle catchment and a further three sites on the Frome and Usk catchments were surveyed by snorkelling, to make direct observations of the habitat being used by juvenile salmonids. At the time these surveys were carried out it was not known whether the sites were at full carrying capacity for both juvenile trout and salmon. To address this question, it was necessary to use an independent model, based on a series of real, physical habitat and geographical measurements to predict the carrying capacities at each of the individual sites. The model chosen to make these predictions was HABSCORE 3.1 for Windows.

Because of the contrasting geology and altitude of the catchments HABSCORE 3.1 was the obvious choice as it is designed to work for both upland catchments and chalk streams. For various reasons (lack of permission, rising river levels etc.), we were unable to complete surveys at one site on each of the Frome, Usk and Devon study areas. All other sites were electric fished to obtain a real population estimate and to confirm that the real population estimates fitted within the confidence limits that the HABSCORE model would predict.

Methods

Within each site a section of river was chosen that was believed to contain a representative range of the habitat types present throughout the site as a whole. These section lengths were typically between sixty and eighty metres in length.

The sections to be surveyed were then impounded using stop nets at the upstream and downstream boundaries. Depending on stream width, sites were electric fished with either single or twin anodes at 100 Hz, powered by a 2.5 KVA generator. At each site three passes were made with the fishing gear with a thirty minute period between each shock to allow uncaught fish, that had been shocked, to recover and to allow the water clarity to return.
Fork length (FL) of all fish captured was measured to the nearest mm

Population estimates

From the three catches, population estimates (exact minimum likelihood) were calculated using the IFE "remove 2" program. Data are presented for: number caught; exact minimum likelihood (ML); 2 x standard error of the population estimate (2 x SE (N)); fish population densities (D) and 2 x standard error of the density (2 X SE (D)). These values are displayed in tables 1, 3, 5 & 7.

Habscore

When the electric fishing survey was complete at each site, 'HabscoreV' HAB*forms* were completed for the same section of river. The data from the completed forms were then put into the Habscore software package and the model run to obtain: Observed density; habitat quality score (HQS), this is a prediction of density per 100m^2, and the habitat utilisation index (HUI), which takes into account potential error in the calculation of the observed density. These results along with the corresponding upper and lower confidence limits are presented in tables B.1 – B.6.

Results

Dartmoor Target Area

Habscore and electric fishing surveys were carried out on the 21 and 22 October 1999, after the completion of three separate snorkelling surveys. The Habscore surveys were intended to be carried out soon after the snorkelling surveys however, bad weather and higher than normal flows meant that this work had to be carried out as conditions allowed. The four sites surveyed were the River Plym at Ham, the River Meavy at Dewerstone, The West Dart at Crockern Tor and the River Walkham at Ward Bridge.

As a result of heavy rain on 22 October electric fishing on the River Walkham at Ward Bridge had to be cancelled on the grounds of safety and therefore, observed densities are not available from electric fishing for this site. The habscore survey was however carried out, thus providing predicted densities and their associated confidence limits.

Because of adverse weather conditions resulting in failure to electric fish the River Walkham at Ward Bridge, no observed density data are available. For this reason data have been used from the August snorkelling survey. Densities have been calculated for the numbers of each species observed within a known surface area of the Ward Bridge site, thus giving a crude estimate of the known densities of each species present.

The observed densities of 0+, >0+ salmon, 0+ trout and >0+<20cm trout arrived at, either by electric fishing or snorkelling appear to fit within the Habscore HQS confidence limits, with the exception of 0+ salmon at the West Dart River and for 1+ salmon at Ham Bridge. These values were fractionally higher than the HQS upper confidence limits. At all sites HUI confidence limits span 1, indicating that where observed densities fall outside the HQS confidence limits, this is likely to be due to the error associated with the observed density estimate. It is however clear from the Habscore output that all sites were within their predicted range of carrying capacity for all age groups of both salmon and trout, at the time the snorkelling surveys were carried out.

Observed density, Habscore HQS and HUI values along with their associated confidence limits are presented in Table B-2.

Table B-1: Dartmoor: 'Remove' population estimates

		Walkham at Ward Bridge	Plym at Ham	Meavy at Dewerstone	West Dart at Crocken Tor
0+ Salmon	No. caught	14*	66	8	35
	Exact ML		71		55
	2 x SE (N)		7.6		34.9
	Density 100m2	2.4*	12.7		14.1
	2 x SE (D)		1.4		8.9
0+ Trout	No. caught	6*	24	21	38
	Exact ML		25	22	48
	2 x SE (N)		2.6	2.7	15.8
	Density 100m2	1.0*	4.5	5.5	12.3
	2 x SE (D)		0.5	0.7	4.0
Salmon >0+	No. caught	38*	47	26	16
	Exact ML		50	26	16
	2 x SE (N)		5.3	0	0
	Density 100m2	6.6*	8.9	6.4	4.1
	2 x SE (D)		1.0	0	0
Trout >0+ <20cm	No. caught	36*	26	69	29
	Exact ML		26	73	31
	2 x SE (N)		0	6.1	4.1
	Density 100m2	6.3*	4.7	18.1	7.9
	2 x SE (D)		0	0.01	0.01

* direct observation from snorkelling data.

Table B-2: Dartmoor study area: 'Habscore' outputs with observed densities

	Site	Walkham at Ward Bridge	Plym at Ham	Meavy at Dewerstone	West Dart at Crocken Tor
0+ Salmon	Observed density	2.45*	13.02	2.03	14.41
	HQS	4.08	4.83	4.08	3.45
	HQS lower CL	1.29	1.35	1.22	0.85
	HQS upper CL	12.89	17.28	13.59	14.02
	HUI	0.60	2.7	0.5	4.18
	HUI lower CL	0.08	0.35	0.07	0.5
	HUI upper CL	4.23	20.53	3.62	34.63
0+ Trout	Observed density	1.05*	4.58	5.57	12.58
	HQS	3.38	5.57	4.61	4.41
	HQS lower CL	0.9	1.44	1.22	1.22
	HQS upper CL	12.75	21.52	17.46	15.91
	HUI	0.31	0.82	1.21	2.85
	HUI lower CL	0.05	0.12	0.18	0.44
	HUI upper CL	2.06	5.56	8.07	18.4
1+ Salmon	Observed density	6.64*	9.17	6.59	4.19
	HQS	2.85	2.66	3.23	7.84
	HQS lower CL	0.85	0.78	0.97	2.61
	HQS upper CL	9.52	9.07	10.8	23.56
	HUI	2.33	3.45	2.04	0.53
	HUI lower CL	0.38	0.55	0.33	0.09
	HUI upper CL	14.45	21.75	12.65	3.1
Trout <20cm	Observed density	6.29*	4.77	18.49	8.12
	HQS	9.28	13.87	7.25	21.55
	HQS lower CL	2.19	3.05	1.73	4.9
	HQS upper CL	39.35	63.14	30.42	94.71
	HUI	0.68	0.34	2.55	0.38
	HUI lower CL	0.11	0.05	0.43	0.06
	HUI upper CL	4.04	2.17	15.09	2.32

* direct observation from snorkelling data.

Piddle Target Area

Habscore and electric fishing surveys were again carried out as weather conditions permitted after the snorkelling surveys had been completed. The River Piddle, downstream of the Bere Stream confluence and the Bere Stream itself were both surveyed on 1 October 1999, with the River Piddle, upstream of the Bere Stream confluence and the River Piddle further upstream at Throop both surveyed on 26 October 1999.

With the exception of the Bere Stream and the River Piddle, downstream of the Bere Stream confluence sites, where the observed densities of 0+ salmon are considerably higher than the HQS upper confidence limits, the other observed densities for 0+ salmon, trout and salmon >0+ all lie within the HQS confidence limits as predicted by Habscore. At all sites HUI (habitat utilisation index) confidence limits spanned 1, again suggesting that those values lying outside the HQS confidence limits are likely to be due to the error associated with predicting the observed densities.

It can therefore be assumed that at the time of the snorkelling surveys, all four sites were within the predicted range of carrying capacity, which could be expected for all age groups of both salmon and trout, in rivers with similar physical characteristics.

Observed density, Habscore HQS and HUI values along with their associated confidence limits are presented in Table B-4.

Table B-3: Piddle Target Area: 'Remove' population estimates (** minimum density estimate)

		Bere Stream at Higher Hyde	**R. Piddle, ds Bere Stream at Higher Hyde**	**R. Piddle, us Bere Stream at Higher Hyde**	**Piddle at Throop**
0+ Salmon	No. caught	61	166	49	19
	Exact ML	62	182	56	19
	2 x SE (N)	2.5	15.1	10.8	0
	Density $100m^2$	10.9	27.7	16.1	4.4
	2 x SE (D)	0.4	2.3	3.1	0
0+ Trout	No. caught	40	36	13	36
	Exact ML	40	44		36
	2 x SE (N)	0	13.5		0
	Density $100m^2$	7.0	6.7		8.3
	2 x SE (D)	0	2.1		0
Salmon >0+	No. caught	2	13	0	3
	Exact ML		13		3
	2 x SE (N)		0		0
	Density $100m^2$	0.4 **	2.0		0.7
	2 x SE (D)		0		0
Trout >0+ <20cm	No. caught	7	7	2	7
	Exact ML	7			
	2 x SE (N)	0			
	Density $100m^2$	1.2	1.1 **	0.6 **	1.6 **
	2 x SE (D)	0	0	0	

Table B-4: River Piddle target are: 'Habscore' outputs with observed densities

	Site	Bere	Piddle DS	Piddle US	Piddle Throop
0+ Salmon	Observed density	10.99	27.6	18.79	4.47
	HQS	1.71	5.08	6.49	7.16
	HQS lower CL	0.46	1.41	1.55	1.94
	HQS upper CL	6.35	18.32	27.2	26.41
	HUI	6.45	5.43	2.89	0.62
	HUI lower CL	0.83	0.71	0.34	0.08
	HUI upper CL	50.34	41.52	24.44	4.84
0+ Trout	Observed density	7.09	6.67	4.36	8.47
	HQS	4.15	2.18	3.23	3.51
	HQS lower CL	1.05	0.56	0.84	0.92
	HQS upper CL	16.41	8.46	12.45	13.47
	HUI	1.71	3.07	1.35	2.41
	HUI lower CL	0.25	0.45	0.2	0.36
	HUI upper CL	11.73	20.86	9.13	16.22
1+ Salmon	Observed density	0.35	1.97	0	0.71
	HQS	0.69	0.96	1.33	1.04
	HQS lower CL	0.19	0.27	0.38	0.3
	HQS upper CL	2.54	3.41	4.68	3.66
	HUI	0.51	2.05	0.25	0.68
	HUI lower CL	0.08	0.32	0.04	0.11
	HUI upper CL	3.38	13.26	1.62	4.33
Trout <20cm	Observed density	1.24	1.06	0.67	1.65
	HQS	1.94	1.62	1.82	3.61
	HQS lower CL	0.45	0.38	0.43	0.85
	HQS upper CL	8.28	6.81	7.74	15.32
	HUI	0.64	0.66	0.37	0.46
	HUI lower CL	0.11	0.11	0.06	0.08
	HUI upper CL	3.83	3.88	2.21	2.72

River Frome Target Area

During the year 2000, Habscore and electric fishing surveys were carried out at two sites on the Frome catchment. The Waterbarn Stream at East Burton was electric fished and Habscored on 11 July 2000 with the South Winterbourne and S. Winterbourne carrier surveys being carried out on 17 July 2000

Due to lack of permission we were unable to conduct these surveys on the River Cerne site.

Observed densities for 0+ salmon were significantly higher than the upper HQS confidence limits at both the South Winterbourne and Waterbarn Stream sites. Observed densities of 0+ trout were also significantly higher than the upper HQS confidence limit at the South Winterbourne site, however, no trout or older salmon were captured from the Waterbarn Stream and no salmon or trout older than 0+ were captured from the South Winterbourne site. These sites were selected primarily because of the large numbers of 0+ salmon or 0+ trout known to be present and consequently have not been used to construct Habitat Suitability Indices for the size classes that were either absent or below the predicted carrying capacity of these sites. HUI confidence limits do not span 1 for either 0+ trout or salmon at either site, suggesting that the non random selection of these sites has resulted in the Habscore model being unable to predict these unusually high densities, or indeed the lack of trout at the Waterbarn Stream.

Observed density, Habscore HQS and HUI values along with their associated confidence limits are presented in Table B-6.

Table B-5: River Frome target area: 'Remove' population estimates

		South Winterbourne	**Waterbarn Stream**
0+ Salmon	No. caught	61	93
	Exact ML	71	165
	2 x SE (N)	13.8	100.5
	Density 100m^2	0.3	0.5
	2 x SE (D)	0.06	0.3
0+ Trout	No. caught	88	0
	Exact ML	102	
	2 x SE (N)	16.6	
	Density 100m^2	0.4	
	2 x SE (D)	0.1	

Table B-6: River Frome target area: 'Habscore' outputs with observed densities

	Site	South Winterbourne	Waterbarn Stream
0+ Salmon	Observed density	29.97	48.46
	HQS	2.3	2.65
	HQS lower CL	0.6	0.69
	HQS upper CL	8.86	10.23
	HUI	13.04	18.27
	HUI lower CL	1.63	2.28
	HUI upper CL	104.19	146.03
0+ Trout	Observed density	43.05	0
	HQS	1.13	2.7
	HQS lower CL	0.28	0.7
	HQS upper CL	4.56	10.49
	HUI	37.99	0.11
	HUI lower CL	5.46	0.02
	HUI upper CL	264.4	0.74
1+ Salmon	Observed density	0	0
	HQS	0.89	2.49
	HQS lower CL	0.22	0.65
	HQS upper CL	3.55	9.45
	HUI	0.47	0.12
	HUI lower CL	0.07	0.02
	HUI upper CL	3.34	0.8
Trout <20cm	Observed density	0	0
	HQS	0.58	1.4
	HQS lower CL	0.13	0.33
	HQS upper CL	2.55	5.93
	HUI	0.72	0.21
	HUI lower CL	0.12	0.04
	HUI upper CL	4.4	1.25

Usk Target Area

During the September snorkelling surveys it became apparent that each of the sites, had been electric fished by the Agency, just a few days prior to our arrival. For this reason a decision was made not to repeat these surveys so soon after the last, but to use the data that had been collected by the Agency for these sites.

The Agency conducted Electric fishing and Habscore surveys on the River Cilieni on the 6 September 2000 and on the River Ysgir on the 12 September. Electric fishing took place on the River Senni on the 8 August 2000, however, due to rising water levels it was not possible to conduct a Habscore survey at this site.

With the exception of 0+ trout at the Ysgir site, where the observed density was fractionally below that of the lower HQS confidence limit, all other observed densities for 0+ salmon, 1+ salmon and trout <20cm, all fitted within the HQS confidence limits. On the Cilieni site, the observed densities of 0+ trout and <20cm trout both fitted within the HQS confidence limits. The observed densities for 0+ salmon and 1+ salmon were however higher than the upper HQS confidence limits. At both sites, HUI confidence limits for both salmon and trout of all size classes spanned 1. This suggests that any observed densities lying outside the confidence limits of the HQS can be attributed to the error involved in predicting the observed densities. In all cases, observed densities at the Ysgir and Cilieni sites, all fit within the predicted range of carrying capacities.

Habscore output values are not available for the River Senni, however population estimates are presented in Table B-7. Observed density, Habscore HQS and HUI values along with their associated confidence limits are presented in Table B-8.

Table B-7: Population estimates No./100m^2

	Cilieni	Ysgir	Senni
0+ salmon	79.3	42.7	24.6
0+ trout	25.8	2.4	0
>0+ salmon	16.8	3.5	3.7
Trout <20cm	28	2.1	3.7

Table B-8: River Usk target area: 'Habscore' outputs with observed densities

	Site	Ysgir	Cilieni
0+ Salmon	Observed density	41.48	80.54
	HQS	14.18	18.69
	HQS lower CL	4.47	5.81
	HQS upper CL	44.98	60.11
	HUI	2.93	4.31
	HUI lower CL	0.41	0.6
	HUI upper CL	20.71	30.9
0+ Trout	Observed density	2.36	26.19
	HQS	9.83	11.66
	HQS lower CL	2.62	3.17
	HQS upper CL	36.86	42.83
	HUI	0.24	2.25
	HUI lower CL	0.04	0.34
	HUI upper CL	1.59	14.67
1+ Salmon	Observed density	3.37	17.02
	HQS	4.72	4.88
	HQS lower CL	1.44	1.55
	HQS upper CL	15.44	15.32
	HUI	0.71	3.49
	HUI lower CL	0.12	0.58
	HUI upper CL	4.38	20.86
Trout <20cm	Observed density	2.02	30.45
	HQS	3.51	6.39
	HQS lower CL	0.84	1.54
	HQS upper CL	14.61	26.5
	HUI	0.58	4.76
	HUI lower CL	0.1	0.76
	HUI upper CL	3.38	29.99

Discussion

With the exception of some sites having significantly higher observed densities than predicted upper HQS confidence limits, the observed densities at the majority of sites fit within the HQS confidence limits. In all cases HUI ranges do confirm that when the error associated with the calculation of observed densities and the HQS predictions are taken into account, that all sites used for the construction of HSI's can be considered to be at full carrying capacity at the time the snorkelling surveys were carried out.

The main exceptions were the two Frome sites. The absence of 0+ trout from the Waterbarn Stream has resulted in this site not being used for constructing the Habitat Suitability Index for 0+ trout and the unusually high observed densities of salmon at this site and the high densities of 0+ trout and salmon at the South Winterbourne site are both significantly higher than the upper HQS confidence limits. At neither site do the HUI confidence limits span 1, indicating that the observed densities at both sites are outside the habscore predictions.

The non-random selection of sites has been necessary to fulfil the requirements of this project, in terms of constructing habitat suitability indices and it is therefore inevitable that some observed densities will not fit within the predictions as made by the habscore model. This said, with the exception of trout at the Waterbarn Stream site, the Habscore model has confirmed, at the time the snorkelling surveys were carried out, every site was at or above the full carrying capacity that could be expected.

Conclusion

At the time of the snorkelling surveys were carried out, all sites used for the construction of HSIs, can be considered to have been at full carrying capacity, as predicted by the HABSCORE model.

APPENDIX C:

SUMMARIES OF PHABSIM RAW DATA AND MODELS

C1 River Walkham at Ward Bridge

Table C1.1: River Walkham transect habitat types

Number	Habitat types	RHS surface flow types	Notes
Upper 1	shallow glide	RP	
2	shallow glide	RP	Most appropriate transect for gauging
3	deep glide	RP	
4	glide (medium)	RP, SM	Ok for gauging
5	run (deep)	RP, SM	Ok for gauging
6	run (fast)	RP	
7	riffle(narrower)	UW	Ok for gauging
8	riffle (wider)	UW	
Lower 1	cascade	RP, BW	
2	cascade	RP, BW	

Table C1.2: River Walkham: transect dimensions

C/S No.	Peg width (m)	Water width (m)	Reach length left bank (m)	Reach length right bank (m)
1	13.4	7.1		
2	16.1	11.3	5.3	4.8
3	13.9	9.0	7.9	9.0
4	12.2	9.2	9.0	8.1
5	13.0	8.9	5.5	5.1
6	12.9	7.4	7.2	6.3
7	14.5	6.7	15.8	13.3
8	15.5	9.8	8.1	7.2
Lower 1	16.1	12.2		
Lower 2	13.2	7.7	8.3	8.4

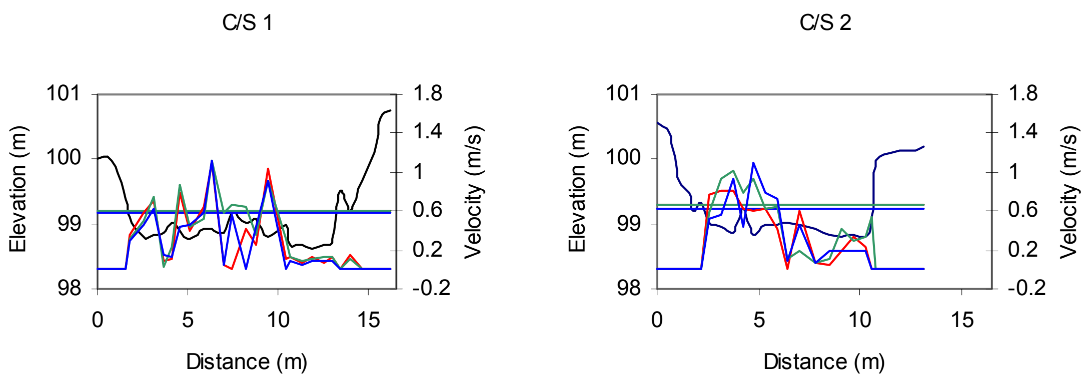


Figure C1.1: River Walkham (lower site): cross section plots showing water surface levels and velocities

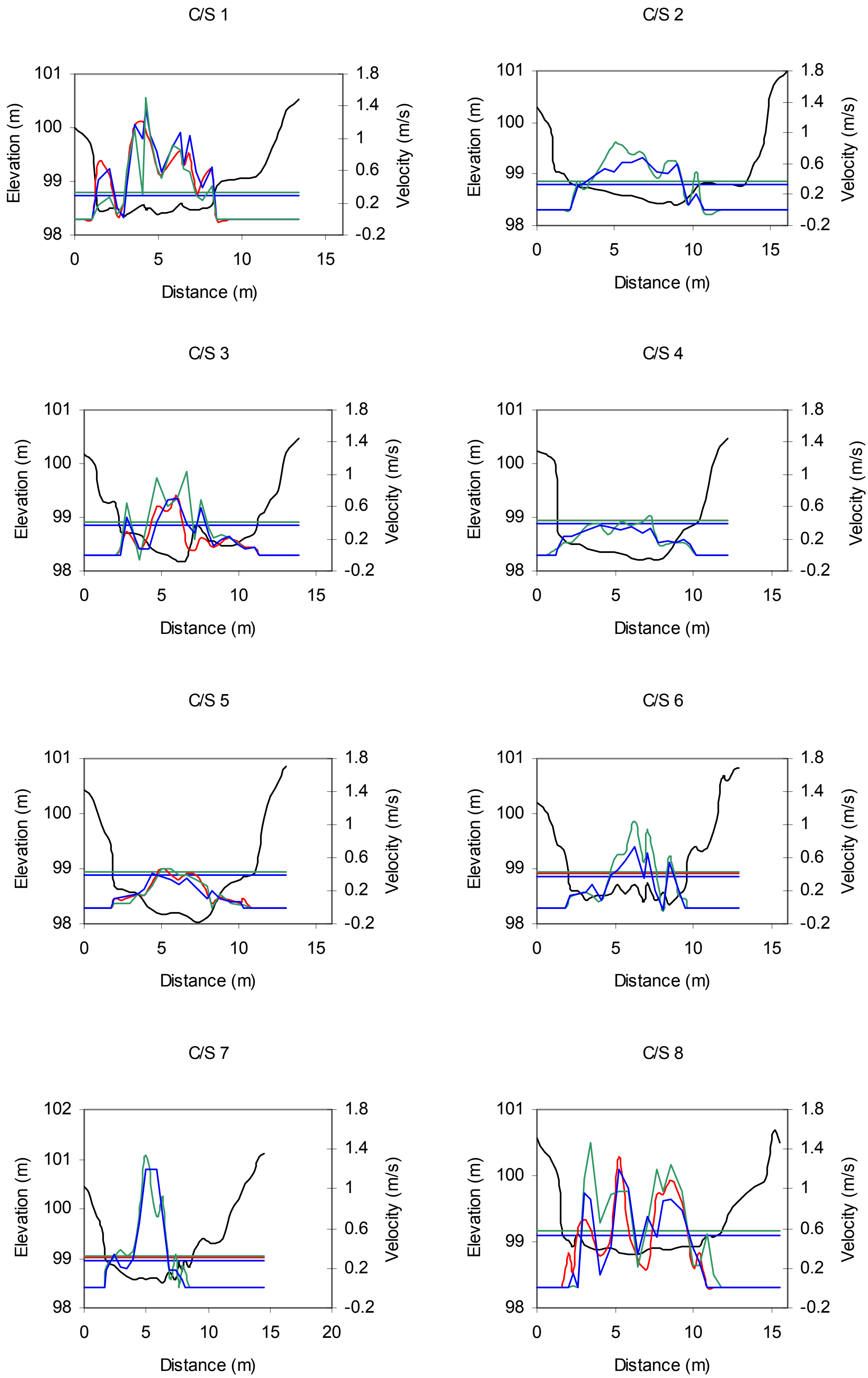


Figure C1.2: River Walkham (upper site): cross section plots showing water surface levels and velocities

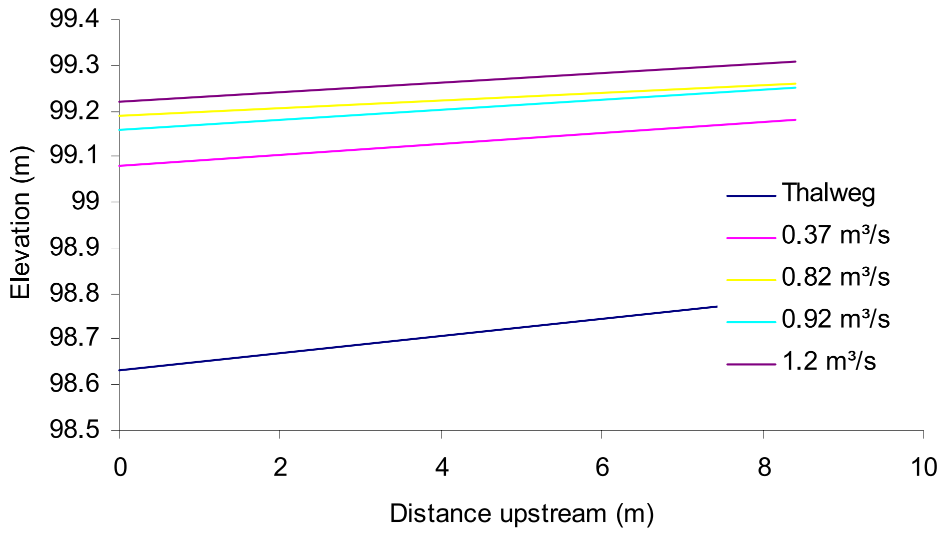


Figure C1.3: River Walkham (lower site): measured water surface profiles.

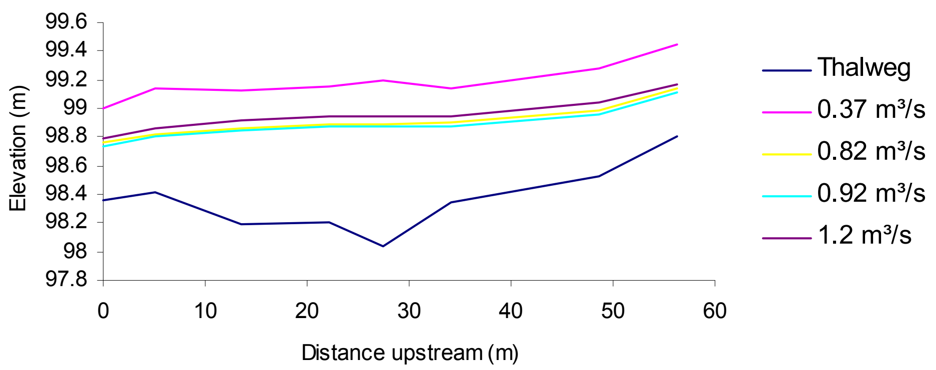


Figure C1.4: River Walkham (upper site): measured water surface profiles.

Table C1.3: River Walkham: water surface and velocity model calibration

CS	N	Beta	Group	Model
1	0.1	0.4	A	WSP1 (MSQ)
2	0.1		A	WSP1
3		0.4	B	MSQ
4	0.045	0.4	C	WSP2 (MSQ)
5	0.045		C	WSP2
6	0.05		C	WSP2
7	0.05		C	WSP2
8	0.06		C	WSP2
9	0.07		C	WSP2
10	0.07		C	WSP2

Table C1.4: River Walkham: water surface profile model details

WSP model	Details
WSP1	Initial cal 1.2cumecs, 1.2 and 0.4 only used for RMODS (0.4 cal RM = 1.3)
WSP2	Initial cal 1.2cumecs, 1.2 and 0.4 only used for RMODS (0.4 cal RM = 1.2)

Table C1.5: Velocity model details

	Cross sections	Cal set (m^3/s)	VAFs
VEL1	1-8	1.65	Y
VEL2	9-10	0.38	Y
VEL3	1-8	0.38	Y
VEL4	9-10	1.65	N

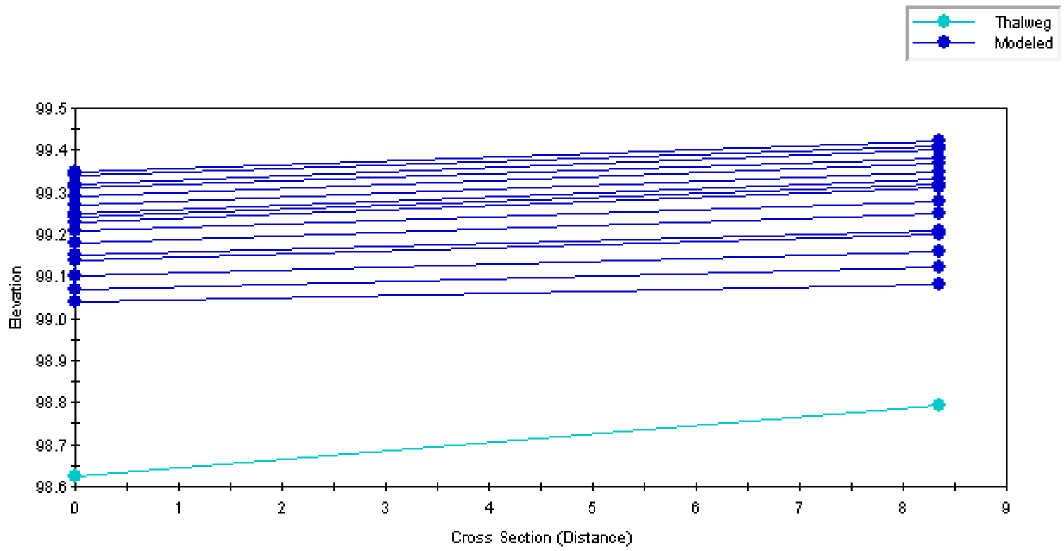


Figure C1.5: River Walkham (lower sites): simulated water surface profiles

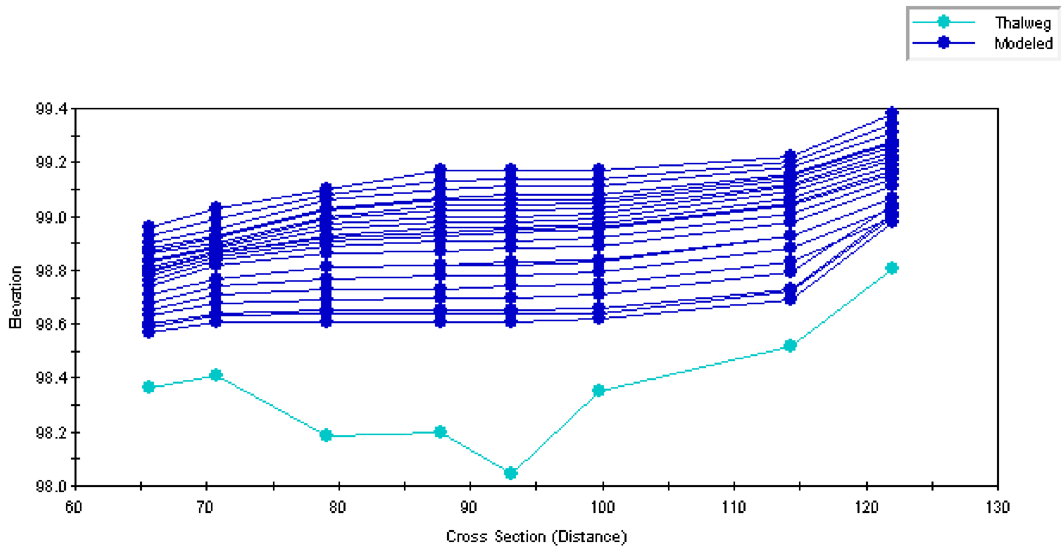


Figure C1.6: River Walkham (upper sites): simulated water surface profiles.

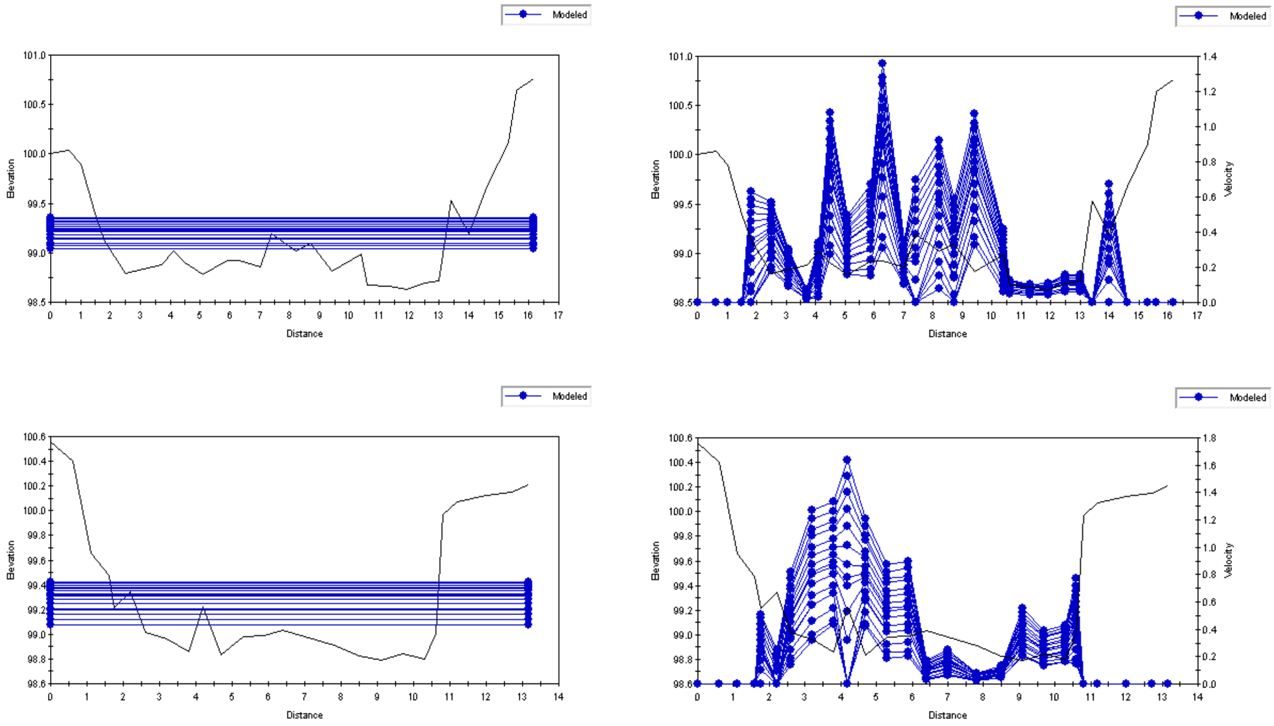


Figure C1.7: River Walkham (lower site): simulated water surface levels and velocities.

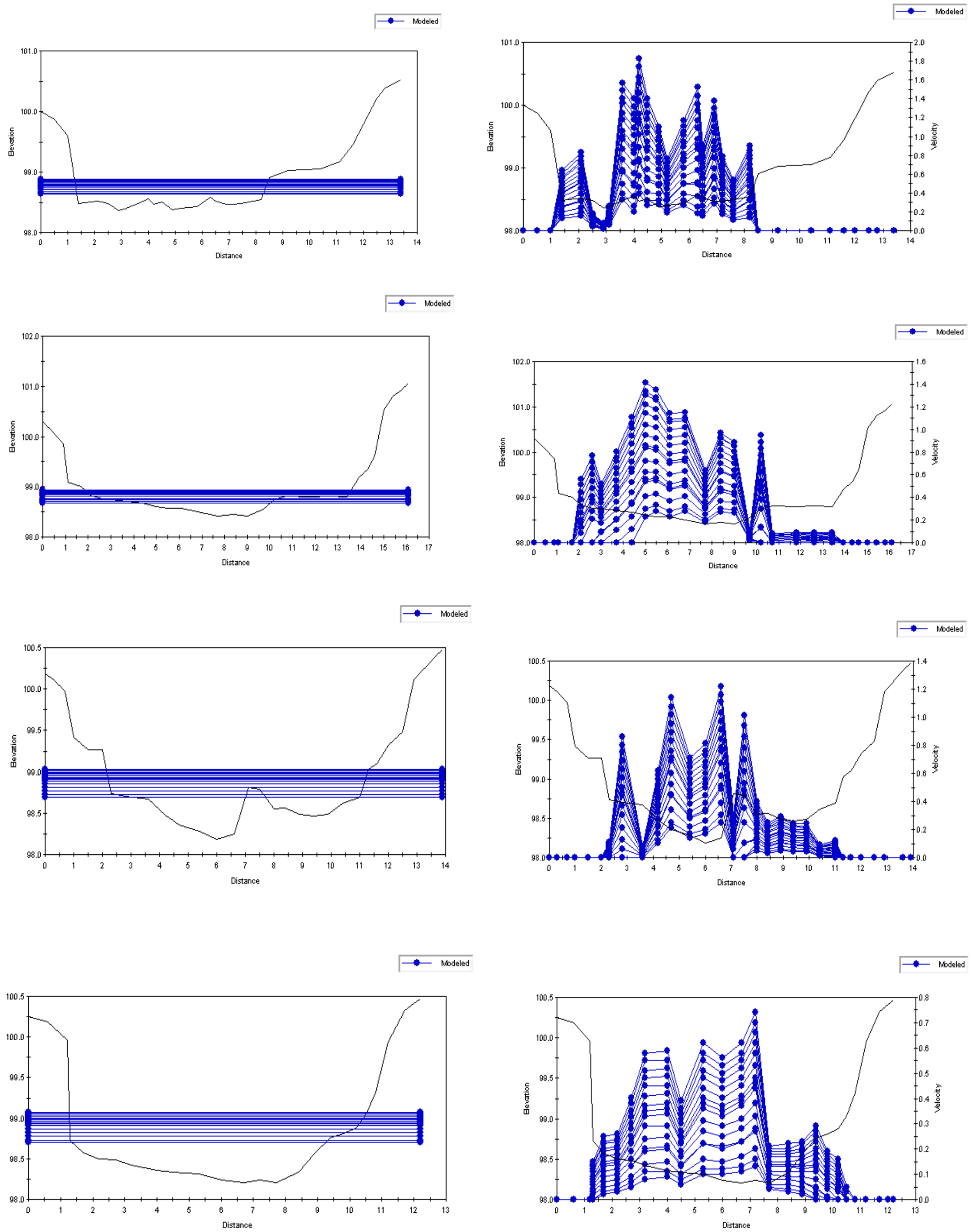


Figure C1.8. River Walkham (upper site): simulated water surface levels and velocities

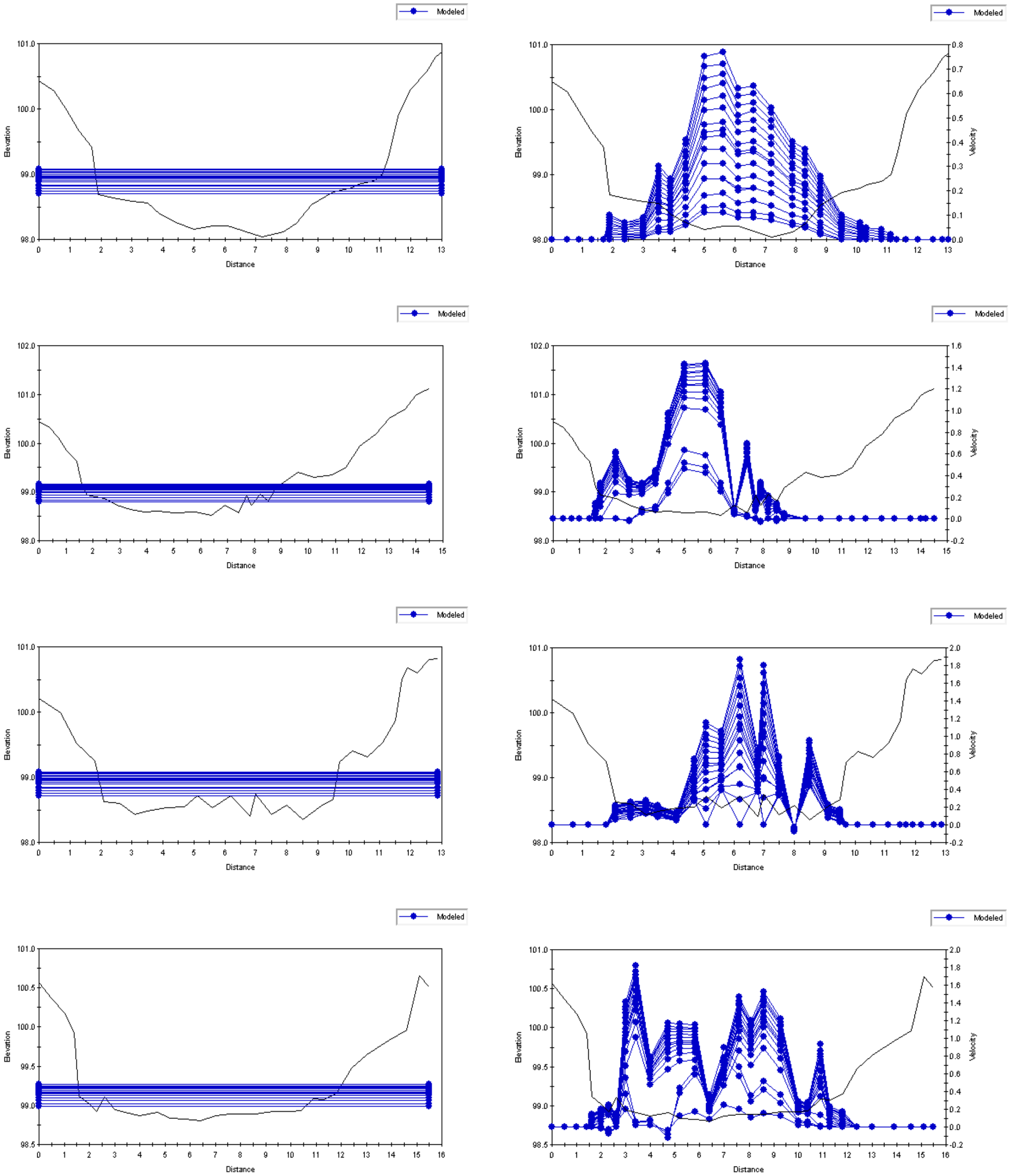


Figure C1.8: River Walkham (upper site) simulated water surface levels and velocities (cont).

C2. RIVER PIDDLE AT HIGHER HYDE

Table C2.1: River Piddle: transect habitat types

Number	Habitat type	Max depth (m)	Notes
1	shallow glide	0.5	
2	deep glide	1.3	
3	deep glide	0.55	Ok for gauging
4	deep glide (narrow)	0.85	
5	riffle	0.45	Gauge at v. high flows (shallowest point)
6	shallow glide	0.4	Most suitable for gauging at low flows
7	deep glide		
8	deep glide	0.95	
9	deep glide	0.8	
10	deep glide	1.05	
11	deep glide	0.65	Ok for gauging

Table C2.2: River Piddle: transect dimensions

C/S No.	Peg width (m)	Water width (m)	Reach length left bank (m)	Reach length right bank (m)
1	16.03	9.58	0	0
2	13.33	8.10	18.44	19.85
3	10.90	8.95	15.00	10.34
4	14.53	7.00	26.40	22.72
5	16.42	11.40	12.51	14.85
6	14.77	11.06	8.62	10.30
7	15.13	6.65	5.93	6.49
8	16.31	7.00	7.53	6.94
9	13.85	7.35	17.17	5.21
10	11.11	8.03	8.40	6.14
11	10.82	8.49	20.55	25.18

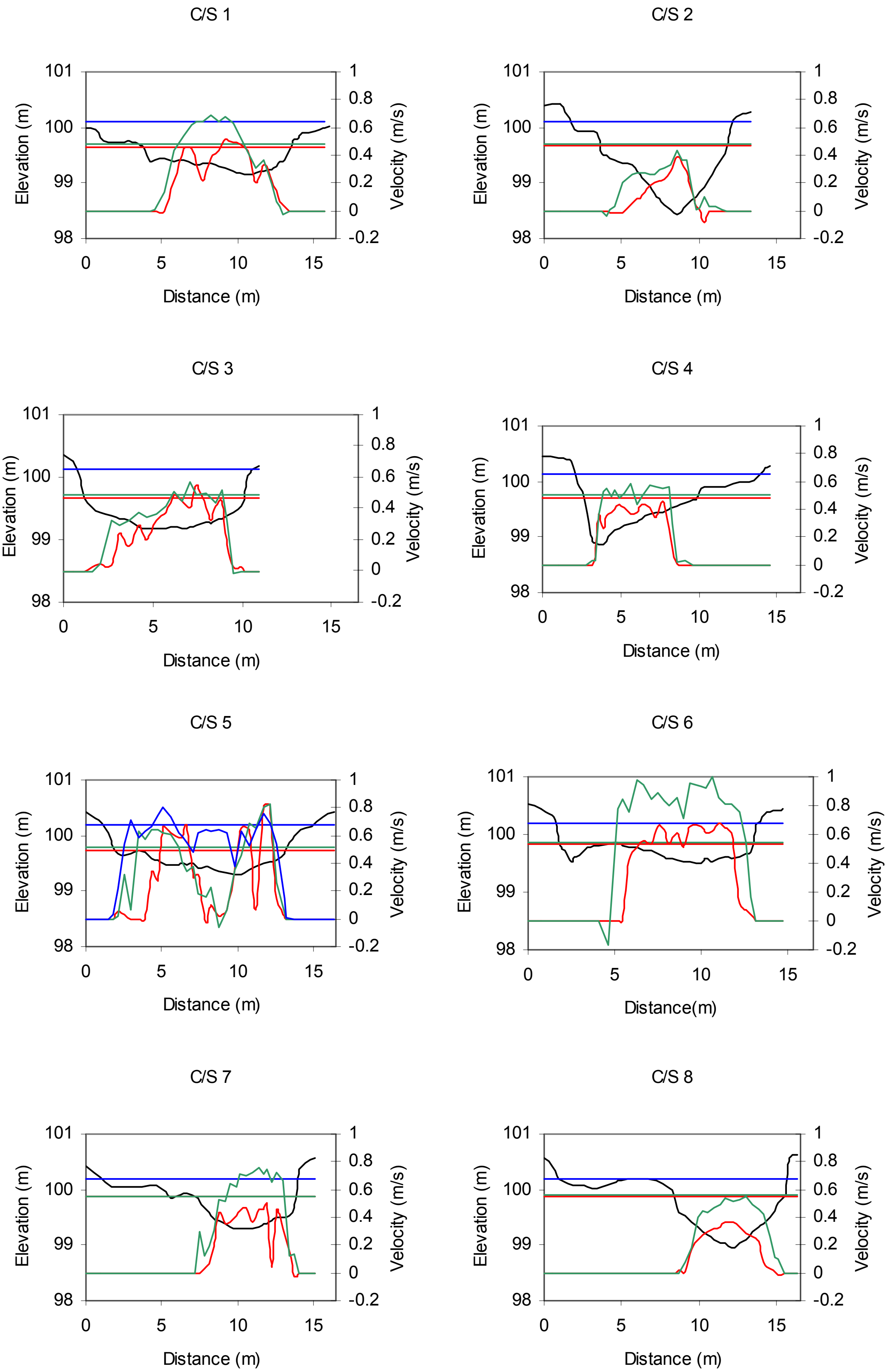


Figure C2.1: River Piddle: cross section plots showing water surface levels and velocities

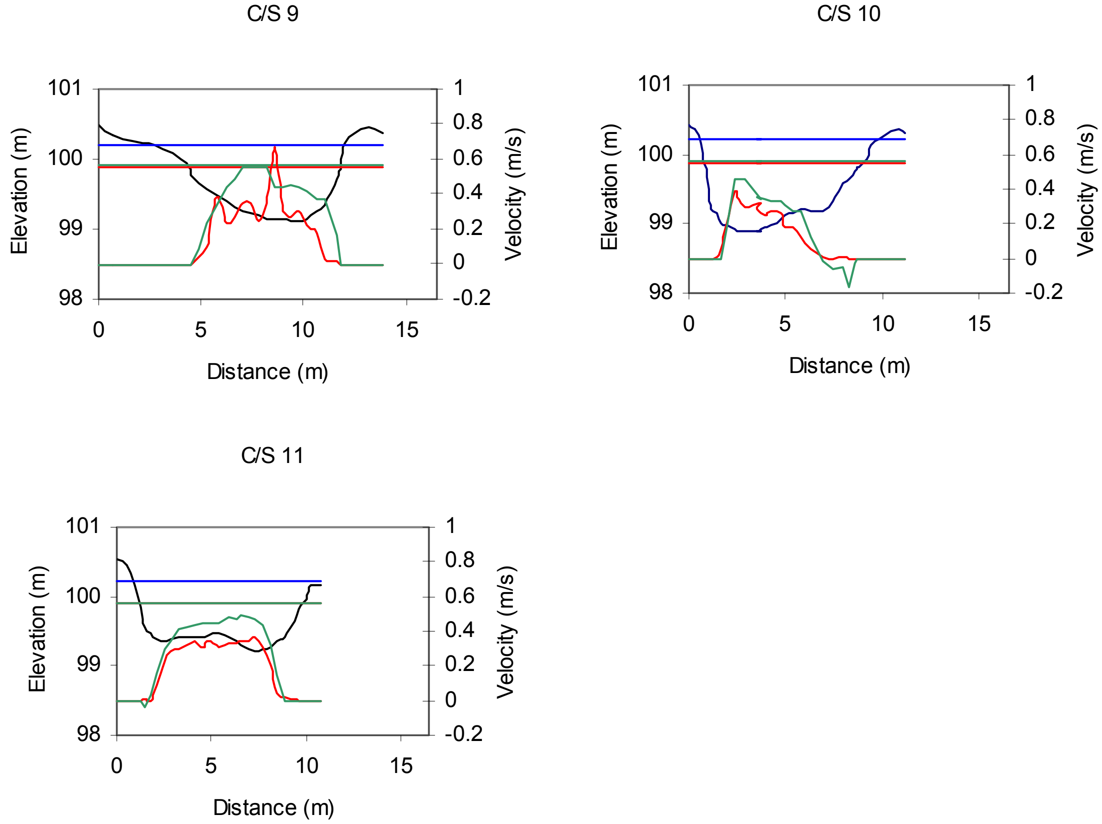


Figure C2.1 (continued) River Piddle: cross section plots showing water surface levels and velocities

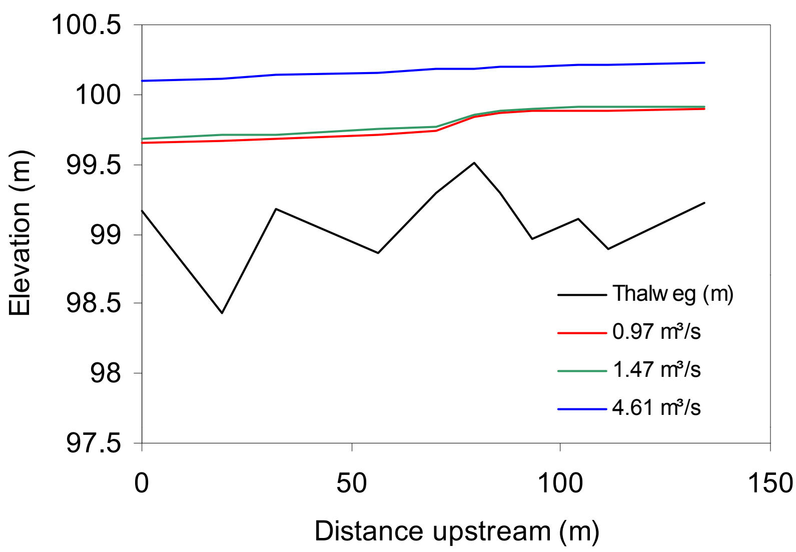


Figure C2.2. River Piddle: measured water surface profiles.

Table C2.3. River Piddle: water surface model calibration

CS	N	Group	Model	Notes
1	0.028	A	WSP (IFG4 linear)	Initial cal to 1.47 m³/s flow, RMOD = 1.2 at 1 m³/s, 0.8 at 4.6 m³/s
2	0.028	A	WSP	
3	0.035	A	WSP	
4	0.045	A	WSP	
5	0.019	A	WSP	
6	0.040	A	WSP	
7	0.005	B	WSP (IFG4 log-log)	Initial cal to 1.47 m³/s flow, RMOD = 1 at all discharges
8	0.005	B	WSP	
9	0.005	B	WSP	
10	0.005	B	WSP	
11	0.005	B	WSP	

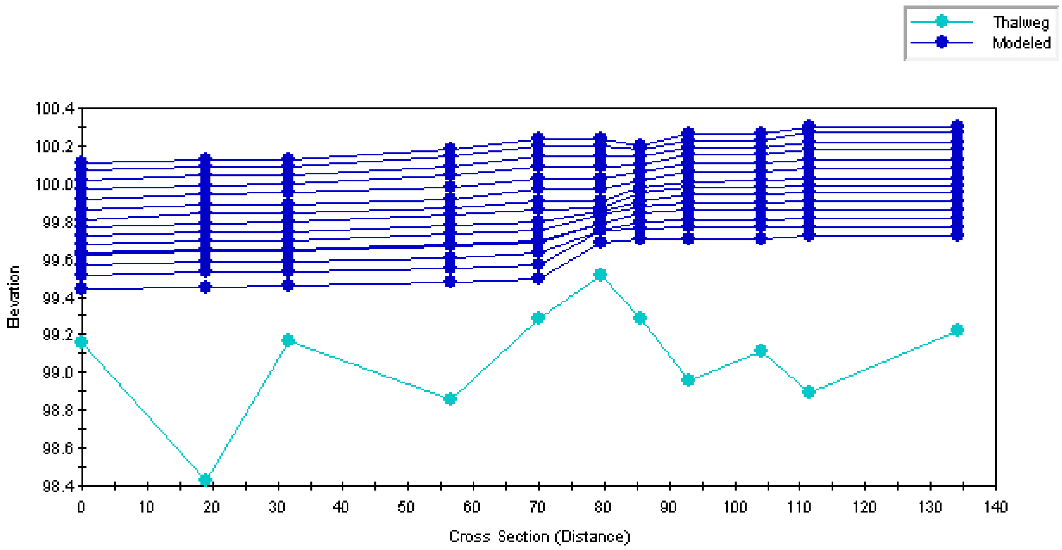


Figure C2.3 River Piddle: simulated water surface profiles

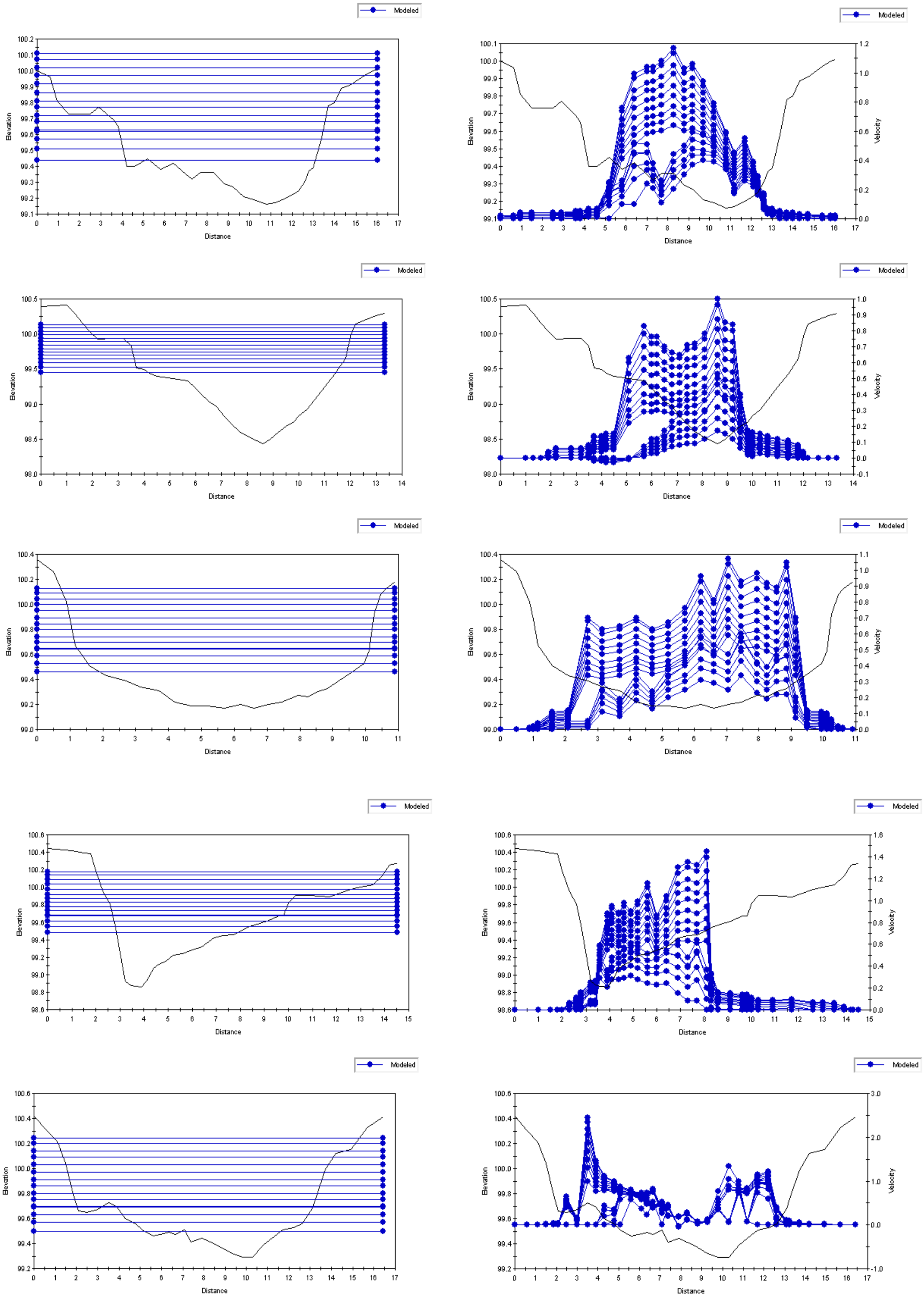


Figure C2.4 River Piddle: simulated water surface levels and velocities

C3. River Senni at Abersenny

Table C3.1 River Senni: transect habitat types

Number	Habitat type	RHS flow type	Notes
1	hydraulic control	UP	Not used for habitat modelling
2	pool	SM	
3	pool	SM	
4	cascade	CH	Not used for habitat modelling
5	cascade	CH	
6	run	RP	
7	riffle	RP	
8	glide	SM	
9	glide	SM	Suitable for gauging
10	glide	SM	Suitable for gauging
11	run	RP	
12	riffle	RP	

Table C3.2 River Senni: attributes of PHABSIM transects

C/S No.	Peg width (m)	Water width (m)	Reach length left bank (m)	Reach length right bank (m)
1	14.47	9.00	0.00	0.00
2	13.71	7.50	10.75	14.30
3	13.35	8.65	17.80	22.20
4	12.90	5.40	13.25	17.40
5		7.50	5.50	9.90
6	13.95	9.70	4.30	3.50
7	13.72	7.50	9.40	10.15
8	15.40	10.60	11.05	11.70
9	12.75	8.35	11.20	6.45
10	14.62	9.40	6.35	5.47
11	10.93	8.05	41.60	38.10
12	12.25	8.70	12.05	10.15

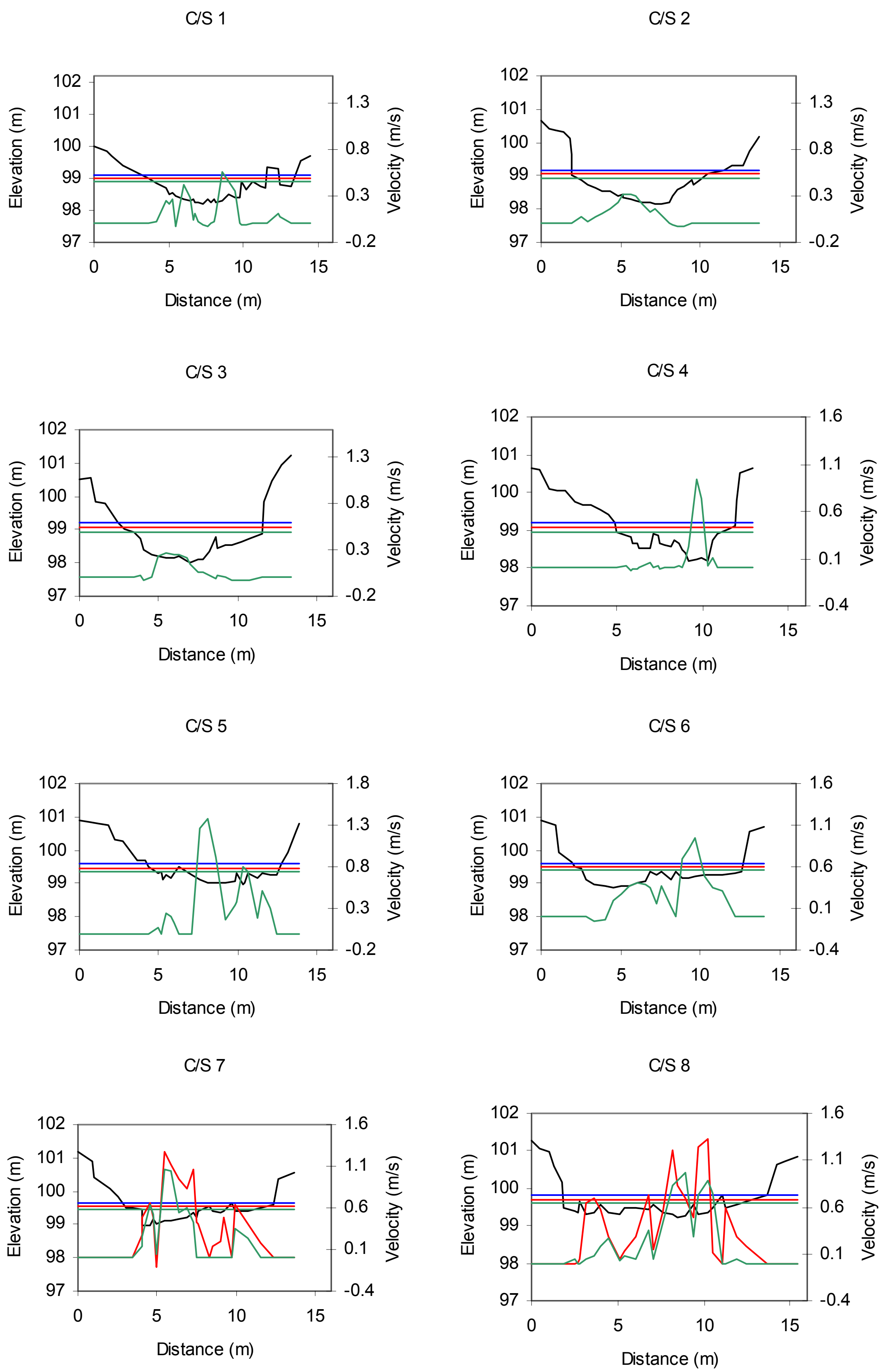


Figure C3.1 River Senni: cross section plots showing water surface levels and velocities

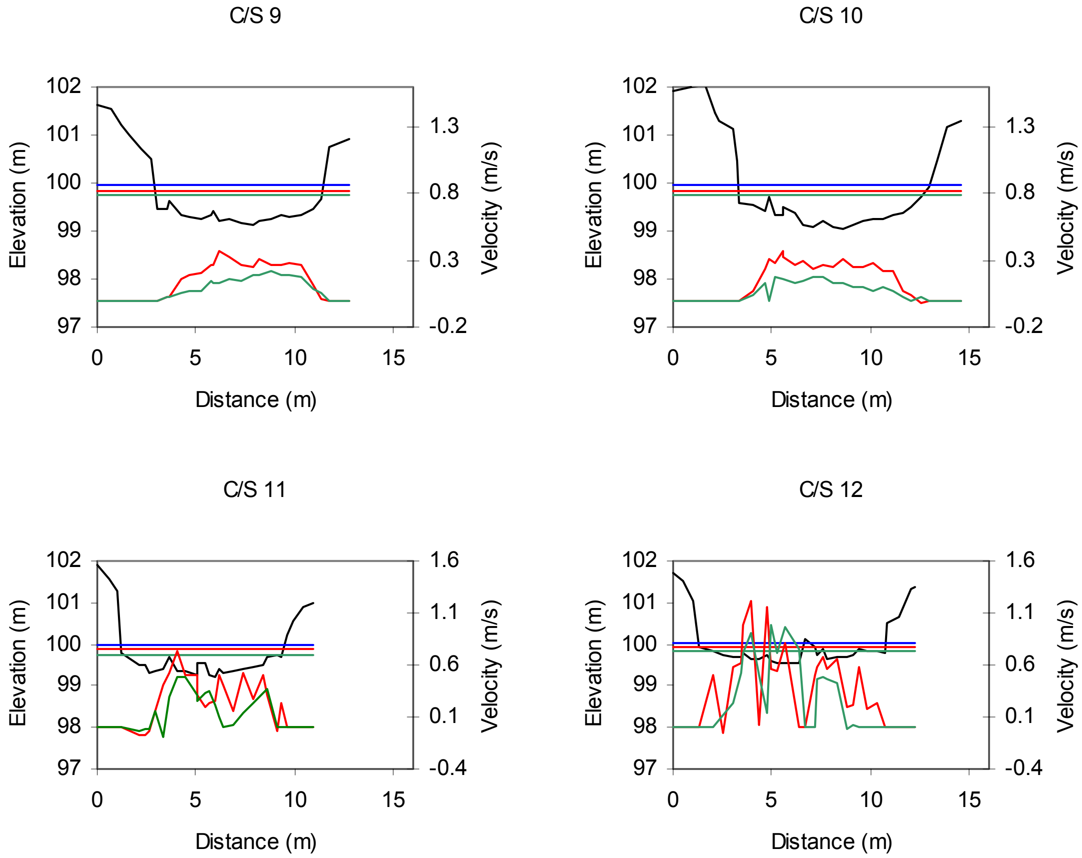


Figure C3.1 (continued) River Senni: cross section plots showing water surface levels and velocities

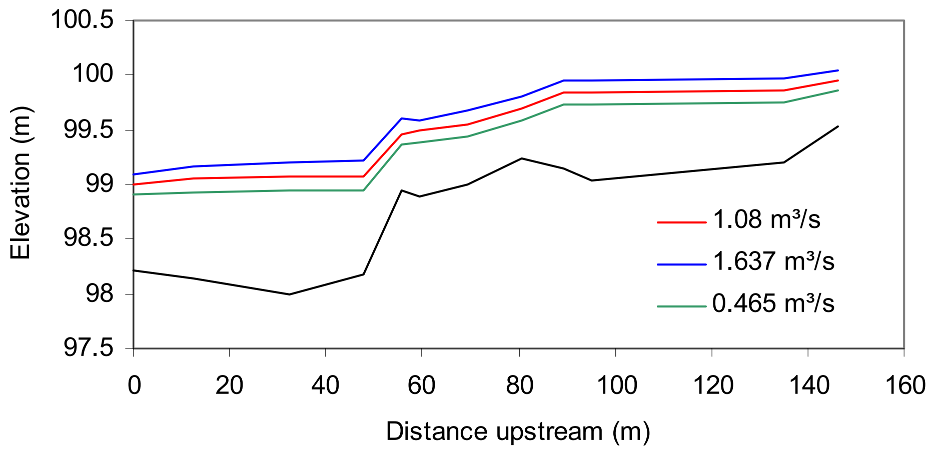


Figure C3.2. River Senni: measured water surface profiles

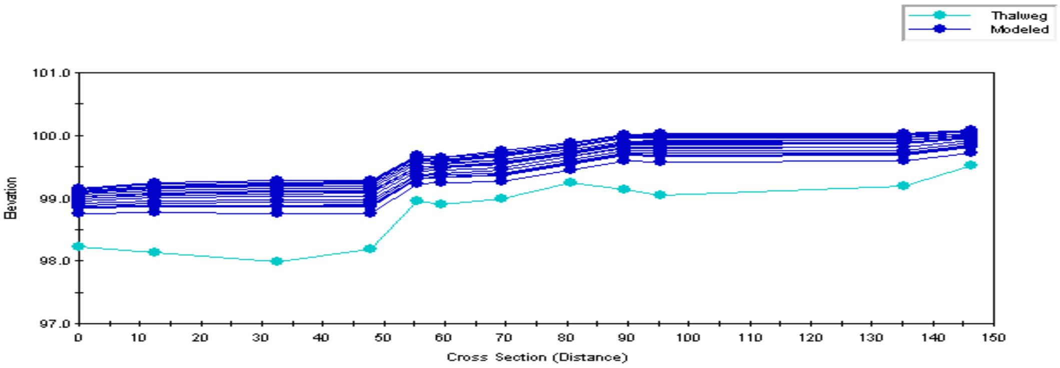
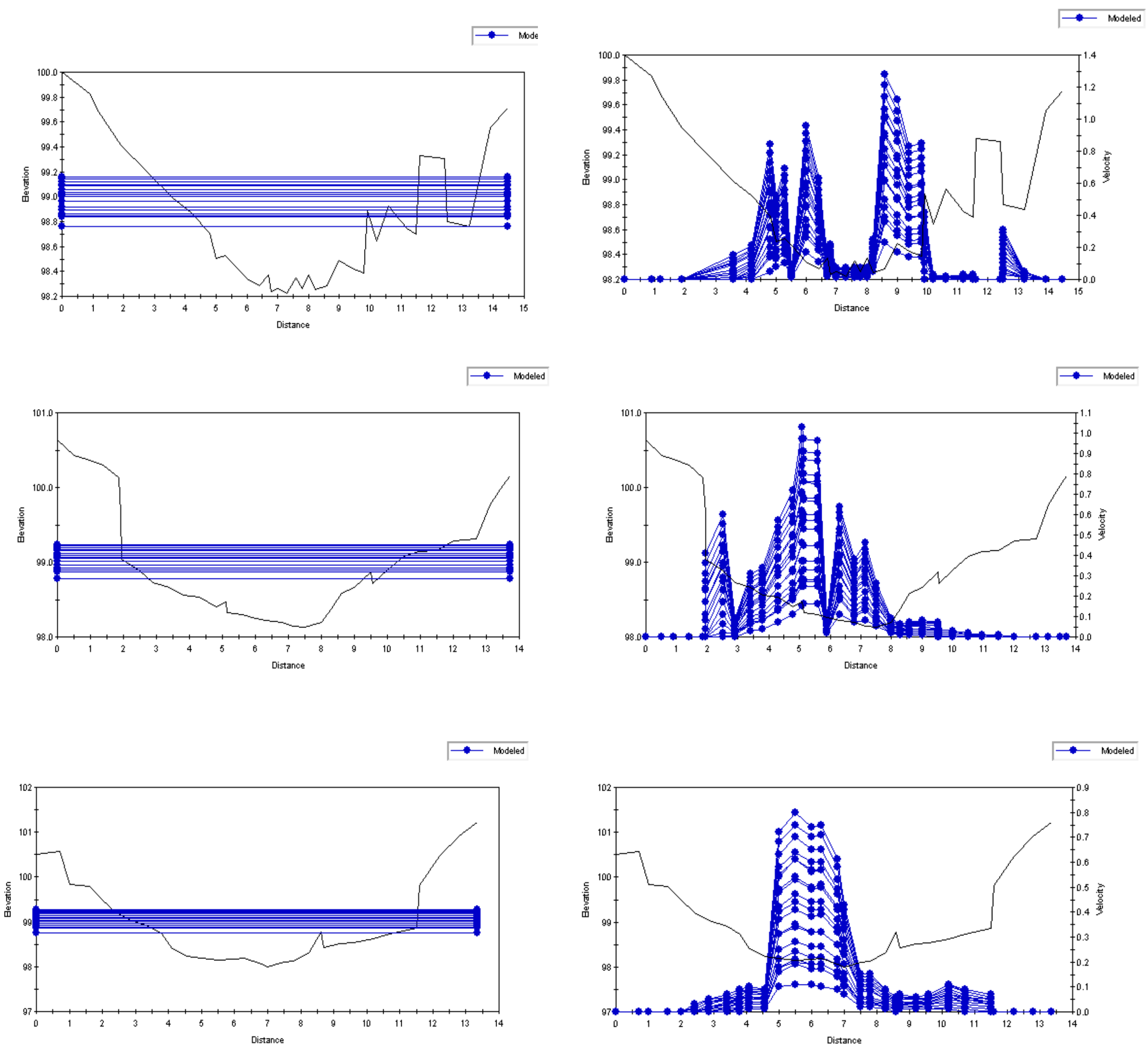
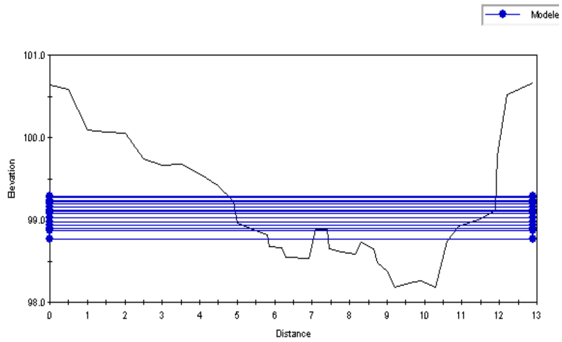
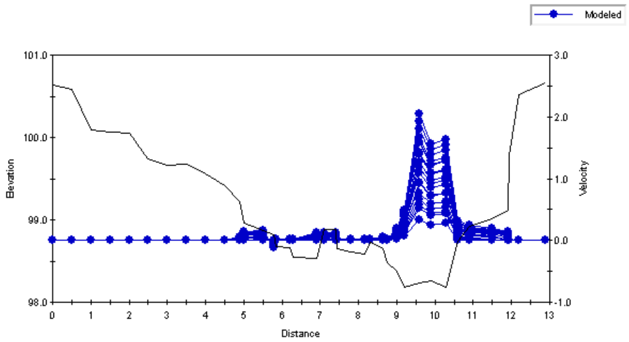


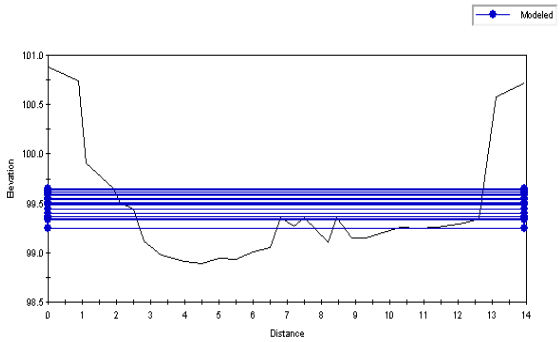
Figure C3.3 River Senni: simulated water surface profiles

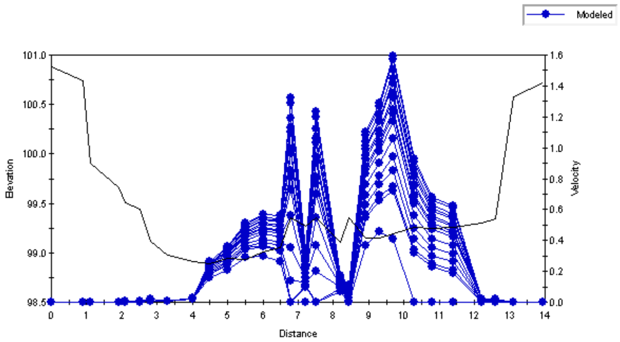
Figure C3.4.River Senni: simulated water surface levels and velocities

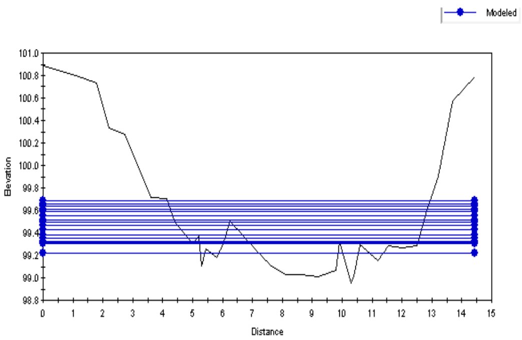


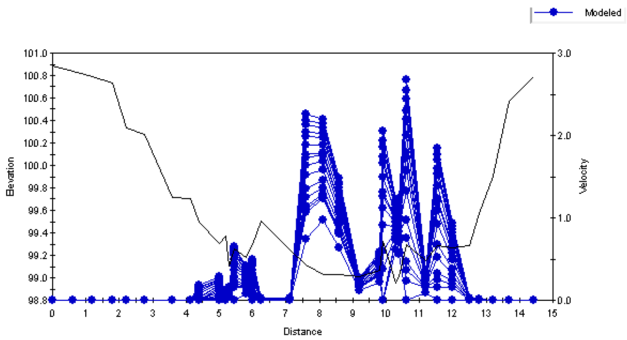

Modele
Elevation
Distance

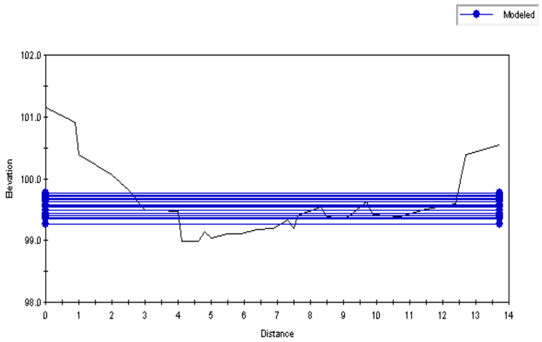

Modeled
Elevation
Velocity
Distance

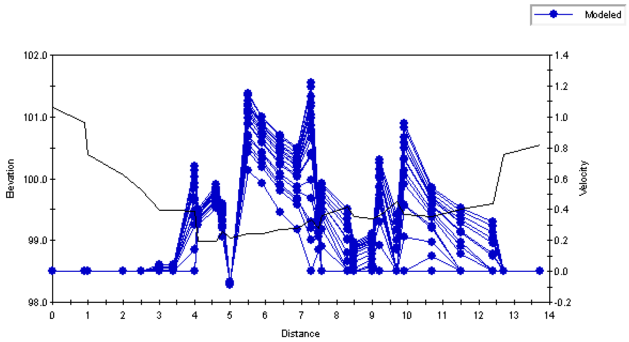

Modeled
Elevation
Distance

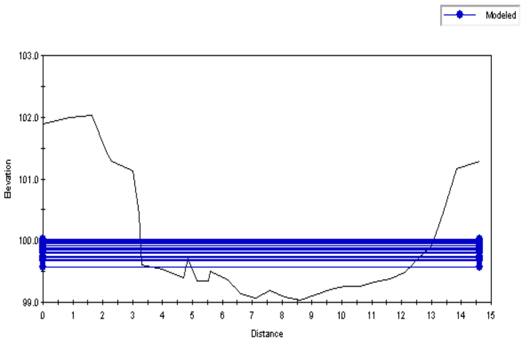

Modeled
Elevation
Velocity
Distance

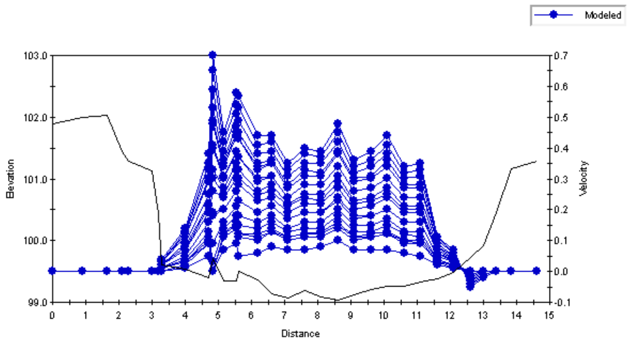

Modeled
Elevation
Distance


Modeled
Elevation
Velocity
Distance


Modeled
Elevation
Distance


Modeled
Elevation
Velocity
Distance


Modeled
Elevation
Distance


Modeled
Elevation
Velocity
Distance

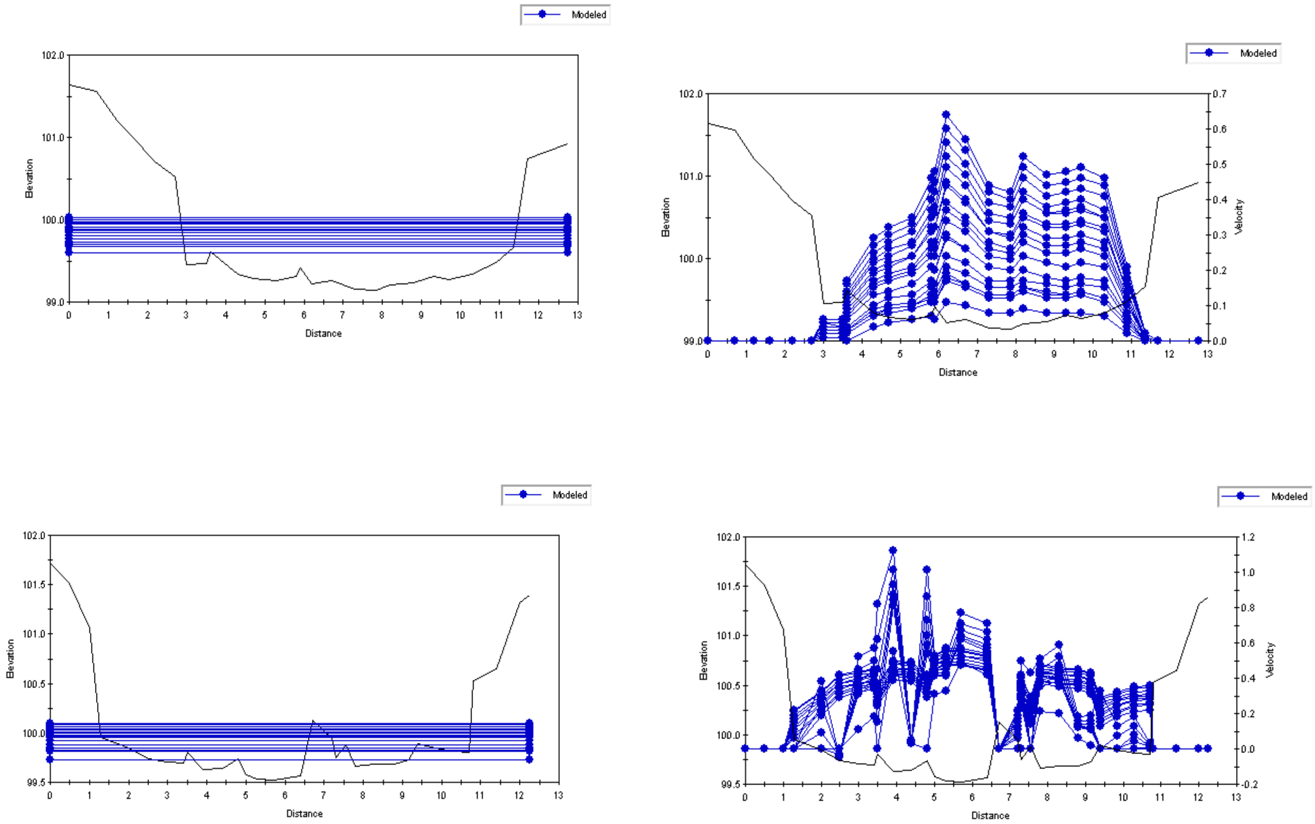


Figure C3.4. River Senni: simulated water surface levels and velocities (cont)

C4. South Winterbourne at West Stafford

Table C4.1 South Winterbourne: transect details

Number	*Habitat type*	Max depth	% area vegetation	Notes
Main channel				
1	Shallow glide	28	10	
2	Shallow glide	39	50	
3	Shallow glide	30	80	
4	deep glide	52	70	
5	Shallow glide	28	20	shaded on left bank
6	Riffle	20	30	shaded on left bank
7	Shallow glide	28	10	shaded on left bank
Carrier				
1	Rifle	20	20	cattle wade u/s
2	sallow glide	32	20	
3	sallow glide	38	30	
4	sallow glide	35	60	

Table C4.2 South Winterbourne: dimensions of PHABSIM transects

C/S No.	Peg width (m)	Water width (m)	Reach length left bank (m)	Reach length right bank (m)
1	12.70	5.05	0.00	0.00
2	11.23	7.10	29.00	29.75
3	14.35	6.65	16.68	16.44
4	12.62	5.65	9.30	8.15
5	11.23	6.90	19.84	19.75
6	13.00	7.70	17.47	17.93
7	18.65	7.80	11.92	11.94
Carrier				
1	5.95	4.20	0.00	0.00
2	6.26	3.55	10.24	0.00
3	6.26	3.75	31.57	0.00
4	5.79	3.15	10.88	0.00

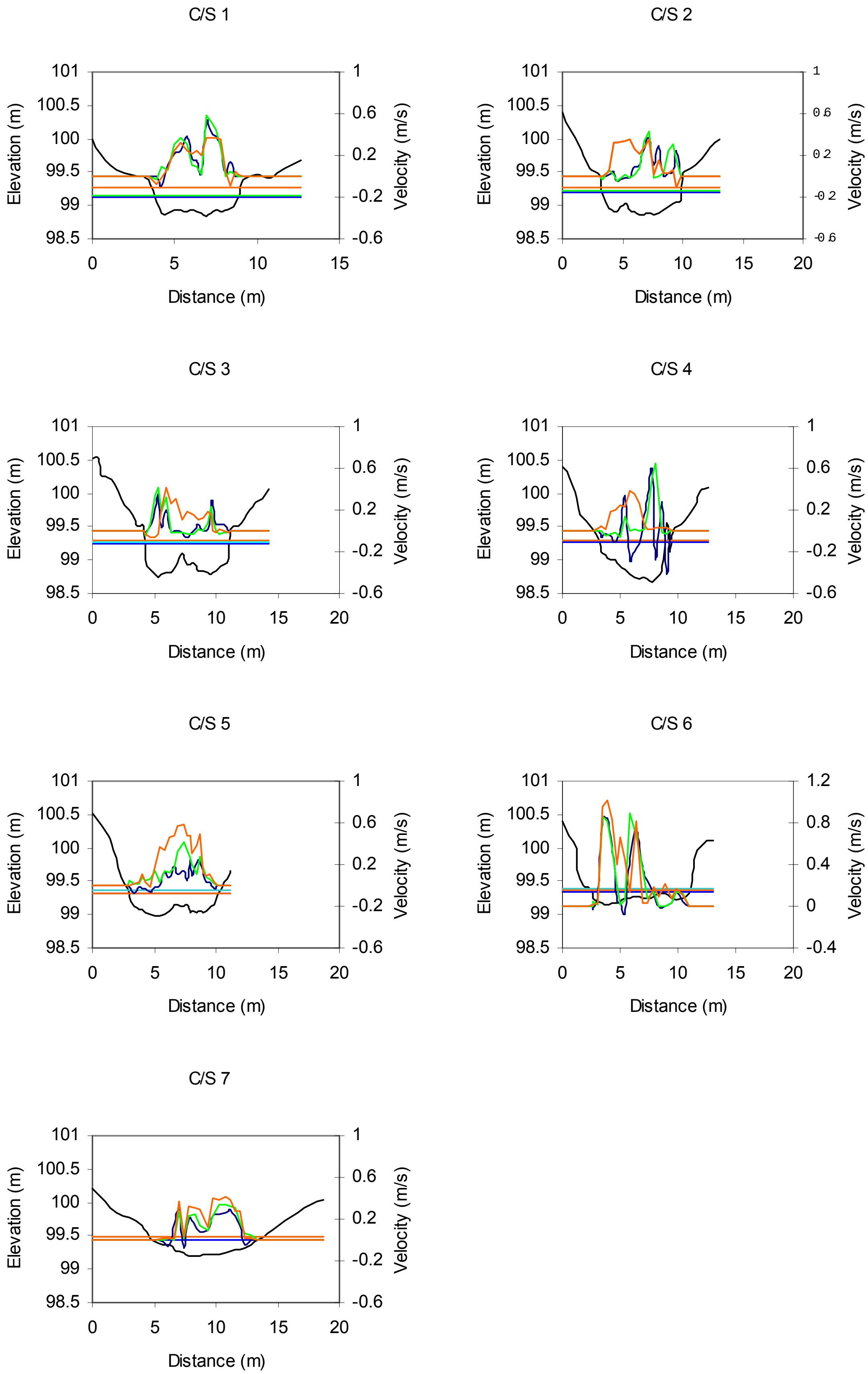


Figure C4.1 West Stafford: cross section plots showing water surface levels and velocities

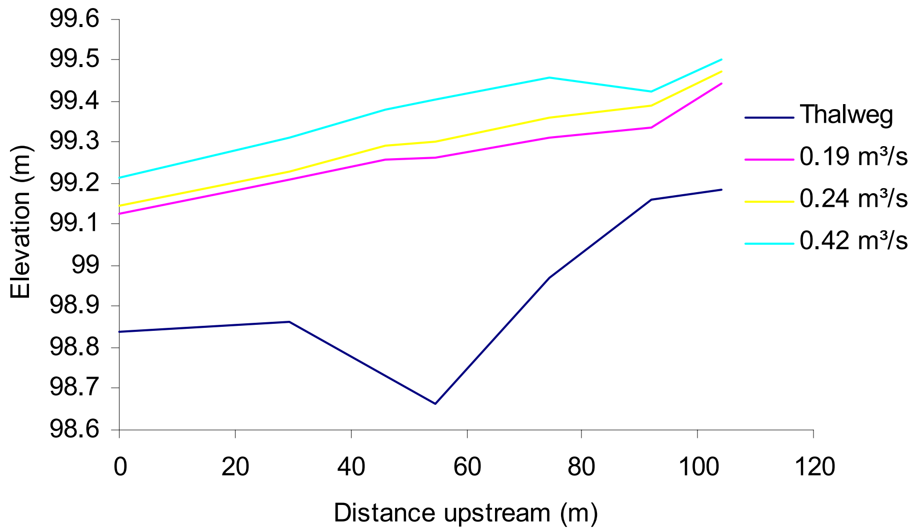


Figure C4.2 West Stafford: measured water surface profiles

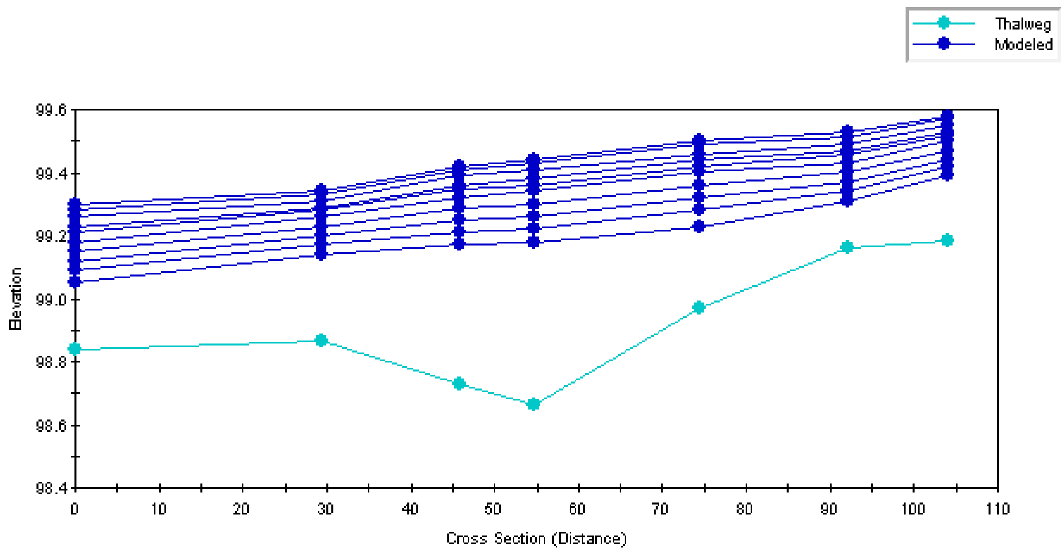
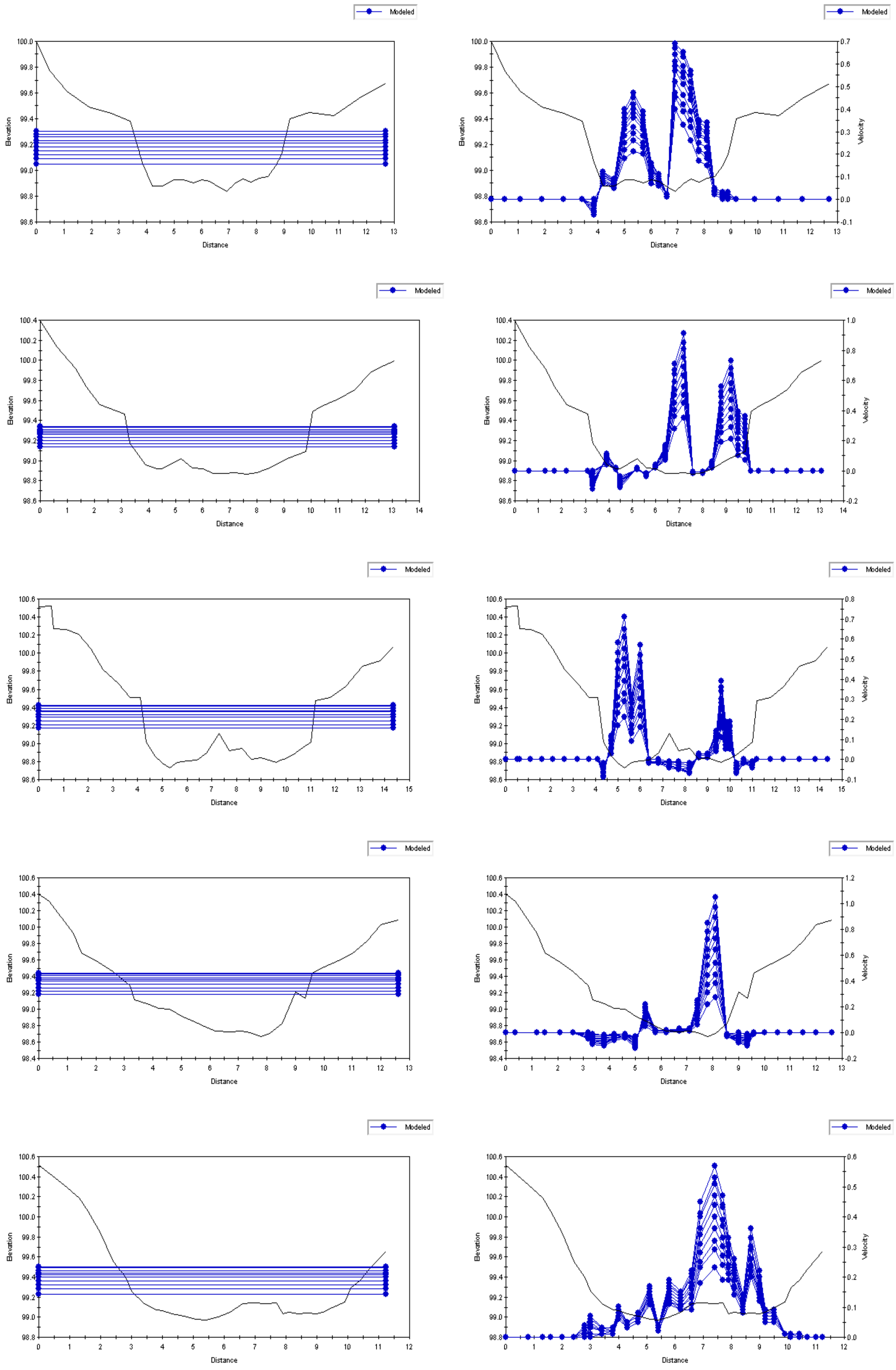


Figure C4.3 West Stafford: simulated water surface profiles.

Figure C4.4 West Stafford: simulated water surface levels and velocities.



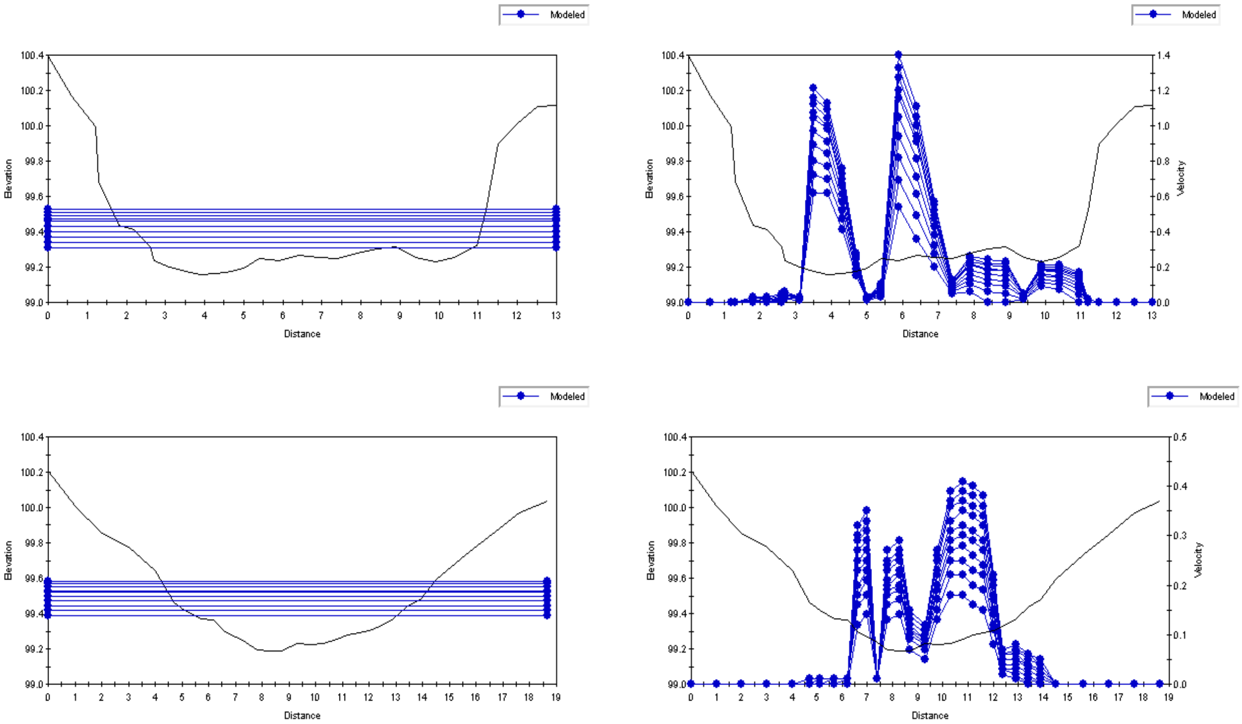


Figure C4.4 West Stafford: simulated water surface levels and velocities (cont)

Table 4.1. *South Winterbourne / Carrier:water surface model calibration parameters*

CS	N	Beta	Mode	Note
Main				
1		0.6	MANS	
2	0.2		IFG	
3	0.2		WS	0.24 flow (middle) initialRMOD of 0.9 for flo
4	0.15		WS	
5	0.17		WS	
6	0.05		WS	
7	0.15		WS	
Carrie				
1		0.01	MANS	
2			IFG	
3			IFG	
4			IFG	

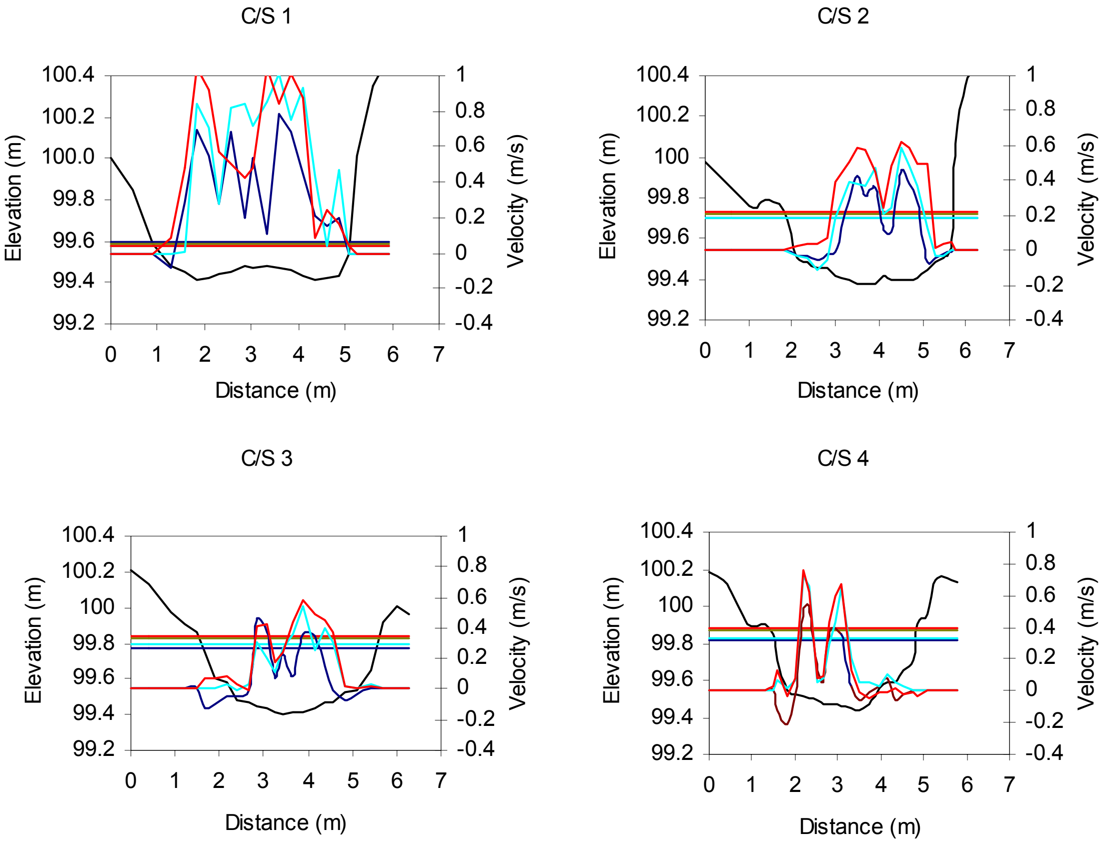


Figure C4.5 West Stafford Carrier: cross section plots showing water surface levels and velocities

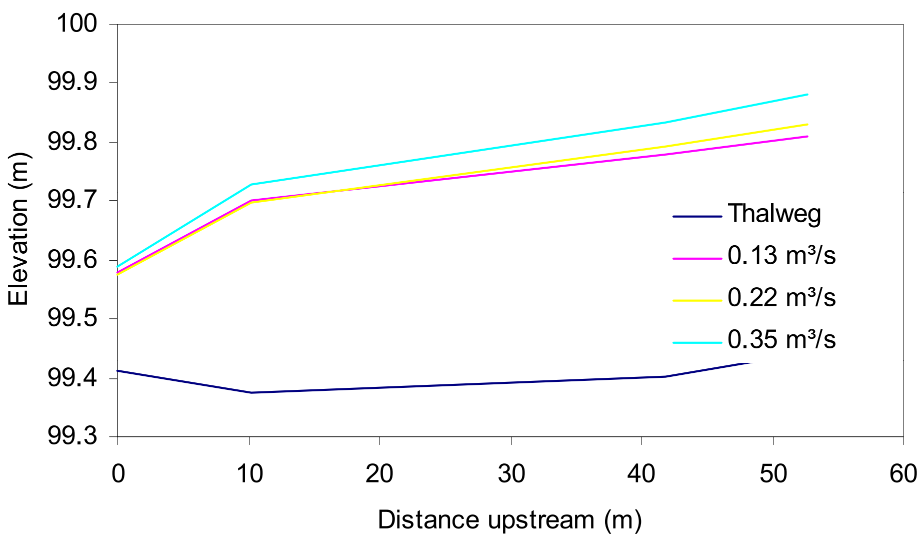


Figure C4.6 West Stafford Carrier: measured water surface profiles

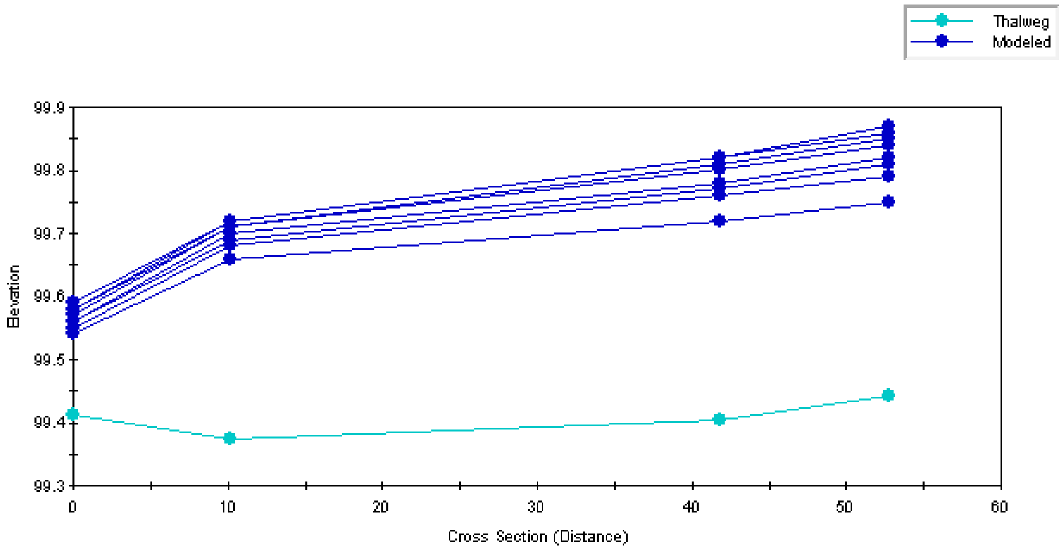


Figure C4.7 West Stafford Carrier: simulated water surface profiles.

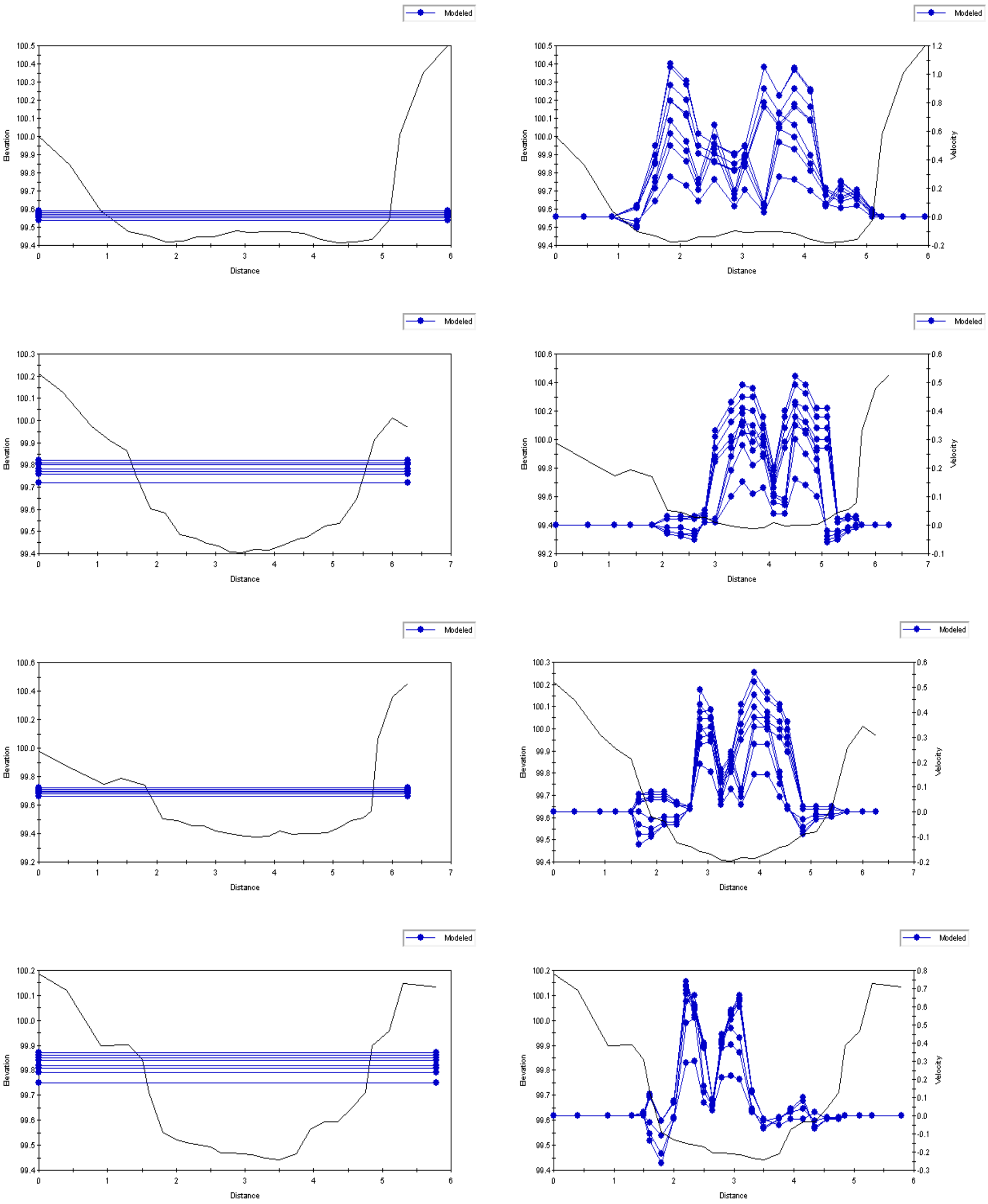


Figure C4.8 West Stafford Carrier: Simulated water surface levels and velocities

APPENDIX D:
HYDRAULIC TESTING: DETAILED RESULTS

River Walkham Habitat Survey 1
Discharge: 0.58 m³/s

Re-weighted PHABSIM

	3	4	5	6	7	8	Total
4		5.0	1.4	1.4	0.9	0.0	8.6
5		8.8	4.4	9.0	5.4	2.6	30.1
6		**15.3**	8.9	9.0	6.8	0.0	40.0
7		5.1	6.4	8.9	5.9	2.2	28.5
8		10.2	7.2	**22.1**	1.4	0.9	41.8
9							0.0
Total		44.3	28.2	50.4	20.4	5.7	149.0

Re-weighted Availability

	3	4	5	6	7	8	Total
4	2.5	5.0	3.0	4.5	0.5	1.5	16.9
5	2.5	6.0	6.0	12.0	4.5	3.5	34.4
6	1.0	**6.0**	8.5	9.5	8.0	4.0	36.9
7	1.0	4.5	5.5	9.0	4.0	2.5	26.4
8	4.0	4.5	5.0	**14.5**	1.5	2.0	31.4
9	0.5		0.5	1.5	0.5		3.0
Total	11.0	25.9	27.9	49.3	18.4	13.5	149.0

Chi-squared test

Availability (Expected)	PHABSIM (observed)	chi-squared
7.5	5.0	0.8
8.5	8.8	0.0
7.0	15.3	**10.0**
5.5	5.1	0.0
9.0	10.2	0.2
9.0	5.8	1.2
5.5	7.2	0.5
16.4	10.3	2.3
15.9	22.1	2.4
10.0	8.9	0.1
12.0	6.8	2.3
10.5	10.4	0.0
8.5	8.9	0.0
9.5	9.0	0.0
5.5	6.4	0.2
9.0	8.9	0.0

chi-squared	19.91
df(n-1)	15
probability	**0.18**

River Walkham Habitat Survey 2
Discharge: 0.27 m³/s

Re-weighted PHABSIM

	3	4	5	6	7	8	Total
4	2.6	8.1	3.5	7.7	1.0	0.0	22.8
5	6.7	9.3	7.8	6.6	4.4	0.0	34.8
6	**1.2**	**15.7**	3.4	9.9	1.1	1.2	32.5
7	1.0	7.6	5.4	3.5	2.1	0.0	19.6
8	0.0	13.6	7.3	5.4	0.0	0.0	26.3
9							0.0
Total	11.5	54.3	27.4	33.0	8.6	1.2	136.0

Re-weighted habitat availability data

	3	4	5	6	7	8	Total
4	2.5	7.6	3.2	3.8	1.9	1.9	20.9
5	5.7	9.5	6.3	11.4	1.9	0.6	35.4
6	**2.5**	**7.0**	5.7	12.0	3.2	3.2	33.5
7	3.2	5.7	3.8	5.7	3.8	1.3	23.4
8	2.5	10.1	3.2	3.8	2.5		22.1
9			0.6				0.6
Total	16.4	39.9	22.1	36.7	13.3	7.0	136.0

Chi-squared test

Availability (Expected)	PHABSIM (observed)	chi-squared
10.1	10.7	0.03
15.2	16.0	0.04
9.5	16.9	**5.80**
8.9	8.7	0.00
12.7	13.6	0.07
7.0	11.2	2.53
9.5	8.8	0.05
17.7	13.3	1.08
7.6	12.7	3.45
20.2	9.8	**5.37**
6.3	7.8	0.35
11.4	6.6	2.04

chi-squared	20.8
df(n-1)	11.00
probability	0.035

River Walkham Habitat Survey 3
Discharge: 1.28 m³/s

Re-weighted PHABSIM

	3	4	5	6	7	8	Total
4	1.1	3.9	0.7	4.6	1.1	0.0	11.3
5	0.0	4.0	3.9	5.2	0.4	0.0	13.5
6	0.0	7.7	3.9	4.9	6.9	9.8	33.2
7	0.0	6.4	10.3	8.0	5.4	5.1	35.3
8	0.0	6.6	17.3	**32.8**	13.1	8.1	77.9
9	0.0	0.0	0.0	**4.8**	0.0	0.0	4.8
Total	1.1	28.6	36.1	55.5	26.9	23.0	176

Re-weighted Availability

	3	4	5	6	7	8	Total
4	1.2	1.8	1.8	2.4	3.0	0.6	10.7
5	2.4	5.4	3.6	4.8	4.2	7.7	27.9
6	3.6	5.9	3.6	10.7	8.3	4.2	36.3
7	0.0	6.5	3.0	9.5	11.3	6.5	36.9
8	2.4	8.3	8.3	**17.8**	16.1	6.5	59.5
9		0.6	0.6	**1.8**	1.8		4.8
Total	9.5	27.9	20.2	45.2	42.8	25.6	176

Chi-squared test

Availability (Expected)	PHABSIM (observed)	chi-squared
10.7	9.0	0.3
9.5	7.7	0.3
6.5	6.4	0.0
11.3	6.6	2.0
8.9	8.4	0.0
12.5	18.3	2.7
8.9	17.3	7.9
7.1	9.7	0.9
19.6	37.6	**16.5**
15.5	8.4	3.2
17.8	10.6	3.0
17.8	13.1	1.2
12.5	9.8	0.6
6.5	8.1	0.4
10.7	4.9	3.1

chi-squared	42.2
df(n-1)	14.0
probability	0.000

River Piddle Habitat Survey 1
Discharge 0.94 m³/s

Re-weighted PHABSIM

	3	4	5	6	7	8	Total
4	6.0	2.1	0.0	0.7	0.8	0.0	9.64
5	4.8	5.9	1.6	2.5	1.5	0.0	16.18
6	8.3	8.8	1.7	9.4	8.4	1.8	38.41
7	4.6	8.6	3.8	9.4	5.6	0.0	31.98
8	6.9	11.0	10.6	69.9	4.3	0.0	102.62
9	1.5	1.6	0.9	22.2	0.0	0.0	26.17
Total	30.5	36.3	17.7	91.9	20.7	1.8	225.00

Re-weighted Availability

	3	4	5	6	7	8	Total
4	1.3	0.7	0.0	1.3	0.7	0.0	4.0
5	2.0	3.3	2.0	6.0	4.0	0.7	18.0
6	4.7	4.0	1.3	13.4	6.7	0.7	30.7
7	4.0	2.7	2.7	16.7	4.0	0.0	30.0
8	13.4	16.0	13.4	55.4	4.0	0.0	102.2
9	2.0	4.7	16.7	16.7	0.0	0.0	40.1
Total	25.4	26.7	19.4	92.8	19.4	1.3	225.0

Chi-squared test

	Availability (Expected)	PHABSIM (observed)	chi-squared
	7.3	18.7	**17.6**
	8.7	17.1	8.2
	6.7	13.1	6.3
	15.4	8.4	3.2
	20.7	12.6	3.2
	6.0	7.1	0.2
	20.7	12.6	3.2
	12.7	12.6	0.0
	8.0	9.9	0.4
	30.0	11.4	**11.5**
	16.7	9.4	3.2
	55.4	69.9	3.8
	16.69	22.2	1.8

chi -squared	60.7
n=	12.0
probability	0.000

River Piddle Habitat Survey 2
Discharge 1.23 m³/s

Re-weighted PHABSIM

	3	4	5	6	7	8	Total
4	12.8	1.9	0.0	1.6	0.0	0.0	16.3
5	8.0	10.1	0.7	2.3	0.7	0.0	22.0
6	2.7	12.7	1.6	**5.3**	10.8	1.8	34.8
7	4.9	7.4	5.2	9.1	6.5	0.0	33.1
8	5.5	13.7	7.9	64.3	16.7	0.0	108.0
9	0.0	3.8	0.9	21.8	1.2	0.0	27.7
Total	33.9	45.9	15.4	82.6	34.7	1.8	242.0

Re-weighted Availability

	3	4	5	6	7	8	Total
4	4.4	2.2	0.7	2.2	0.7	0.0	10.2
5	2.9	2.9	1.5	9.5	4.4	0.7	21.9
6	1.5	4.4	1.5	16.8	8.0	0.0	32.2
7	5.1	2.9	1.5	16.1	5.1	0.0	30.7
8	16.1	9.5	24.1	57.8	1.5	0.0	108.9
9	2.2	5.1	19.0	11.7	0.0	0.0	38.0
Total	30.0	21.9	29.2	102.4	19.7	0.7	242.0

Chi-squared test

	Availability (Expected)	PHABSIM (observed)	chi-squared
	6.6	14.7	10.1
	5.8	18.2	**25.9**
	5.8	15.4	15.5
	8.0	12.3	2.3
	18.3	5.5	8.9
	14.6	17.5	0.6
	13.9	4.7	6.1
	32.9	14.4	10.4
	30.7	22.7	2.1
	13.9	13.3	0.0
	6.6	24.4	**48.2**
	24.1	7.9	10.9
	57.8	64.3	0.7

chi-squared	141.9
n=	12
probability	0.000

River Piddle Habitat Survey 3
Discharge 2.10 m³/s

Re-weighted PHABSIM

	3	4	5	6	7	8	Total
4	6.3	9.7	0.0	1.1	0.0	1.4	18.5
5	2.5	9.0	0.8	0.0	0.0	4.0	16.3
6	1.3	11.1	2.8	1.4	0.7	3.8	20.9
7	0.0	6.5	4.2	**4.9**	3.5	9.7	28.8
8	1.5	22.3	4.6	40.4	62.7	2.3	133.8
9	0.0	6.5	3.2	25.4	16.7	0.0	51.8
Total	11.6	58.6	12.4	**47.8**	66.8	21.1	270.0

Re-weighted Availability

	3	4	5	6	7	8	Total
4	0.8	0.0	0.0	0.0	0.0	0.0	0.8
5	4.8	0.8	0.8	0.0	0.0	0.0	6.4
6	3.2	1.6	0.8	0.0	0.0	0.0	5.6
7	1.6	1.6	0.8	**4.0**	0.8	0.0	8.8
8	3.2	24.7	22.3	61.3	33.5	1.6	146.5
9	4.8	6.4	8.8	67.7	14.3	0.0	101.9
Total	13.5	28.7	24.7	**65.3**	34.2	1.6	270.0

Chi-squared test

	Availability (Expected)	PHABSIM (observed)	chi-squared
	6.4	27.5	**69.9**
	8.0	18.8	**14.8**
	39.0	30.3	1.9
	6.4	15.1	12.1
	31.1	7.8	17.4
	35.8	87.9	**75.7**
	14.3	16.7	0.4
	61.3	40.4	7.1
	67.7	25.4	**26.4**

chi -squared	225.8
n=	8.0
probability	0.000

River Senni Habitat Survey 1
Discharge: 0.76 m³/s

Re-weighted PHABSIM

	3	4	5	6	7	8	Total
4	3.2	2.5	3.2	7.7	2.1	0.0	18.7
5	5.8	6.1	5.6	10.8	4.1	4.5	36.8
6	1.7	7.9	2.7	4.0	7.5	3.4	27.0
7	1.0	6.5	3.1	5.6	8.9	5.7	30.8
8	1.5	11.2	13.5	29.6	1.1	3.7	60.5
9	0.0	2.5	2.5	5.2	0.0	0.0	10.2
Total	13.1	34.1	28.1	57.7	23.7	17.2	184.0

B2 Reweighted Availability

	3	4	5	6	7	8	Total
4	1.4	4.1	3.2	2.3	1.4	0.0	12.3
5	4.1	7.3	6.4	9.1	3.6	3.6	34.2
6	3.6	5.5	4.6	9.1	8.7	5.5	36.9
7	0.9	4.6	4.1	14.6	5.5	1.8	31.4
8	1.8	10.0	12.8	27.3	5.9	3.2	61.0
9	0.5	1.4	1.8	4.1	0.5	0.0	8.2
Total	11.8	31.4	31.0	62.4	25.0	14.1	184.0

Chi-squared test

Availability (Expected)	PHABSIM (observed)	chi-squared
5.5	5.7	0.0
7.7	7.5	0.0
5.5	7.4	0.7
13.7	15.1	0.2
9.6	8.8	0.1
8.7	5.8	0.9
14.6	16.0	0.1
11.4	18.5	4.4
23.7	9.6	**8.4**
31.4	34.8	0.4
8.7	10.7	0.5
7.3	9.1	0.4
9.6	9.6	0.0
7.3	6.1	0.2
5.5	7.9	1.1
8.7	7.5	0.2
5.5	8.9	2.2

chi-squared	19.7
df(n-1)	16
probability	**0.233**

River Senni Habitat Survey 2
Discharge 0.38 m³/s

A2 Reweighted PHABSIM

	3	4	5	6	7	8	Total
4	7.6	2.7	2.6	**9.5**	0.8	0.0	23.2
5	3.9	5.3	4.5	6.5	2.2	0.0	22.5
6	2.1	7.4	2.2	6.4	8.3	7.6	34.1
7	3.3	5.8	8.4	7.7	1.4	0.0	26.6
8	0.6	9.3	**21.8**	6.5	0.0	0.0	38.3
9	0.0	0.0	**1.4**	0.0	0.0	0.0	1.4
Total	17.6	30.6	39.5	36.6	12.7	7.6	146.0

B2 Reweighted Availability

	3	4	5	6	7	8	Total
4	4.9	4.5	0.9	**2.7**	0.4	0.4	13.9
5	8.5	8.1	7.2	9.0	1.8	5.4	40.0
6	4.0	6.7	4.5	10.8	2.2	1.8	30.1
7	2.2	9.0	6.7	4.0	1.8	1.3	25.2
8	3.6	13.5	**10.3**	6.3	0.4	0.4	34.6
9	0.4	1.3	**0.4**	0.0	0.0	0.0	2.2
Total	23.4	41.8	29.6	32.8	6.7	9.4	146.0

Chi-squared test

	Availability (Expected)	PHABSIM (observed)	chi-squared
	9.4	10.4	0.1
	8.1	7.1	0.1
	11.7	16.0	1.6
	16.6	9.3	3.3
	10.8	9.5	0.2
	11.2	9.1	0.4
	11.2	10.6	0.0
	14.8	14.1	0.0
	18.9	9.9	4.2
	10.8	23.2	**14.4**
	6.7	12.7	5.2
	9.4	7.6	0.4
	6.3	6.5	0.0

chi-squared	29.9
df(n-1)	12
probability	0.003

River Frome at West Stafford Habitat Survey 1
Discharge: 0.50 m³/s

Re-weighted PHABSIM

	3	4	5	6	7	8	Total
4		2.9					2.9
5	6.6	5.3	1.2				13.1
6	3.5	15.4	7.3	22.3	9.1	1.4	59.0
7	2.6	32.2	13.5	7.0	6.3	2.4	63.9
Total	12.7	55.8	22.0	29.4	15.4	3.8	139

Re-weighted Availability

	3	4	5	6	7	8	Total
4		0.9					0.9
5	1.3	2.2	0.9	0.9			5.3
6	4.8	11.4	7.9	15.0	9.7		48.8
7	15.4	17.6	9.7	22.0	18.9	0.4	84.0
Total	21.6	32.1	18.5	37.8	28.6	0.4	139.0

Chi-squared test

	Availability (Expected)	PHABSIM (observed)	chi-squared
	4.4	14.8	**24.7**
	16.3	18.9	0.4
	8.8	8.5	0.0
	15.8	22.3	2.7
	9.7	10.5	0.1
	33.0	34.8	0.1
	19.4	8.7	5.9
	9.7	13.5	1.5
	22.0	7.0	**10.2**

chi-squared	45.5
df(n-1)	8
probability	**0.000**

River Frome at West Stafford Habitat Survey 2
Discharge: 0.24 m³/s

Re-weighted PHABSIM

	3	**4**	**5**	**6**	**7**	**8**	**Total**
4	4.0	6.6	0.8				11.3
5	1.4	6.6	3.2	4.9	0.4	0.4	16.9
6	9.6	31.4	13.5	**17.6**	5.6	0.6	78.4
7	3.8	9.0	4.7	3.6	2.2		23.4
Total	18.7	53.7	22.2	26.2	8.2	1.0	130.0

Re-weighted Availability

	3	**4**	**5**	**6**	**7**	**8**	**Total**
4	0.9	1.8	0.9		0.5		4.1
5	0.5	20.4	5.4	5.9	2.7		34.9
6		38.5	11.8	**27.2**	5.4		82.9
7		6.8		0.5	0.9		8.2
Total	1.4	67.5	18.1	33.5	9.5	0	130.0

Chi-squared test

	Availability (Expected)	PHABSIM (observed)	chi-squared
	23.6	18.5	1.1
	12.7	8.9	1.1
	41.0	38.5	0.2
	6.8	12.8	**5.4**
	11.8	18.2	**3.6**
	28.5	23.5	0.9
	8.2	7.0	0.2

chi-squared	12.4
df(n-1)	6
probability	**0.054**

Frome Carrier Habitat Survey 1
Flow of 0.15

PHABSIM Data

	3	4	5	6	7	8	Total
4		3	2		2		7
5		5	4	3	5		17
6		24	3	11	7		45
Total		32	9	14	14	0	69

Habitat Availability

	3	4	5	6	7	8	Total
4	2.7	1.1	0.5		0.5		4.9
5		8.8	1.1	3.8	10.4	0.5	24.6
6		12.6	3.3	8.2	15.3		39.4
Total	2.7	22.5	4.9	12.0	26.3	0.5	69.0

	Availability (expected)	PHABSIM (observed)	chi-squared
	4.4	5	0.1
	11.5	7	1.8
	4.4	7.0	1.6
	12.0	14	0.3
	21.4	29	**2.7**
	15.3	7	**4.5**

chi-squared	11.0
df(n-1)	6
probability	0.089

APPENDIX E:
RESTATEMENT OF PHABSIM DATA COLLECTION AND MODELLING PROCEDURES

E1. Introduction

PHABSIM is a flexible modelling tool allowing the assessment of changes in physical habitat with changes in discharge regime, or channel morphology, for a wide range of rivers. Individual application of the model will vary greatly depending on the issues involved, the river(s) in question and the target species being assessed. However, in general terms, the procedures used when applying PHABSIM to water resource issues elsewhere in the UK have been based on the following procedures.

E2. Scoping Phase

This section is taken from Dunbar *et al.* 1996 and based on earlier work by Bovee and others.

Prior to the initiation of a PHABSIM project, a number of scoping activities are essential. However there is no one 'correct' way to perform a PHABSIM study and actual methodologies used will depend in part on the scope and objectives of the study. Major types of study include:

- Assessment of future project impact
- Assessment of impact of current water resources scheme
- Determination of instream flow requirements (management objectives) for a river system
- Use of the model as a research tool

Project scoping should follow a pragmatic approach based on the perceived importance of the issues to be addressed. The following sections are suggested as a guide only, each should include supporting evidence for the choices made.

1. A statement of study objectives (**why?**). The outputs, expectations and requirements of the project should be stated in as much detail as practicable and agreed before starting.

2. Identification of the impacted areas or areas to be studied **(where?)**. Decision on the best approach to study site selection: critical reach or habitat mapping, and preliminary characterisation of study sector or sectors.

3. Identification of skills required and selection of personnel. Application of PHABSIM requires the skills of a multi-disciplinary team, including skills in aquatic biology, hydrology, hydraulic modelling, interpretation of the PHABSIM hydro-ecological models, and negotiation.

4. Confirmation that physical habitat is the main factor limiting target species populations. This may include characterisation of macrohabitat issues (e.g. water quality and temperature) and consideration of further factors such as exploitation and stocking, food availability and competition, channel dynamics and sediment transport. Some of these aspects will be best addressed with other models, or using more conventional techniques such as multivariate regression.

5. Selection of target species and life stages (**who?**). It will probably not be possible to evaluate effects on all species in a river. Management objectives, combined with advice from fisheries and conservation personnel will determine if the study is to concentrate on a broad range of species, or one specific species or even life stage. It should also be noted that an important component of the IFIM, is assessing trade-offs between the discharge regimes required by different species / life stages. Food availability for some fish species may be modelled using habitat suitability data for selected invertebrate communities.

One method used to select species is to rank them numerically, according to various criteria, including their importance, vulnerability and extent of available information.

Scoping should locate any existing sources of habitat suitability information, their 'transferability' (see below), as well as possible strategies for suitability curve development, should existing information not be available or comprehensive enough. The importance of characterising fish species by size / age class cannot be underestimated, as size may have a significant impact on habitat use. The classification to be used must of course be compatible with suitability data.

6. Construction of species periodicity charts, identification of hydrological regime **(when?)** Consideration of location of gauging stations.

E3. Hydraulic data collection

(for further details see Elliott *et al.* 1996).

1. Using a habitat mapping approach, identify the habitats (e.g. pools, glides, riffles) available within the appropriate river sectors and their relative occurrence. Then define a "representative" reach, or reaches, within the selected river sectors, which contain examples of these habitats which may then be used for PHABSIM modelling.

2. Select study transects within each representative reach to characterise each habitat type and to satisfy the data requirements of the PHABSIM hydraulic and habitat models as necessary.

3. Mark the position of each transect within the study reach, survey the relative elevation of each transect to a fixed datum level and measure the inter-transect distances.

4. Survey the topographic shape of each transect using sufficient data collection points to represent the habitat available within the transect (all further observations refer to these same data collection points).

5. Observe the dominant substrate (or other fixed channel characteristic as necessary) at each data collection point.

6. Under steady discharge conditions, measure the mean column velocity at each wetted survey point and survey the water surface elevations relative to the fixed datum level.

7. Repeat step 6 on further occasions (e.g. under high, medium and low discharges) to provide sufficient data to allow rigorous simulation of the physical habitat properties (i.e. flow depths and velocities and their associated substrate) of the river reach over the full range of simulation discharges required.

8. Enter data into spreadsheets in IH metric format (designed as part of R&D project "Ecologically Acceptable Flows Phase II" R&D Report W20 for the Environment Agency.

9. Run check programs to check consistency of data and indicate which hydraulic modelling approach is appropriate

E4. PHABSIM hydraulic modelling

Full details of the hydraulic modelling procedures that can be applied with PHABSIM are contained elsewhere (Elliott *et al.*, 1996, Dunbar *et al.* 1996). PHABSIM hydraulic modelling is a two-stage process, involving firstly modelling of water surface levels (a one-dimensional up/down stream process) and secondly modelling of velocities, which are modelled one-dimensionally across *each* cross-section. Thus accurate modelling of water level is required not only for precise description of depths, but also for good velocity predictions.

Hydraulic modelling can be the most technically demanding aspect of a PHABSIM application, and it is recommended that someone undertaking this either have some grounding in open channel hydraulic modelling, or have attended a PHABSIM training course.

E4.1. Water surface level modelling

The approaches available for modelling of water surface levels are listed in Table E-1 below.

Table E-1. PHABSIM water surface level models

Method	Model name	Sets of WSL data required	Notes
1. Stage-discharge using a log-log relationship	IFG4	2 (but 3 recommended)	Best for simple applications
2. Use of Manning's equation	MANSQ	1 (but 3 recommended)	Good for channel control
2. The step-backwater method	WSP	1 (but 3 recommended)	Good for backwater effects. Requires a starting set of WSLs from the downstream cross section.

Many rivers have compound control, ie the location and number of hydraulic controls can change as the discharge is varied. It is thus possible for a PHABSIM application to use different models and different transects at different discharges, in order to produce a robust model calibration. Available resources may limit the degree to which hydraulic modelling may be taken.

In a typical PHABSIM study, a first attempt is usually made at calibrating the IFG4 model, as this is the simplest procedure. IFG4 fits a straight line regression to a log-log graph of stage versus discharge. Examination of this relationship for the calibration discharges at each cross section can clearly indicate if this assumption is valid. Two common reasons for it being invalid are more complex channel morphology (e.g. a stepped channel or uneven bottom) and backwater effects.

Once calibrated, IFG4 may then be used to simulate water surface levels within and outside the calibration discharge range. Plots of these simulated discharges provide a clear indication of model performance, again IFG4 works well in simple channels and can have problems with backwater effects.

If IFG4 does not prove suitable (for example if it is clear that the stage-discharge relationship does not follow log-log form), one of the other models should be used. These use a greater combination of applied hydraulic theory in their calculations. Although these models may be used with less data with IFG4, best results use the same amount of data, i.e. water surface levels for at least three discharges.

For complex situations, a MANSQ model of water surface levels, or ideally the stage-discharge relationship taken from a data logger at the most downstream cross section, combined with levels calculated by WSP at cross sections upstream is the usual way to proceed. Complex situations may also require a 'mixed model' approach, possibly using more than three sets of calibration data.

E4.2. Velocity simulation

The IFG4 model is used to simulate velocities across each cross section. The channel is divided up into the measurement cells as described above, and velocity measurements from current metering are used to calibrate a model based on Manning's equation. It assigns an roughness value to each cell, based on water surface level and calibration velocity.

To compensate for the fact that effective roughness across the river changes with discharge, IFG4 also assigns velocity adjustment factors (VAFs) to each cross section at each calibration discharge. It does this by calculating a theoretical discharge from summing velocity multiplied by area for each cell across a cross section and comparing this to the known discharge. A VAF for each simulated discharge and cross section is calculated, and used to ensure a mass balance of water between cross sections at all simulated discharges.

The recommended approach is to calibrate the model on just one set of velocity data. The choice of which calibration discharge to use the velocity set from (and thus to collect field data for) should be documented. Sometimes, field conditions will prevent current metering at high velocity, so the medium discharge can be used. This requires some educated guesswork in assigning roughness values to areas of channel which are infrequently inundated, but this is still acceptable. It is not generally considered sensible to extrapolate up from the lowest velocity set, but it is stressed that each situation will be different and should be considered on its own merit.

Other calibration velocity sets should be compared with simulation outputs, if inaccurate, the modeller should consider simulating ranges of discharge using other velocity sets, and combining results.

E5. Habitat suitability indices

E5.1. Introduction

A fundamental assumption of PHABSIM studies is that the target species/life stages exhibit a quantifiable preference/avoidance behaviour to certain levels of one, or more, physical microhabitat variables i.e. depth, mean column velocity and substrate and cover type. These habitat requirements are represented by functions known as Habitat Suitability Indices (HSI). HSIs are curves describing the suitability, ranging from 0 (unsuitable) to 1 (most suitable), of each of the microhabitat variables. Since individual target species and life stages may exhibit different habitat requirements, it may be necessary to develop HSI relationships for different life stages of each target species. This may be carried out using published data, expert opinion, or by field observations. Figure 2.2 presents examples of HSI data developed by using direct observation to develop a relationship between the relative species frequency and a given physical characteristic. The relationships illustrated are for the fry/juvenile life stage of brown trout living in lowland chalk streams in southern UK (Bird *et al* 1995) and have been normalised to show the relative suitability of depth, velocity and substrate. More detailed information on current practice for using HSIs is contained in this report. Further background information is contained in Bovee (1986), Bovee and Zuboy (1988) and Bovee et al. 1998. Readers should note that some recommendations in earlier work have been superseded.

E5.2. Target species, life stages and habitat variables

E*5.2.1 Selection of target species*

The first step in developing HSIs is to identify the target species and life stages that are to be the subjects of the PHABSIM study. Obviously, the eventual choice will depend on the objectives of the study, but there is no limit to the number of species or life stages that can be incorporated into any one study. Often, in multi-species situations it is useful to concentrate on a species from each functional group, if that is possible. Some other studies may have different priorities such as the protection of endangered species, or sport fishery interests.

E5.2.2 Discrete and continuous variables

The four commonly used variables in the PHABSIM model are depth, velocity, substrate and cover. Variables such as substrate and cover type tend to be coded as discrete, and developed in the form of categorical histograms rather than continuous functions. Conditional criteria (see below) may also be developed using categorical variables. Depth and velocity are continuous variables and therefore can be drawn as curves, although they may also be put into categories of varying sizes.

E5.2.3 Conditional indices

These employ a separate set of criteria for each category of a discrete variable. Typically, these are useful in describing behavioural interactions with variables such as depth and cover.

For example, some species of fish may exhibit cover conditional behaviour; that is using shallow water only in the presence of cover or fast flowing water only where there is large substrate to shelter behind.

E5.2.4. Stratification of HSIs

This refers to the division of HSIs to reflect changes in size, behaviour pattern, season, life stage etc. Commonly, this will include changes in diurnal or seasonal use of habitat, species associations or water quality characteristics.

A good example is the life stage periodicity chart (Table E-2). This will focus the investigator on key times of the year and indicate discrete periods when life stages are absent or present. It is advisable to be generous when designating the seasons that life stages are present or absent because annual variations in weather patterns can move the time intervals forwards or backwards.

Table E-2 Example species and life stage periodicity chart.

	Autumn			**Winter**			**Spring**			**Summer**		
Target Species/Life Stage	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**
Adult Trout	x	x	x	X	x	x	x	x	x	x	x	x
Juvenile Trout								x	x	x	x	x
Fry Trout						x	x	x	x			
Spawning Trout		x	x	X	x							

E5.4. Format of Habitat Suitability Index

'Format' refers to the manner in which the habitat suitability variables are used within PHABSIM. Examples are binary, univariate and multivariate. Further details are contained in Elliott *et al.* 2000.

E6. Habitat modelling

The habitat models within PHABSIM are used to calculate the area of habitat available within the study reach, for each target species/life stage at each simulation discharge. This available habitat is termed "Weighted Usable Area" (WUA) and is expressed in m^2 per 1000m of river. The computation of WUA, for a selected study reach at a given simulation discharge, is based on the summation of individual "cell" values (WUA(*i*)) over a computational grid. This "grid" is defined across the river by the data points spaced across each study transect. WUA for each transect is then weighted by the relative importance of its habitat type in the represented river sector as a whole. The values of depth (D*i*), velocity (V*i*) and channel index (frequently substrate, S*i*) for each individual cell, at each simulation discharge, are output from the hydraulic model simulations.

For a given target species/life stage, the WUA is calculated by weighting the total available stream area at a given discharge by a measure of its suitability to the species/life stage. For applications using *univariate HSIs*, assessment of suitability is based on the computation of a composite suitability index (CSI) which combines estimates of suitability for three microhabitat variables: depth, mean column velocity and substrate (or cover) type. For a given data point in the computational grid defined above the CSI is defined as:

$$CSI(Vi, Di, Si) = HSIV(Vi) * HSID(Di) * HSIS(Si)$$

Where HSIV, HSID and HSIS are the individual habitat suitability indices for velocity, depth and substrate, respectively.

The cell WUA, WUA*i*, associated with data point *i* is defined by:

$$WUAi = CSI(Vi, Di, Si) * Ai$$

Where A*i* is the area of the cell surrounding data point *i*. The total WUA for the study reach is then given by the sum of the individual WUA*i* values. In order to compare habitat area predictions from different reaches and different rivers, it is convenient to standardise the estimated WUA by the reach length (*L*) and to express the WUA in terms of habitat area per 1000m length of river:

$$WUA = \left(\left(\sum WUAi \right) / L \right) * 1000$$

For multivariate HSIs, habitat suitability is represented by a multivariate function of any number of hydraulic or non-hydraulic variables. Calculation of composite suitability is then made by sequentially entering the modelled combinations of these variables into the function. This is currently best undertaken in a spreadsheet package using the standard PHABSIM hydraulic output data.

APPENDIX F: DESCRIPTION OF DATABASE

The EAF III field survey campaign began in June 1999 resulting in the collection and storage of a vast array of both hydraulic and ecological data. The data vary from physical habitat conditions at a given fish location within a river reach to a detailed survey of a river reach including bed elevation, velocity data and water surface profiles. The collection of these data necessitated the implementation of a database to facilitate their access and retrieval.

The data collected can be divided into three sections, firstly habitat availability data, secondly fish location data and finally PHABSIM calibration data. Surveys were carried out on variety of rivers on three separate occasions and as a result each trip would require a unique reference number, which can be seen below.

River name	Catchment	Site	Unique site code
Walkham	Devon	Ward Bridge / Upstream	1WWBU
Walkham	Devon	Ward Bridge / Downstream	1WWBD
Plym	Devon	Ham	2PHB
Meavy	Devon	Dewerstone	3MD
West Dart	Devon	Crockern Tor	4WDCT
Piddle	Piddle	Higher Hyde / Downstream	5PHHD
Piddle	Piddle	Higher Hyde / Upstream	5PHHU
Piddle	Piddle	Throop	5PT
Bere Stream	Piddle	Higher Hyde / Upstream	6BSHHU
Bere Stream	Piddle		6BS
Frome	Frome	West Stafford	7FWS
Frome	Frome	West Stafford Carrier	7FWSC
Cerne	Frome	Manor House	9CEMH

The following data were collected on each survey:

Data Type	Example	Notes
Site code	1WWBU	Formed from a sequential number for the river, 2-3 characters for the river and site, and a single sub-site letter classification.
Survey number	2	Values of 1,2,3
Staff measuring / recording	IG	
Day/time measurement taken	1/3/1999 13.45	
Distance upstream / across	20 / 1.5	Measured in metres
Water depth	.43	Depth in meters, measured with wading rod
Surface flow angle / direction	12	Relative to 12 oclock = directly upstream
Mean column velocity	0.125	Velocity taken at .6 of depth measured from surface, using current meter 30 second averaging
Substrate *	5F40.8	Refer to substrate coding scheme
Distance to overhanging cover > .5m and < .5m	0.8	Refers to height above water
Instream cover distance	0.2	Measured in metres
Instream cover type *	W	Refer to cover type coding scheme
Surface Flow type *	RP	Refer to flow type coding scheme (Table 5.1)
Data unique to Fish observations: recorded by snorkelling team		
Fish marker no.	136	Marker number assigned to fish location
Species	S	Salmon / Brown Trout / Sea Trout / Other
Size	.05	
Distance off bed	.01	Distance off the bed the fish was observed
Activity *	F	Refer to activity coding scheme
Date/time obs	1/3/99 12.34	Day/time of fish observation
Staff obs	NM	Staff member snorkeling
Fish angle	11	Angle fish was pointing when observed
Unique to PHABSIM survey		
Transect number	1	
WSL	2.315	Mean water surface level across transect
Levelling loop		Elevation of transect marker pegs relative to common datum

Substrate coding scheme

Coding	Explanations
0	organic detritus
1	rooted vegetation annotated by (in place of ‘0’) qualify by:
T	terrestrial (only likely during flood flows)
A	aquatic
2	clay (cohesive)
3	silt (non-cohesive)
4	sand (0.062-2mm)
5	gravel (2-64mm) (nb record if Fine (2-8) or Coarse (9-64)
6	cobble (64-250mm) (nb record if Fine (64-128) or Coarse (65-250)
7	boulder (250+mm)
8	bedrock
9	man-made (concrete etc)

Activity of fish coding scheme

Code	Activity
F	Feeding
A	Active
R	Resting

APPENDIX G:
SITE PHOTOGRAPHS

Plate A: River Piddle looking upstream from cross section 3.

Plate B: River Walkham looking downstream from cross section 7.

Plate C: River Senni looking downstream.

Plate D: River Frome, West Stafford downstream

Plate E: River Frome, West Stafford upstream

Plate F: River Frome, carrier looking upstream