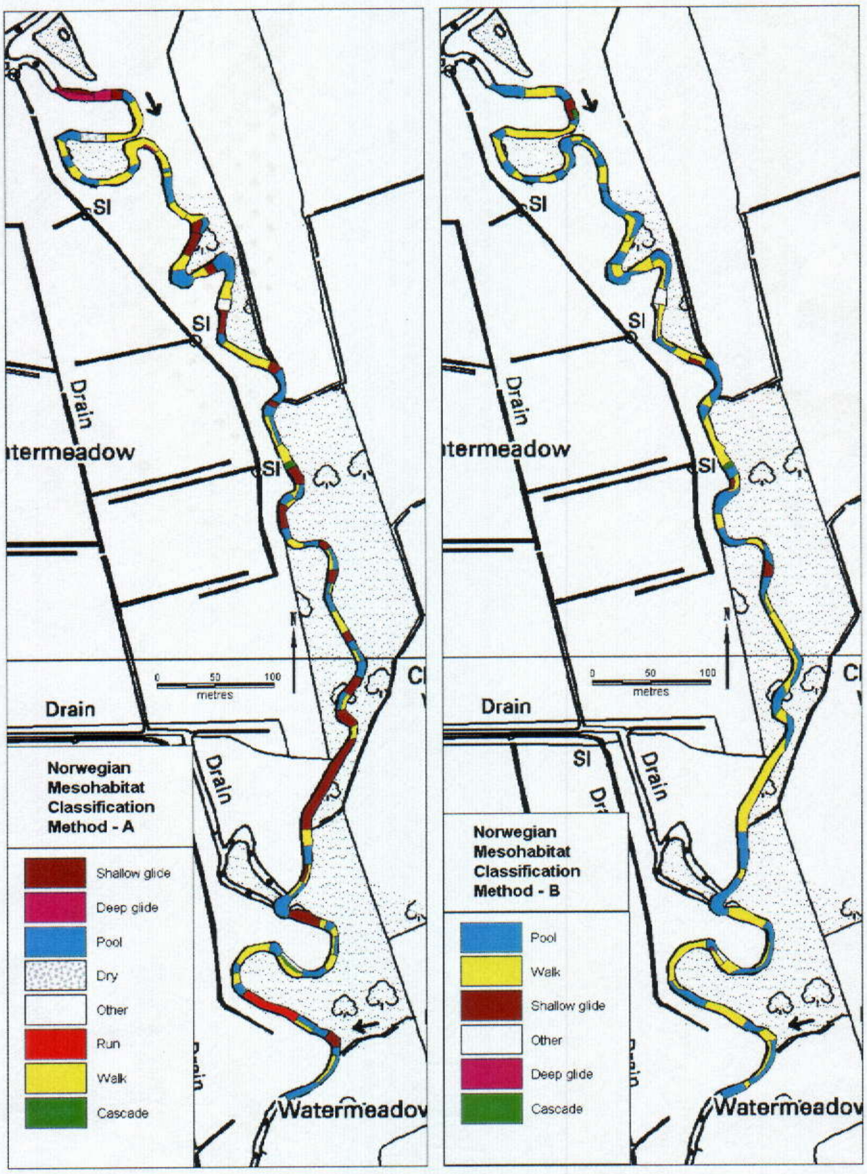
University of Worcester

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

River Habitat Mapping: A Comparison of Approaches Based on a Field Workshop on the River Windrush, July 2004



R&D Project: RAPHSA - Rapid Assessment of the Physical Habitat Sensitivity to Abstraction

May 2006

Project details

Title:	River Habitat Mapping: A Comparison of Approaches Based on a Field Workshop on the River Windrush, July 2004
Project Managers:	Mike Acreman (CEH) and Mike Dunbar (CEH)
Project Manager: **Researcher:**	Ian Maddock (University of Worcester) Graham Hill (University of Worcester)
Bibliographic Details:	Maddock I. & Hill, G. (2005) *River Habitat Mapping: A Comparison of Approaches Based on a Field Workshop on the River Windrush, July 2004.* Report to the Centre for Ecology and Hydrology. CEH Wallingford.

Table of Contents

List of figures

List of tables

1. Background

1.1 Context of this report

The Centre for Ecology and Hydrology (CEH) are undertaking an R&D project with the Environment Agency (EA) on the Rapid Assessment of the Physical Habitat Sensitivity to Abstraction (RAPHSA) (EA Project W6 – 094, CEH Project C02388/C01753). The overall objective of the project is to investigate the technical feasibility of developing a catchment wide tool to determine the sensitivity of physical habitat to abstraction, thus assisting in setting environmental river flow objectives (Booker et al 2005).

Stage 3 of the project involves work on the spatial and temporal scales of habitat variation. This stage is further sub-divided into two tasks, i.e.:-

3.1 Analysis of several long reaches of river to assess the appropriateness of different levels of data resolution (e.g. transect spacing and sampling schemes) to defining habitat at different scales

3.2 Defining the relationship between river flow, river morphology and physical habitat (defined by surface flow / meso-habitat types)

This report describes the results of research subcontracted to University of Worcester (UoW) by CEH and forms part of task 3.2 of the RAPHSA project.

1.2 Background to the project

1.2.1 River Habitat Mapping

River habitat mapping methods are normally completed as part of aquatic habitat modelling studies, either to model physical habitat availability directly from mapping results, or to identify representative reaches for further and more detailed data collection. River habitat mapping aims to identify the types and spatial configuration of geomorphic and hydraulic units. Physical habitat units have been defined and classified by many authors, leading to an array of terms in use to describe the physical environment utilised by the instream biota. The terms used to describe these units differ between authors and include 'channel geomorphic units' (CGU's) (e.g. Hawkins et al. 1993), 'mesohabitats' (e.g. Tickner et al. 2000), 'physical biotopes' (e.g. Padmore 1997) and 'hydraulic biotopes' (e.g. Wadeson 1994). Newson and Newson (2000) provide a review of the use of some of these terms and the differences between them.

Identification and mapping of channel geomorphic units can be accomplished in a variety of ways including in-channel measurements (Jowett 1993) or with the use of air photo interpretation and/or airborne multispectral digital imagery (Whited et al. 2002). The most common approach however is to walk the relevant sector of river and use subjective visual assessment (Hawkins et al. 1993, Maddock 1999, Parasiewicz 2001).

'Habitat mapping' or 'mesohabitat mapping' potentially offers two developments over traditional physical habitat assessments involving detailed modelling of water depth and velocity. Firstly, at the reach scale, they offer major time savings for field data collection. Secondly, they offer the ability to characterise longer lengths of river enabling questions about the representativeness of short reaches to be addressed. They also allow data collection over a larger scale (the terms 'river sector' or 'process zone' are often used) more relevant to the life history strategies of many fish species.

Several mesohabitat methods have been developed in recent years. Key differences between methods include the habitat classification system used, which channel characteristics are assessed (e.g. channel width, water velocity and depth, substrate sizes etc.) and how they are assessed (visual estimation versus physical measurement). These factors influence the time required to undertake the survey method, and the potential application of the results. However, little research has compared their effectiveness and accuracy, and in particular they lack an overall conceptual basis both in terms of linkage to biology and linkage to changes in habitat with discharge.

Existing habitat methods have often been developed as part of research projects for specific geographical areas and/or river types, but then applied outside of these areas or on other river types with no formal testing. In addition to this, methods may be applied by practitioners who are familiar with the theory of river habitat mapping in general (based on published reports and limited field experience), but who have had no formal field training in habitat classification and identification for that particular method. This raises questions regarding the reliability of comparing results between surveys applying the same field technique but undertaken by different field surveyors (operators). Where the classification of the same habitat feature varies between different surveyors, this may be called '***operator variability***'.

1.2.2 Field Workshop

CEH organised a field workshop on the River Windrush between 26-30 July 2004 to test and compare four mesohabitat-based methods. Participants of the Field Workshop included:-

- Doug Booker (CEH Wallingford, UK – technical assistance)
- Mike Dunbar (CEH Wallingford, UK)
- Kristin Eastman (Stuttgart University, Germany)
- Andi Eisner (Stuttgart University, Germany)
- Graham Hill (University of Worcester, UK)
- Ian Maddock (University of Worcester, UK)
- Ans Mouton (Ghent University, Belgium)
- Monica Rivas-Casado (Cranfield University, UK)
- Anne Sinnott (University of Worcester, UK – technical assistance)
- Natasa Smolar-Žvanut (Limnos Water Ecology Group, Slovenia)

The workshop was organised as part of the EU Cost Action '626 Aquatic Modelling Network', which aims to facilitate exchange of ideas between European scientists. The workshop aimed to:-

1. Enable participants to gain experience with the methods
2. Compare the usefulness of the methods
3. Compare observer variability when applying the methods

4. Build collaboration for further research in this area.

Four different approaches were assessed, including:-

1. MesoCASiMiR (developed in Germany)
2. MesoHABSIM (USA)
3. Norwegian Mesohabitat Classification Method (NMCM)
4. Rapid Habitat Mapping (RHM – developed and applied in the UK & USA)

1.3 Project Aims and Objectives

The aims of this report were to collate and present the field data collected during the field workshop, and to provide preliminary analysis of each survey method.

The specific objectives of this project were to:-

- Receive, manage and collate data for three methods (i.e. MesoHABSIM, NMCM & RHM) and to endeavour to ensure data for the MesoCASiMiR results were compiled by the co-ordinator responsible for that method (Andi Eisner, University of Stuttgart).
- Ensure digitisation of the field results using GIS.
- Assess each set of survey results and calculate the areas of river defined by different habitat types.
- Compare operator variability for each method, based on the areas assigned to each habitat type.
- Suggest how further work could compare operator variability between methods.
- Comment on the suitability of methods for mapping and modelling river sectors, especially for identifying physical sensitivity to abstraction.

Therefore, this report involved collating and analysing three of the four methods (MesoHABSIM, NMCM and RHM), whilst analysis of the fourth, i.e. MesoCASiMiR was conducted by its developer, Andi Eisner at University of Stuttgart, Germany.

2. Background to methods

2.1 Background

Four different approaches to mesohabitat mapping were assessed during the field workshop. The four methods were:-

1. MesoCASiMiR, developed in Germany,
2. MesoHABSIM, developed in the USA,
3. Norwegian Mesohabitat Classification Method (NMCM), developed in Norway, and
4. Rapid Habitat Mapping (RHM) developed and applied in the UK and USA.

The following sections briefly outline the approach used by each of these four methods.

2.2 MesoCASiMiR

This method has been developed in Germany, utilising single-stage data collection. Data are analysed in a Geographic Information System (GIS) to predict habitat availability for target species, using 'fuzzy logic' (Eisner et al. 2005). Follow-up fieldwork is not required.

Operators walk the riverbank, visually identifying habitats and recording them onto the data sheet or a handheld computer. MesoCASiMiR does not require the operator to identify habitat units by name or description, but only by the fact that they are different to their neighbours in terms of water velocity, depth and/or substrate. Habitat characterisation is completed within the subsequent computer analysis.

Operators complete a data sheet, which allows up to three different habitat units to be described within a short length of river. There are no restrictions on the shape or proportions of the units (figure 1) within the reach; they are mapped 'as seen'.

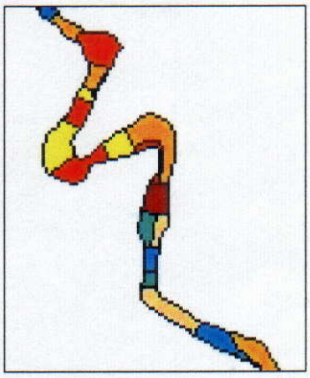


Figure 1.
Example of MesoCASiMiR output, showing habitat unit complexity allowed.
Source: A. Eisner.

For each habitat identified, flow velocity, depth, substrate and in-stream or overhead cover are recorded. Also, for each section of river, landscape character; discharge and river use are recorded.

Subsequent analysis by GIS using fuzzy logic produces habitat quality predictions for the target species. The output does not directly identify mesohabitat units.

2.3 MesoHABSIM

MesoHABSIM has been developed in the USA as a physical habitat suitability modelling system. It is a one-step operation, where all data collected are used in the modelling process, and no follow-up visits are required to complete the process (Parasiewicz, 2001).

Operators walk the riverbank noting onto a map, aerial photograph or handheld computer the location and extent of the dominant mesohabitat type. Lateral diversity is not permitted (figure 2). Habitats are visually identified from written descriptions (table 1)

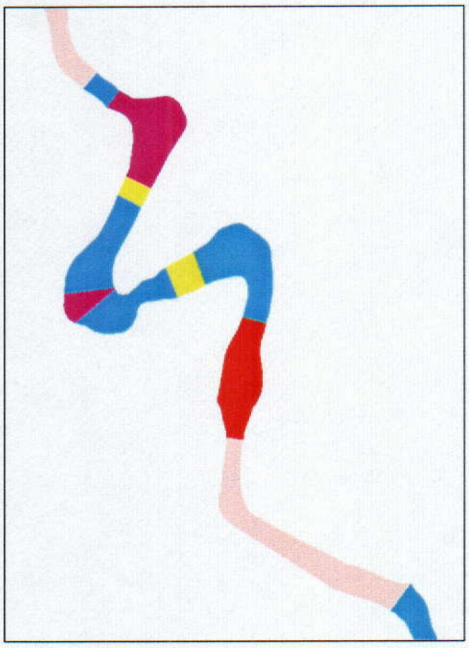


Figure 2.
A short reach of the Windrush mapped using MesoHABSIM.

Table 1. Descriptions of mesohabitat units used by the MesoHABSIM method. (Source: Eisner, A.)

Mesohabitat	Brief description
Backwater	Slack area along channel margin, caused by eddies behind obstructions
Cascade	Stepped rapids with very small pools behind boulders and small waterfalls
Fast Run	Uniform fast-flowing stream channel
Glide	Moderately shallow stream channel with laminar flow, lacking pronounced turbulence. Flat streambed shape
Plunge pool	Area where flow passes over a complete channel obstruction and drops vertically to scour the streambed
Pool	Deep water impounded by a channel blockage, or partial channel obstruction. Slow with concave streambed shape
Rapid	Higher gradient reach than a riffle, with faster current velocity, coarser substrate and more surface turbulence. Convex streambed shape
Riffle	Shallow stream reach with moderate current velocity, some surface turbulence and high gradient. Convex stream bed
Ruffle	Dewatered rapid in transition to either a run or a riffle
Run	Deeper stream reach with moderate current velocity but no surface turbulence. Laminar flow. Streambed is longitudinally flat and laterally concave
Side arm	Channel around an island, smaller than half the width of the river, frequently at a different elevation to the main channel

For each mesohabitat, substrate, shore uses and other attributes are recorded along with depth, velocity and substrate data for seven points randomly selected from an imagined 10 x 10 grid covering the habitat unit. Data are analysed and coupled with fish sampling of units to provide reach habitat suitability information.

2.4 Norwegian Mesohabitat Classification Method (NMCM)

Developed as part of a project to assess in-stream habitat quality in Norwegian rivers, there are two parts to the process – mapping mesohabitat extents, and detailed measurement of water depth and velocity, substrate size, roughness and embeddedness which is combined with fish data to produce habitat suitability extent (Borsanyi, et al. 2003). Only the first part of the process was undertaken in this trial.

Habitat units are determined by water surface pattern, surface gradient, surface velocity and water depth. A 'decision tree' has been developed to assist with consistency of habitat unit identification (table 2) shaded boxes show types that are not expected to be found in the field.

Table 2. 'Decision tree' used by NMCM to identify habitat types.

Surface pattern	Surface gradient	Surface velocity	Water depth	Code	Name
Smooth/ rippled (wave height <0.05m)	Steep	Fast (>0.5m/s)	Deep (>0.7m)	A	Run
			Shallow (<0.7m)		
		Slow (<0.5m/s)	Deep (>0.7m)		
			Shallow (<0.7m)		
	Moderate	Fast (>0.5m/s)	Deep (>0.7m)	B1	Deep glide
			Shallow (<0.7m)	B2	Shallow glide
		Slow (<0.5m/s)	Deep (>0.7m)	C	Pool
			Shallow (<0.7m)	D	Walk
Broken/ unbroken (wave height> 0.05m)	Steep	Fast (>0.5m/s)	Deep (>0.7m)	E	Rapid
			Shallow (<0.7m)	F	Cascade
		Slow (<0.5m/s)	Deep (>0.7m)		
			Shallow (<0.7m)		
	Moderate	Fast (>0.5m/s)	Deep (>0.7m)	G1	Deep splash
			Shallow (<0.7m)	G2	Shallow splash
		Slow (<0.5m/s)	Deep (>0.7m)		
			Shallow (<0.7m)	H	Rill

Operators walk the riverbank and visually assess the river, marking habitat units directly onto a map. The river is first divided longitudinally and then laterally (with up to three lateral types). The longitudinal divisions occur where one of the lateral types ends (figure 3). To prevent the mapping from becoming too detailed and fragmented, a unit must be at least as long as the river is wide.

Operators draw locations of habitat units directly onto maps, although the process could be adapted to hand-held computers with Global Positioning System (GPS) capability. Maps and data are input into a Geographic Information System (GIS) and analysed in conjunction with fish habitat preference information to provide habitat suitability data.

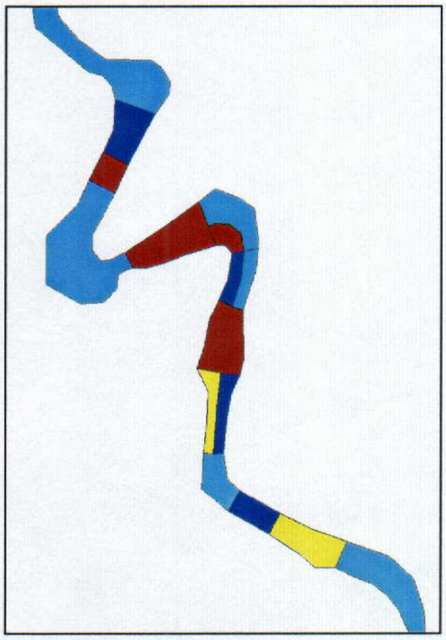


Figure 3.
A short reach of the Windrush mapped using NMCM. Note the lateral diversity allowed.

2.5 Rapid Habitat Mapping (RHM)

Rapid Habitat Mapping is a two-stage process, the first being to identify representative sites for further analysis using PHABSIM/IFIM. The 2nd stage requires detailed measurement of microhabitat characteristics to be coupled with species suitability data to provide flow versus habitat availability relationships (Maddock et al. 2001). In these trials, only the first (survey) stage was completed.

RHM should be performed during representative or typical summer low flow, as habitats are more easily distinguished at that time. Mesohabitat areas may be user defined, based on the classification scheme devised by Hawkins et al. (1993). Table 3 shows those used during the River Windrush Workshop.

Operators walk the riverbank, visually assessing the river for each habitat type. The dominant type across the cross-section is recorded and hence there is no lateral diversity identified (figure 4). In-stream data are collected from each habitat unit and operators record a new habitat where river conditions change.

The location of the start and end of habitats is recorded as 'distance downstream' from the start point, either by measuring lengths of each unit using a laser rangefinder or by using a mapping grade GPS. Habitat type is recorded on the data sheet, together with readings of channel and water widths, water depth and velocity, substrate type, in-stream and overhead vegetation, lateral, point and mid-channel bars, vegetation cover and presence of mature islands. Channel measurements may be estimated where it is not possible to record them. Water depth is measured with a measuring staff and water velocity with a current meter. Each unit is also photographed.

Data are analysed to determine longitudinal distribution, total length and area, and proportion of length and surface area for each type. The data are then used to select representative units for further PHABSIM data collection and modelling.

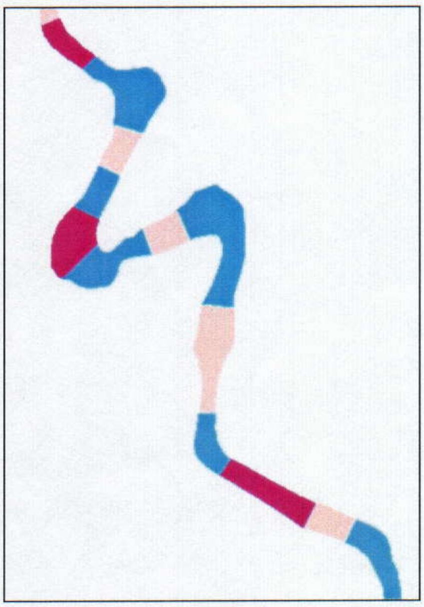


Figure 4.
A short reach of the Windrush mapped using RHM.

Table 3. Mesohabitat unit descriptions used by the RHM system during the Windrush Workshop.

Mesohabitat	Turbulence	Brief description
Fall (Fa)	Turbulent & very fast	Vertical drops of water over the full span of the channel, commonly found in bedrock and step-pool stream reaches
Cascade (Ca)	Turbulent & very fast	Highly turbulent series of short falls and small scour basins, frequently characterised by very large substrate and a stepped profile.
Chute (Ch)	Turbulent & very fast	Narrow steep slots or slides in bedrock
Rapid (Ra)	Turbulent & fast	Moderately steep channel units with coarse substrate, unlike cascades posses planar profile
Riffle (Ri)	Turbulent & moderately fast	Most common type of turbulent fast water mesohabitat in low gradient alluvial channels. Substrate is finer than other fast turbulent mesohabitats. Less white water, with some substrate breaking the surface
Run (Ru)	Non-turbulent & moderately fast	Moderately fast and shallow gradient with ripples on the water surface. Deeper than riffles with little, if any, substrate breaking the surface
Glide (Gl)	Non-turbulent & moderately slow	Smooth 'glass-like' surface, with visible flow movement along the surface. Relatively shallow compared to pools
Pool (Pl)	Non-turbulent & slow	Relatively deep and slow flowing (compared to glides), with fine substrate. Usually little surface water movement visible.
Ponded (Pd)	Non-turbulent & slow	Water ponded behind an obstruction – weir, sluice or other obstruction
Other (O)		To be used in unusual circumstances where feature does not fit any recognised type

2.6 Summary

Whilst all four methods have the same objective, *viz.* identification, characterisation and mapping of mesohabitats at the 'intermediate' scale, they differ in their approaches. RHM and NMCM adopt a two-stage approach in which the first stage is used to gather information to identify representative sites for further data collection at the micro scale. Data from the second stage are assumed to be representative of the mesoscale. By contrast, MesoCASiMiR and MesoHABSIM adopt a single-stage approach. Data from the surveyed reach are used directly to model suitability for fish habitat.

Other key differences include the classification systems used to identify units, whether lateral habitat diversity is acknowledged and mapped, what habitat attributes are measured and if so, at how many points. The four methods are compared below (table 4).

Table 4. Comparison of four methods of rapid river habitat assessment used on the River Windrush, July 2004.

	MesoCASiMiR	MesoHABSIM	NMCM	RHM
Approach	One stage – all data collected initially	One stage – all data collected initially	Two stage – initial assessment used to identify 'representative' reaches for further investigation	Two stage – initial assessment used to identify 'representative' reaches for further investigation
Classification of units	Extent of unit determined visually/ subjectively 'as being different'. No pre-determined classification system	Visual/ subjective, using descriptions of unit types. Similar to RHM classifications, with additions, e.g. 'fast run'	Visual/ subjective. 'Decision tree' aids identification from estimates of depth and velocity	Visual/ subjective using descriptions of unit types
Lateral diversity acknowledged?	Yes	No	Yes	No
Data measurement	Depth and velocity estimated at one location for each unit, measurements taken if uncertain	Seven randomly determined measurements of depth and velocity for each unit	Depth, only if turbidity prevents estimation.	Length and width, depth and velocity at one point in each unit

3. Site Details

3.1 Site description

A 1.5km reach of the River Windrush within Sherborne Park, Gloucestershire (NGR SP 190153) was selected for this study. The reach lies *c.*1.2km north of the village of Windrush and c.30km west of Oxford (figure 5).

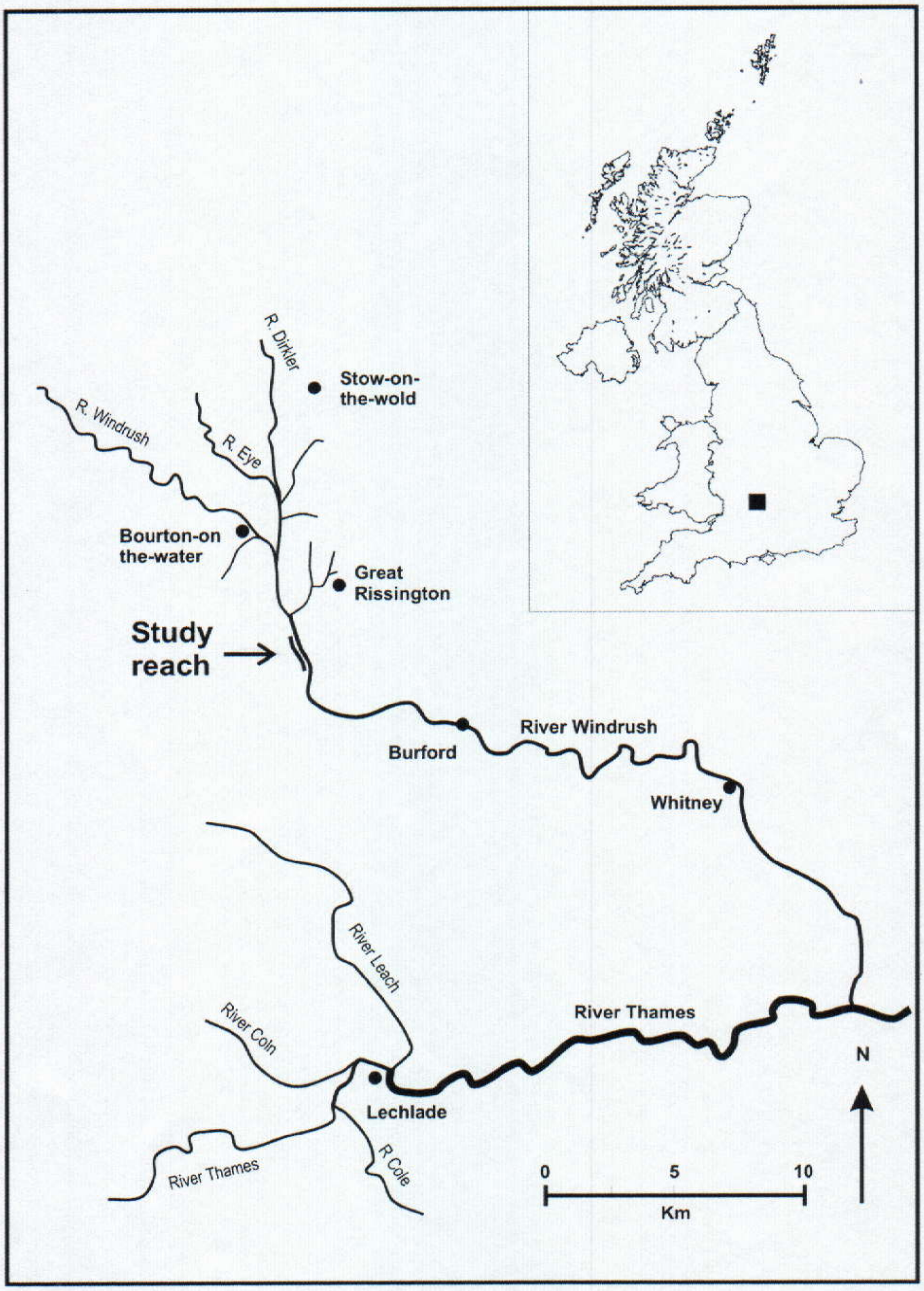


Figure 5. Location of survey site on the River Windrush, Gloucestershire.

An Environment Agency gauging station at Bourton-on-the-Water (3km upstream), has a mean flow of $0.75m^3s^{-1}$ and a catchment of $65.5km^2$, predominately of Oolitic Limestone. The river has a baseflow index of 0.795 (National River Flow Archive, 2005).

The meandering 1.5km long study reach (figure 6) is relatively low gradient, flowing through wet woodland adjacent to Sherborne Watermeadows. Whilst the river channel may be considered semi-natural, the bed has been lowered in parts by gravel abstraction, and some flow is abstracted during the winter to inundate the adjacent water meadows (National Trust, 2004).

The reach was chosen because of the representative range of habitat units present associated with a lowland river. It is also being used for detailed microhabitat modelling for other tasks within the RAPHSA project, e.g. to assess the appropriateness of different levels of data resolution (transect spacing and sampling schemes) to defining habitat at different scales, and defining the relationship between river flow, river morphology and physical habitat (defined by surface flow / meso-habitat types) (Booker *et al.*, 2005).

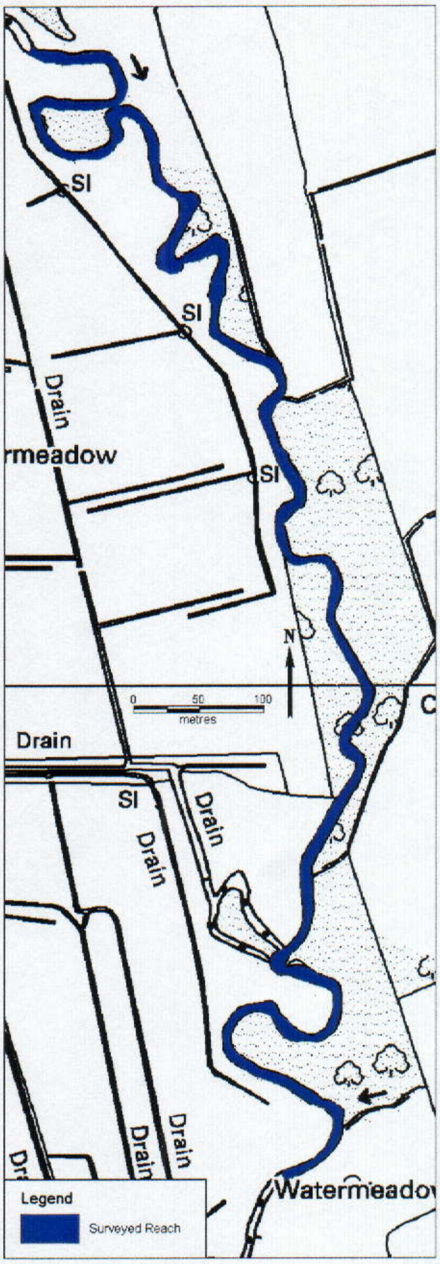


Figure 6.
The 1.5km reach of the River Windrush used for comparative surveys between 28th & 29th July 2004.

4. Field Methods

4.1 Participants

The Centre for Hydrology and Ecology (CEH), Wallingford convened a field workshop between 26th & 30th July 2004. Eight participants were involved with field data collection:-

- Mike Dunbar (CEH Wallingford, UK)
- Kristin Eastman (Stuttgart University, Germany)
- Andi Eisner (Stuttgart University, Germany)
- Graham Hill (University of Worcester, UK)
- Ian Maddock (University of Worcester, UK)
- Ans Mouton (Ghent University, Belgium)
- Monica Rivas-Casado (Cranfield University, UK)
- Natasa Smolar-Žvanut (Limnos Water Ecology Group, Slovenia)

Two additional staff provided fieldwork support:-

- Doug Booker (CEH Wallingford, UK)
- Anne Sinnott (University of Worcester, UK).

4.2 Method

Following an office-based overview of the four methods on Tuesday 27th, fieldwork was conducted on the River Windrush at Sherborne over two days (28th – 29th) and a post fieldwork review was completed at CEH Wallingford on the 30th July 2004.

During the two field days, no precipitation fell. River discharge was low, and remained stable. During the workshop period discharge was 0.729 m^3s^{-1} representing Q_{82}. (Source: E-A)

To establish accurate locations of habitats in the field, a number of flags were positioned at regular intervals on the riverbank, and located by use of a Trimble GeoXT GPS with sub-metre accuracy. These data enabled accurate location of habitats in the subsequent GIS analysis.

The participants completed habitat surveys in pairs, with one person in each pair having some field experience of each method applied. Each pair traversed the same 1.5km reach of the River Windrush applying a minimum of two and a maximum of three methods during the two days of fieldwork. During the time available it was possible to complete three surveys using the NMCM and RHM methods. Only two surveys using MesoCASiMiR and MesoHABSIM were completed due to the additional time required to complete each survey. Each method was applied using the methodology detailed in the 'Background to methods' section above.

Participants retained their data sheets and maps until the final day when they were photocopied and collated. Ian Maddock and Graham Hill (UoW) collated the data sheets for NMCM, MesoHABSIM and RHM, and Andi Eisner (University of Stuttgart) collated the MesoCASiMiR data for later analysis. In the subsequent analysis both sets of results from MesoCASiMiR and MesoHABSIM and three sets of results from NMCM and RHM are shown in the maps. A summary of the methods is shown in table 5.

Table 5. Summary of the four methods used to survey the River Windrush.

	Data collection	Digitisation Method
MesoCASiMiR	Data recorded directly onto spreadsheet; river sections located by distance downstream from known point(s). Spatial extent of habitat units within the section sketched onto spreadsheet. Flow velocity, water depth, embededdness, substrate conditions and cover are recorded in classes for each habitat unit. Average river width and flow situation are recorded for each section.	River sections and habitat units are digitalized by polygons in ArcVIEW GIS, with mapped parameters as attributes related to each habitat unit
Meso-HABSIM	Data recorded directly onto spreadsheet; CGU located by distance downstream from known point(s). Habitat type; substrate; attributes; shore uses recorded for CGU. Depth, velocity and substrate recorded for 7 random points. Dominant CGU across entire channel width only.	CGUs are drawn using start & end points from data sheet and channel width from OS map.
Norwegian Mesohabitat Classification Method	Spatial extent of habitat unit marked directly onto map. Habitat units assigned designation using decision tree based on water surface pattern; gradient; surface velocity; water depth. Up to 3 CGUs across channel width.	CGUs are drawn from hand drawn map to electronic version of OS map in MapInfo.
Rapid Habitat Mapping	Data recorded directly onto a spreadsheet; CGU located by distance downstream from known point(s). Habitat type; channel width; water width; Max depth; Max velocity; Substrate - dominant, sub-dominant & present; instream cover; overhead cover; lateral, point & mid channel bars; mature islands; photos. Dominant CGU across entire channel width only.	CGUs are drawn using start and end points from data sheet, and buffering a channel centre line to the required water width.

With the exception of MesoHABSIM, each survey method was employed once by a pair of surveyors who had field experience with the technique and at least once by a pair of surveyors who had some background knowledge of the method but who had no prior field experience or formal field training with it. Therefore, the field workshop provided an insight into the nature and extent of observer variability when methods are employed by experienced field surveyors versus personnel who have had no formal field training in that specific technique. This may be a common occurrence where habitat mapping methods are developed by research teams and published in the literature but no training courses are provided in their use.

5. Results

5.1 Habitat maps using each method

This report involved collating and analysing three of the four methods (MesoHABSIM, NMCM and RHM), whilst analysis of MesoCASiMiR was conducted by its developer, Andi Eisner at Stuttgart University.

Data from the NMCM, MesoHABSIM and RHM methods were entered into a GIS (MapInfo 8.0) at University of Worcester for analysis. In RHM, estimates of both length and width of habitat units are recorded; the habitat units were digitised based on a line marking the centre of the channel in the study reach. Habitat width was added by 'buffering' habitat units along the 'centre line', which produces a stepped channel width (figure 7).

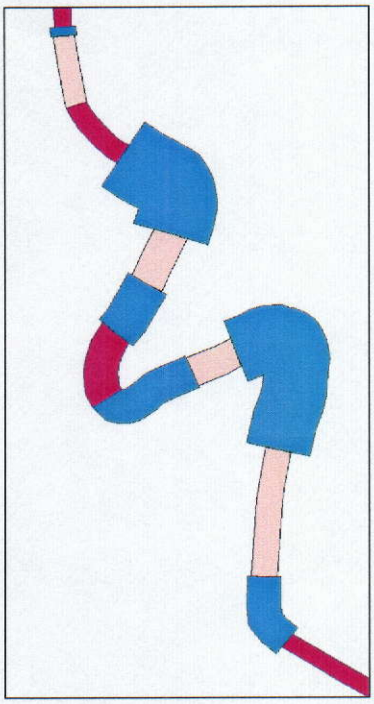


Figure 7. An example of the output from a GIS using habitat length and width data in RHM, note the 'stepped' channel width.

MesoCASiMiR field data were analysed by Andi Eisner (University of Stuttgart) by combining depth, velocity and substrate characteristics of each unit with habitat preference information to illustrate habitat suitability for Brown Trout (figure 8). In the case of MesoHABSIM, NMCM and RHM, recorded habitat areas were drawn over a digitised Ordnance Survey 1:10,000 scale map showing the channel outline (figures 9 to 11). In all cases the length and area of each individual habitat unit were calculated and added to the database.

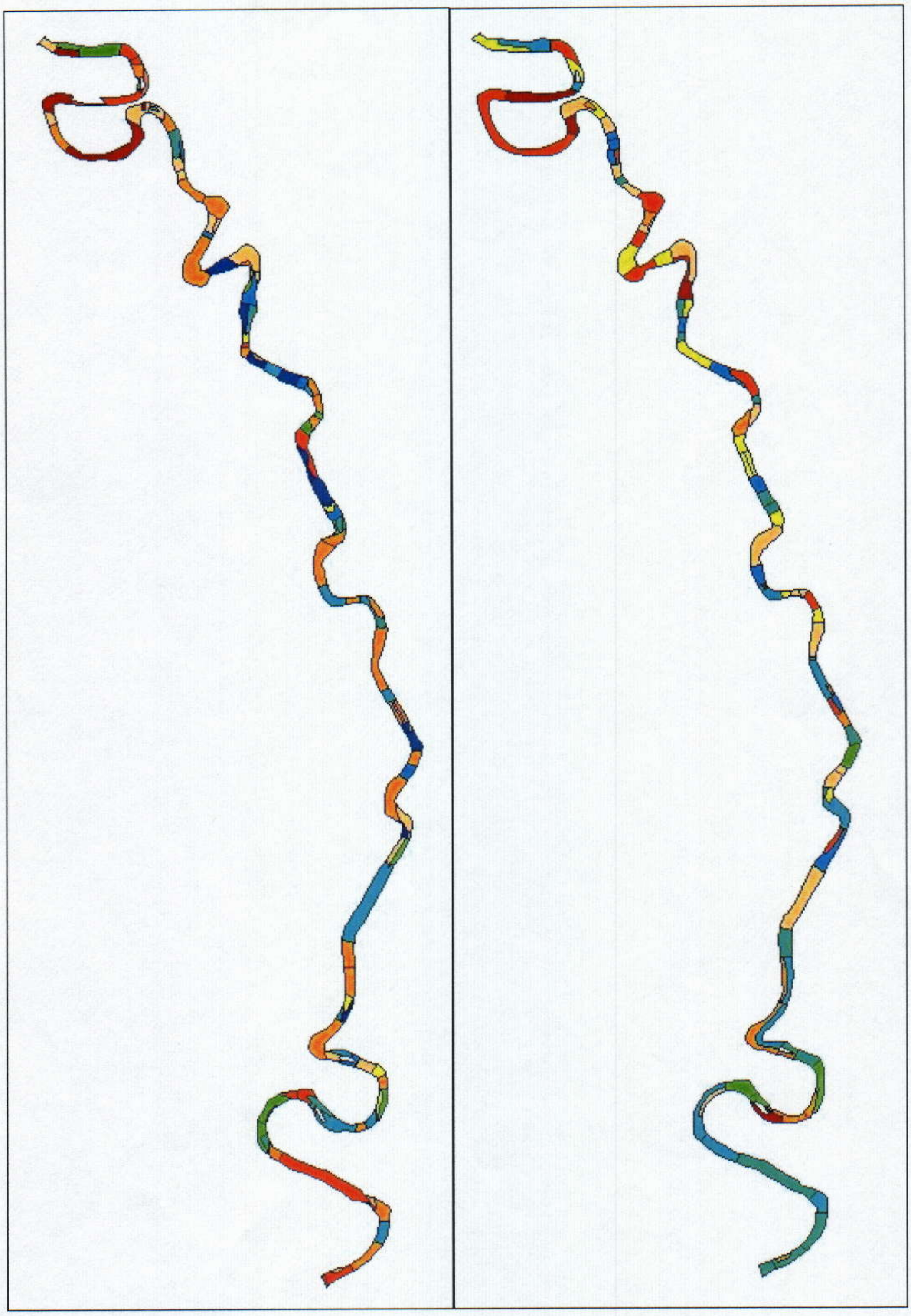


Figure 8. Maps of River Windrush using data from MesoCASiMiR surveys 1 (left) and 2 (right) to predict suitability of habitat for Brown Trout adult. (Source: A. Eisner)

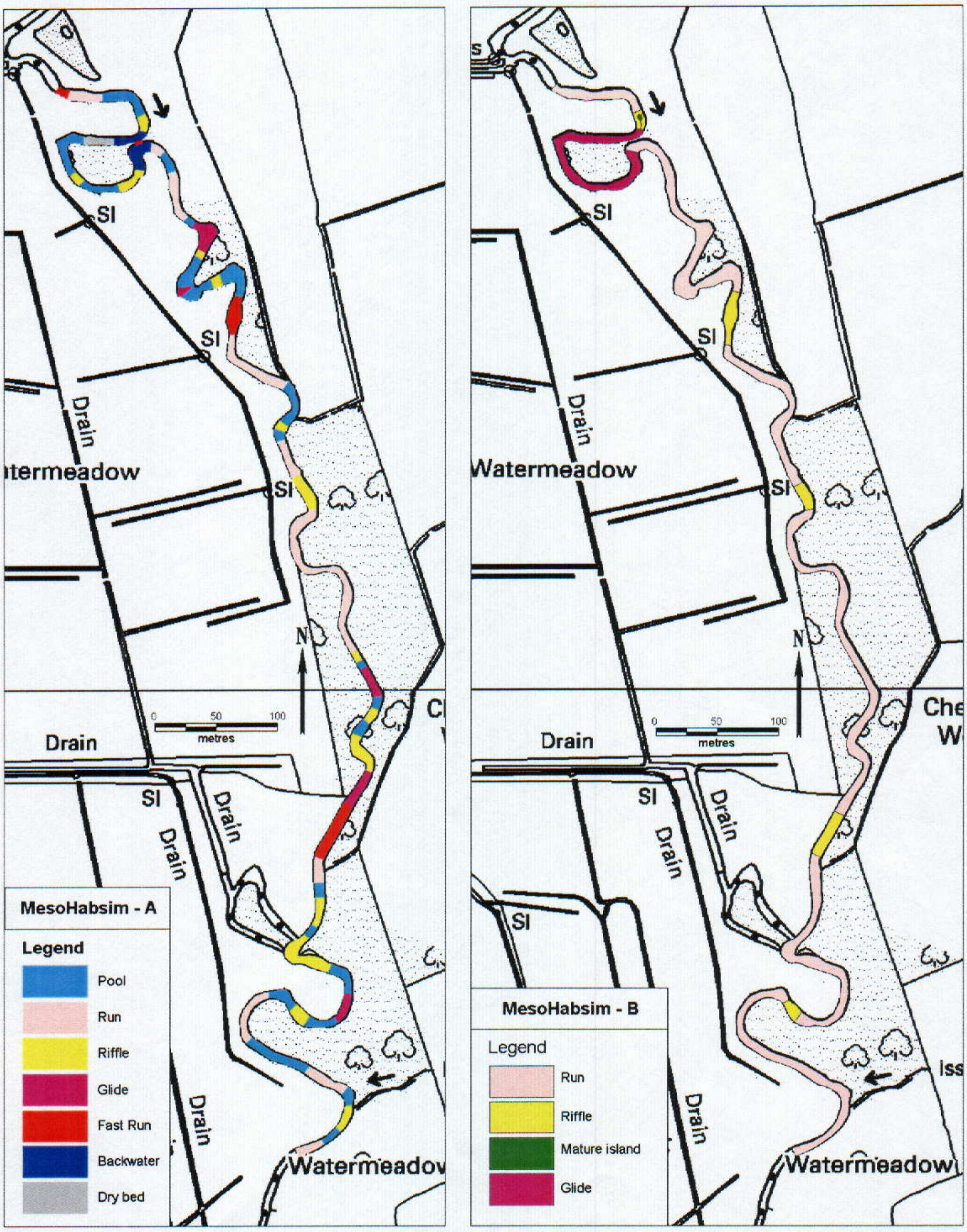


Figure 9. MesoHABSIM habitat maps using survey A (left) and B (right).

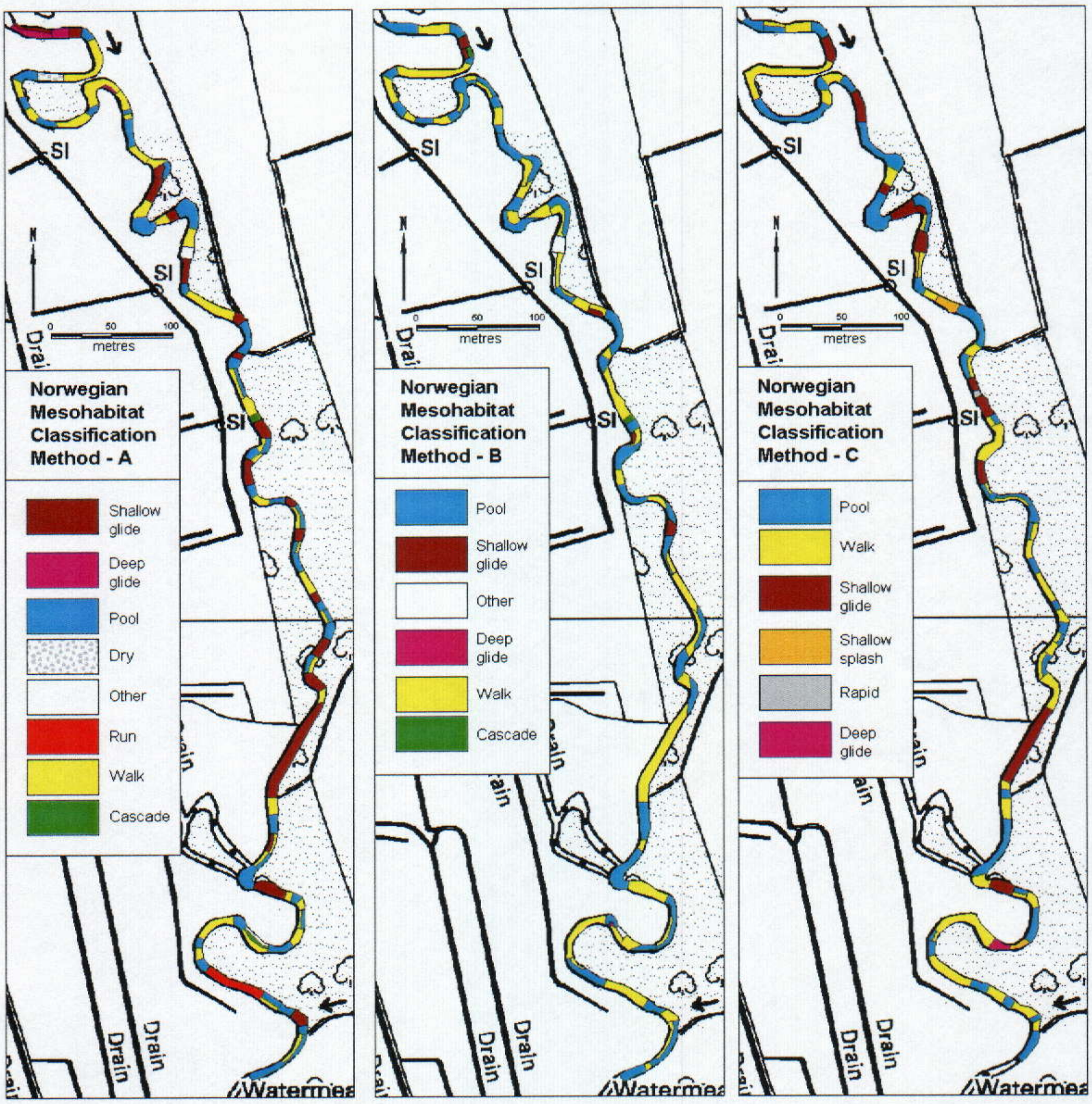


Figure 10. NMCM habitat maps using surveys A, B and C.

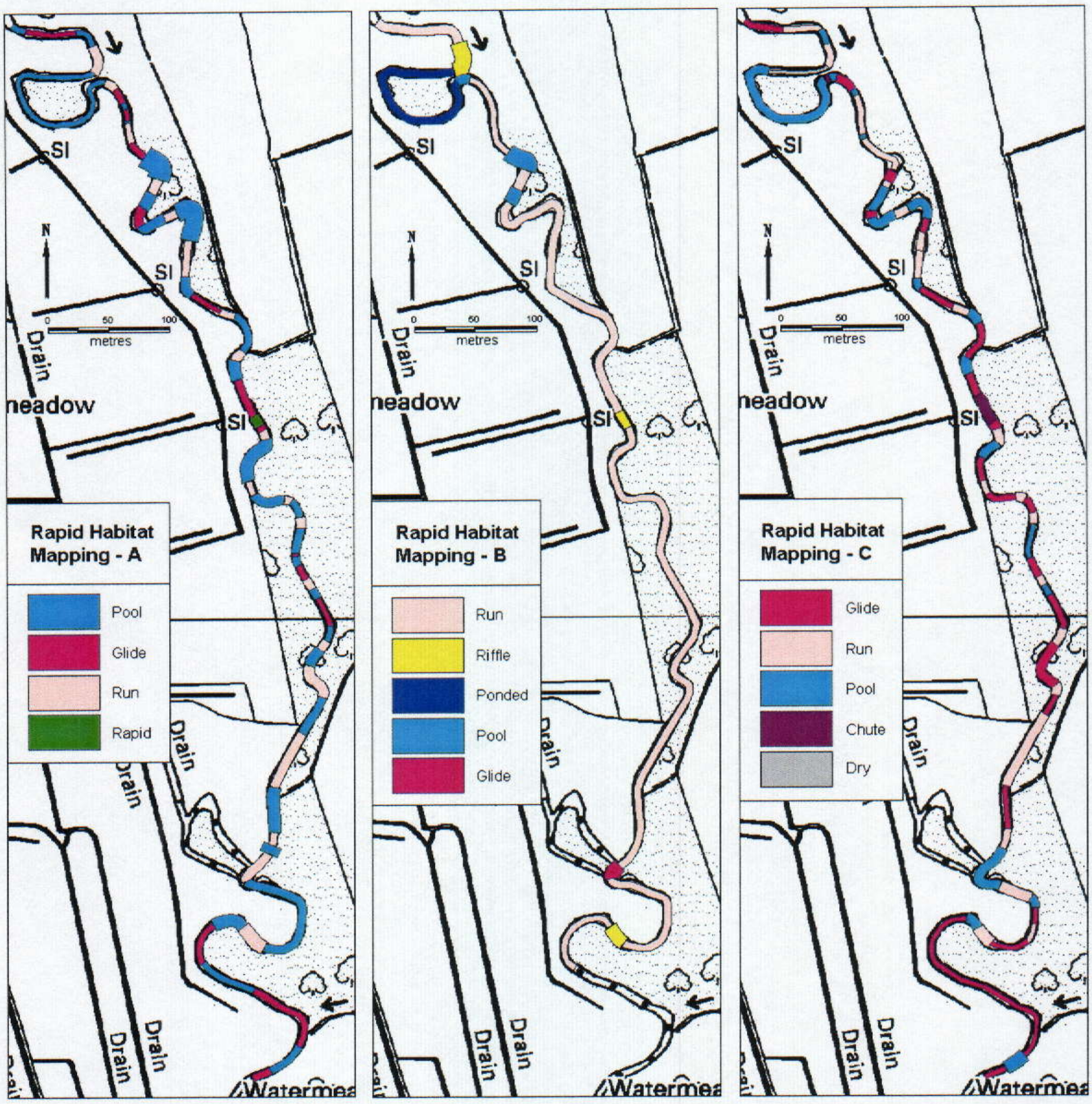


Figure 11. RHM habitat maps using surveys A, B and C.

5.2 Assessing operator variability

Comparisons between operators are described below in two sections. The first (section 5.2.1) considers the operator variability for each method based on ***non-spatial*** information. The second (section 5.2.2) considers ***spatial data*** for operator consistency and variability. Therefore operator variability analyses have been organised in the following way:-

Section 5.2.1

a. Comparison of the numbers of each unit defined along the reach.
b. Comparison of the proportions of each reach defined by habitat unit area.

Section 5.2.2

a. Definition of the location (in map form using GIS) of agreement and disagreement between operators. Where agreement occurred, the type of habitat is also indicated on the map.
b. Comparison of the proportion of the total channel area with agreement (and hence disagreement) between operators.

Data from two replicates of MesoHABSIM and three for NMCM and RHM are shown. To standardise the channel shape across all methods, the data from RHM were re-drawn over the OS 1:10,000 scale map, using the channel shown on the map, and the habitat unit boundaries from surveyed data. Numerical data were analysed in Microsoft Excel.

5.2.1 Comparison of habitat units by number and area

A comparison of the numbers of habitat units identified by each survey for each method is shown in figures 12, 14 & 16. Survey results from river habitat mapping studies are often used to identify the locations and types of habitats that should be sampled by subsequent (microhabitat) data collection (e.g. using RHM). This analysis is based on the use of habitat area data to calculate the proportions of the reach occupied by each type. Therefore, the proportions of each reach defined by habitat unit area have also been calculated and are shown in figures 13, 15 & 17.

MesoHABSIM

MesoHABSIM survey A was characterised by a predominance of pool habitats (22), with high numbers of riffles (14) and runs (13) (figure 12). Survey B also identified a dominance of riffles and runs. Key differences between surveys in terms of habitat units include disagreement over pool units (survey A indicated 22, survey B noted 0), and the much greater number of total units in survey A (60) compared to survey B (14). In other words, survey A identified and mapped a large number of relatively small units, whereas survey B had significantly fewer and hence larger units.

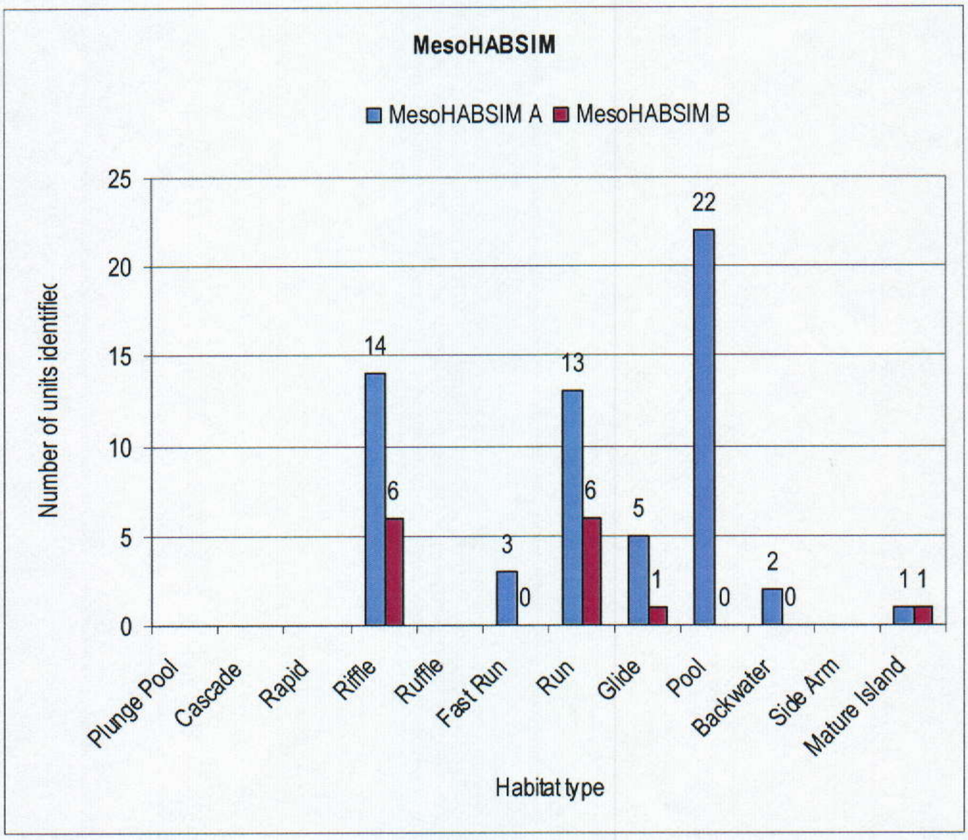


Figure 12. Comparison of the number of habitat units, by type, identified by two operators using MesoHABSIM.

Figure 13 compares the percentage of the total reach area occupied by each habitat type between the two surveys using MesoHABSIM. Survey A results indicate the reach area was dominated by pools (29%), runs (26%), riffles (18%) and glides (18%), with small areas of fast run, backwater and dry bar. Survey B in contrast suggested the reach was dominated by one type of habitat, i.e. run (79%), with relatively small areas of riffle (11%) and glide (10%) also present.

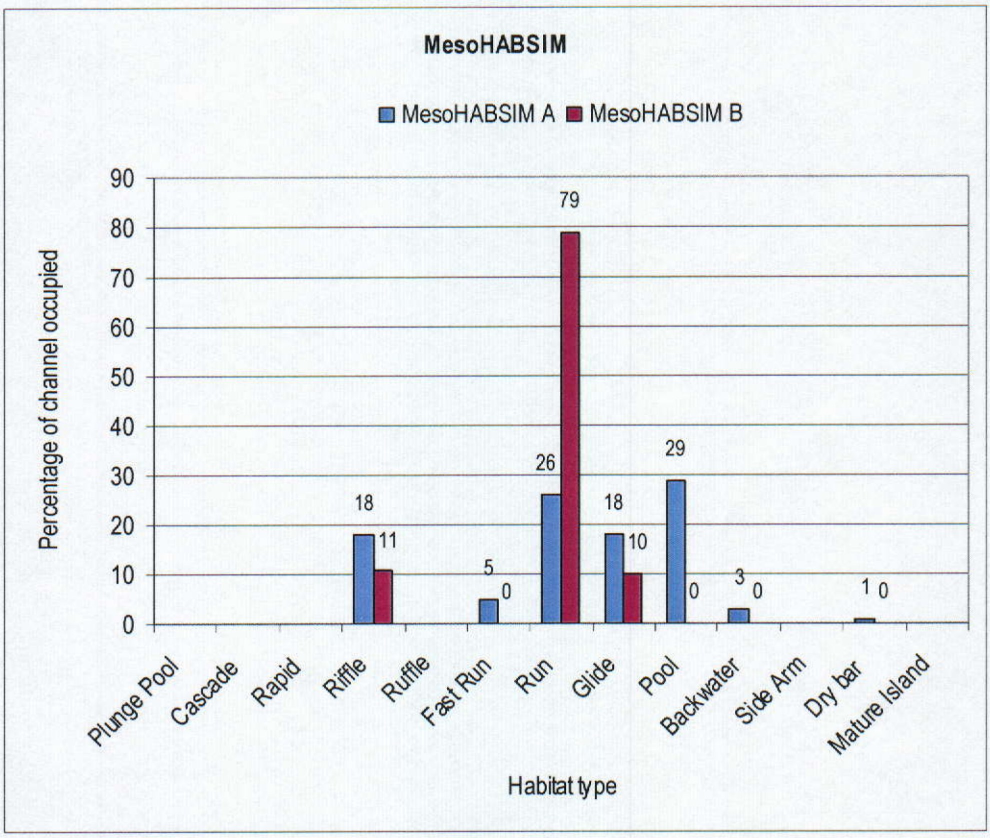


Figure 13. Comparison of the percentages of the reach area assigned to MesoHABSIM habitat units by two surveyors of the River Windrush.

Norwegian Mesohabitat Classification Method (NMCM)

Figure 14 compares the number of habitat types between all three surveys using NMCM. All three surveys suggested the reach was dominated by pools and walks, with a high degree of similarity in terms of the total numbers of each of these units. Further more, all three surveys agreed that shallow glides were the third most dominant type (albeit with a greater degree of difference in the numbers of units between surveys).

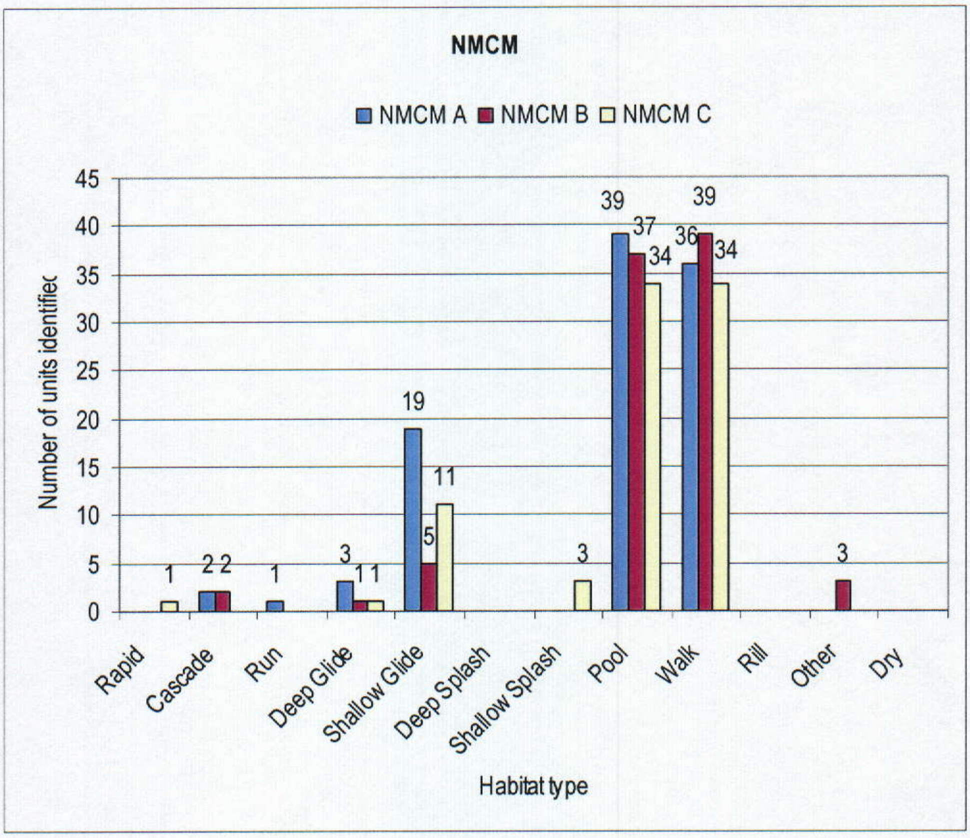


Figure 14. Comparison of the number of habitat units, by type, identified by three surveyors using NMCM.

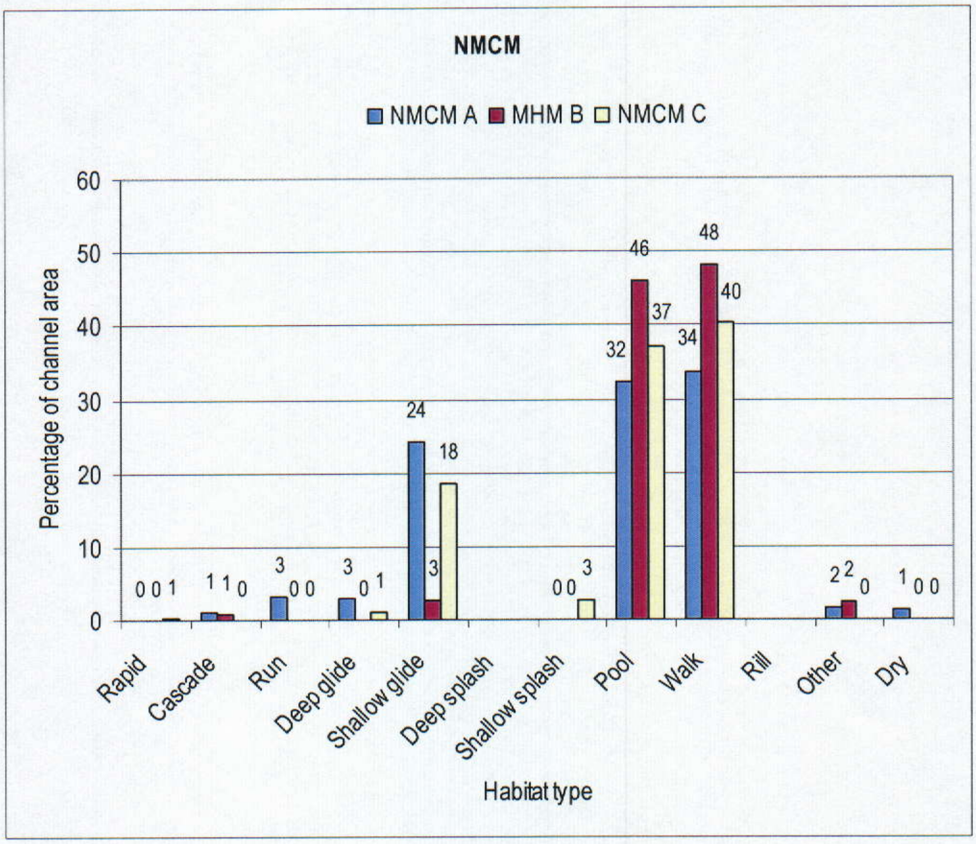


Figure 15. Comparison of the percentages of the reach area assigned to NMCM habitat units by three different surveys of the River Windrush.

When comparing NMCM surveys in terms of habitat unit areas, survey A suggests the reach is dominated by walk (34%), pool (32%) and shallow glide (24%). There was agreement when compared to Survey B and survey C in that they also agreed that pool and walk were dominant, with notable amounts of shallow glide present.

Rapid Habitat Mapping (RHM)

Figure 16. compares the number of habitat types between all three surveys using RHM. Survey A and survey C had the greatest degree of similarity, with both indicating the reach has relatively large numbers of runs, glides and pool units albeit in different orders of dominance. Survey B however differed significantly, both in terms of habitat type and number. Survey B had notably smaller total number of units (15) compared to survey A (62) and survey C (64).

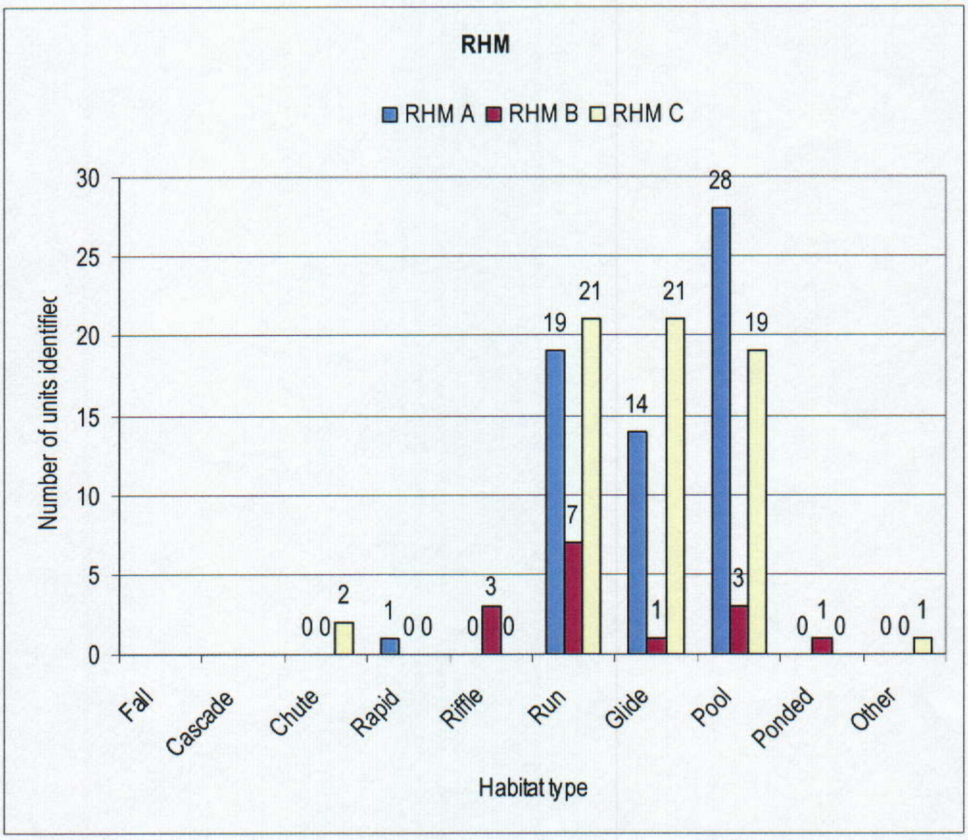


Figure 16. Comparison of the number of habitat units, by type, identified by three operators using RHM.

When comparing habitat area results for the RHM method (figure 17 below), survey A and survey C are the most similar, although significant differences are still evident. For example, both concur that run, glide and pool are the three most dominant types. However, survey A suggest pools are the most dominant (59%), with run (24%) and glide (16%) less so, whereas survey C indicates all three types occur in similar amounts (run 30%, glide 32% and pool 33%). Survey B is significantly different to A and C, indicating the reach area is dominated by run (73%), with smaller areas of ponded (11%), riffle (8%), pool (6%) and glide (2%).

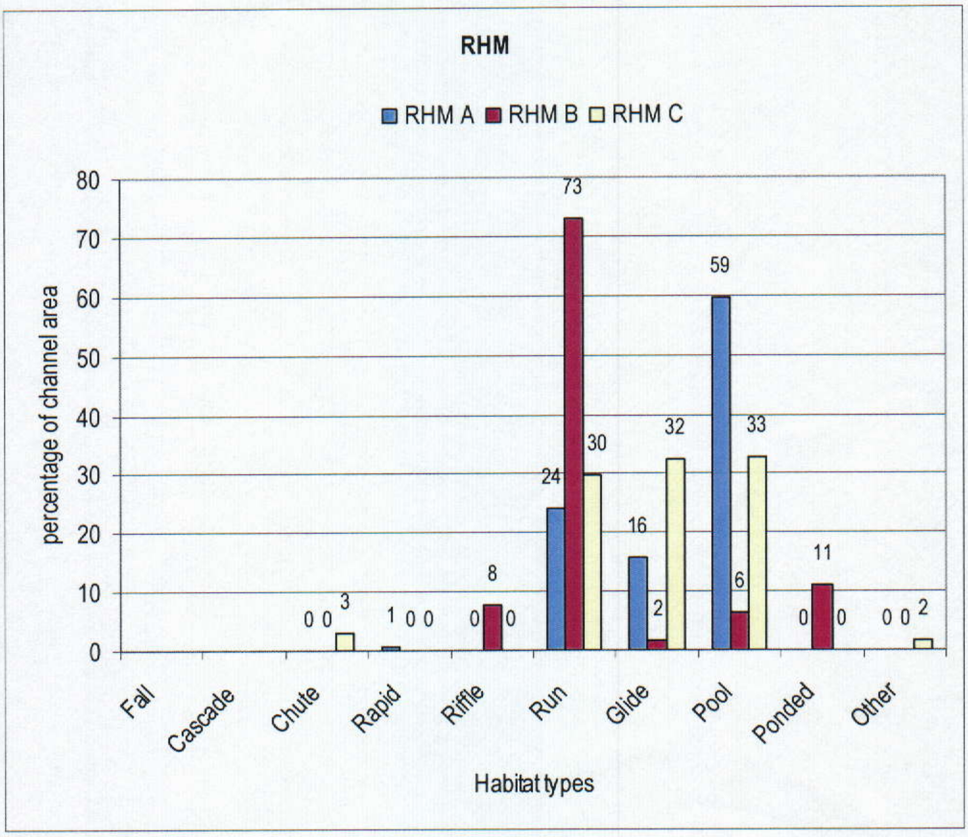


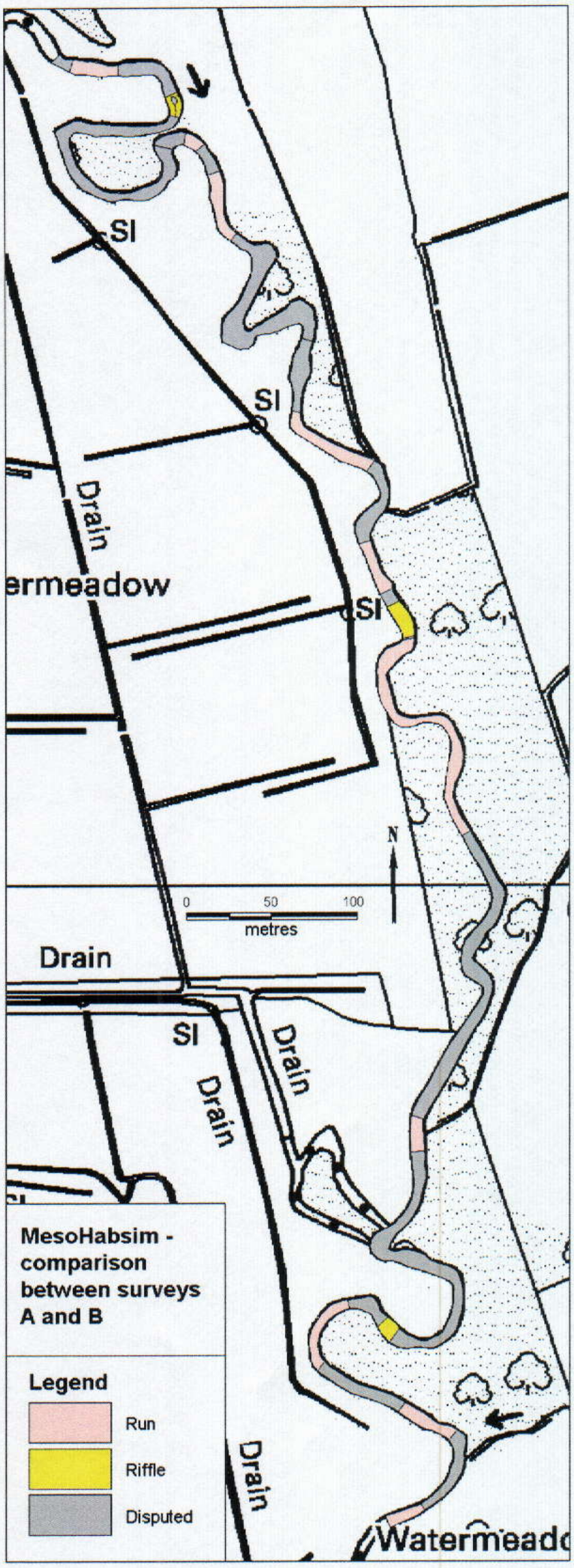
Figure 17. Comparison of the percentages of the reach area assigned to RHM habitat units by three surveyors on the River Windrush.

5.2.2 Comparison of habitat locations and the overall proportion of the reach area with habitat designation agreement

For each method a map was produced to showing the location and extent of where habitat agreement occurred between surveys. Where there was agreement between surveys, the type of habitat unit is also identified. These maps are illustrated for each method, i.e. MesoHABSIM (figure 18), NMCM (figure 19) and RHM (figure 20). The proportion of the total channel area (as a %) where the habitat type was the same (i.e. habitat agreement) between surveys has also been calculated for each method.

MesoHABSIM

The map in figure 18 shows the locations and extent of agreement and disagreement between operators. This shows there was dispute over the type of habitat unit present over 68% of the channel area. Runs and riffles were the only two habitat types where agreement occurred. Despite survey A suggesting 22% of the reach was glide, and survey B suggesting 11% was this type too, the two surveys did not designate this type in the same place at any point along the reach. This demonstrates the importance of examining both the spatial and non-spatial data when assessing the degree of observer variability within and between each method. It also highlights which habitat types are more prone to observer variability.



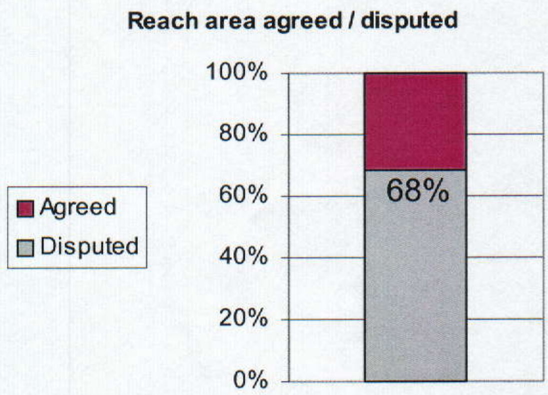


Figure 18. Comparison of habitat agreement between surveys A & B using MesoHABSIM.

Norwegian Mesohabitat Classification Method

Figure 19 shows the location of agreement and disagreement between the two most similar operators and the percentages of the channel area assigned to the habitat units by three operators. In the case of two operators, 58% of the channel area was disputed, and that rose to 81% with three operators. Pool and walk type habitats were agreed in certain locations, but despite being present in both surveys, no agreement on the location of glide habitats is apparent between the two surveys selected. This finding was consistent with the previous method discussed above (MesoHABSIM).

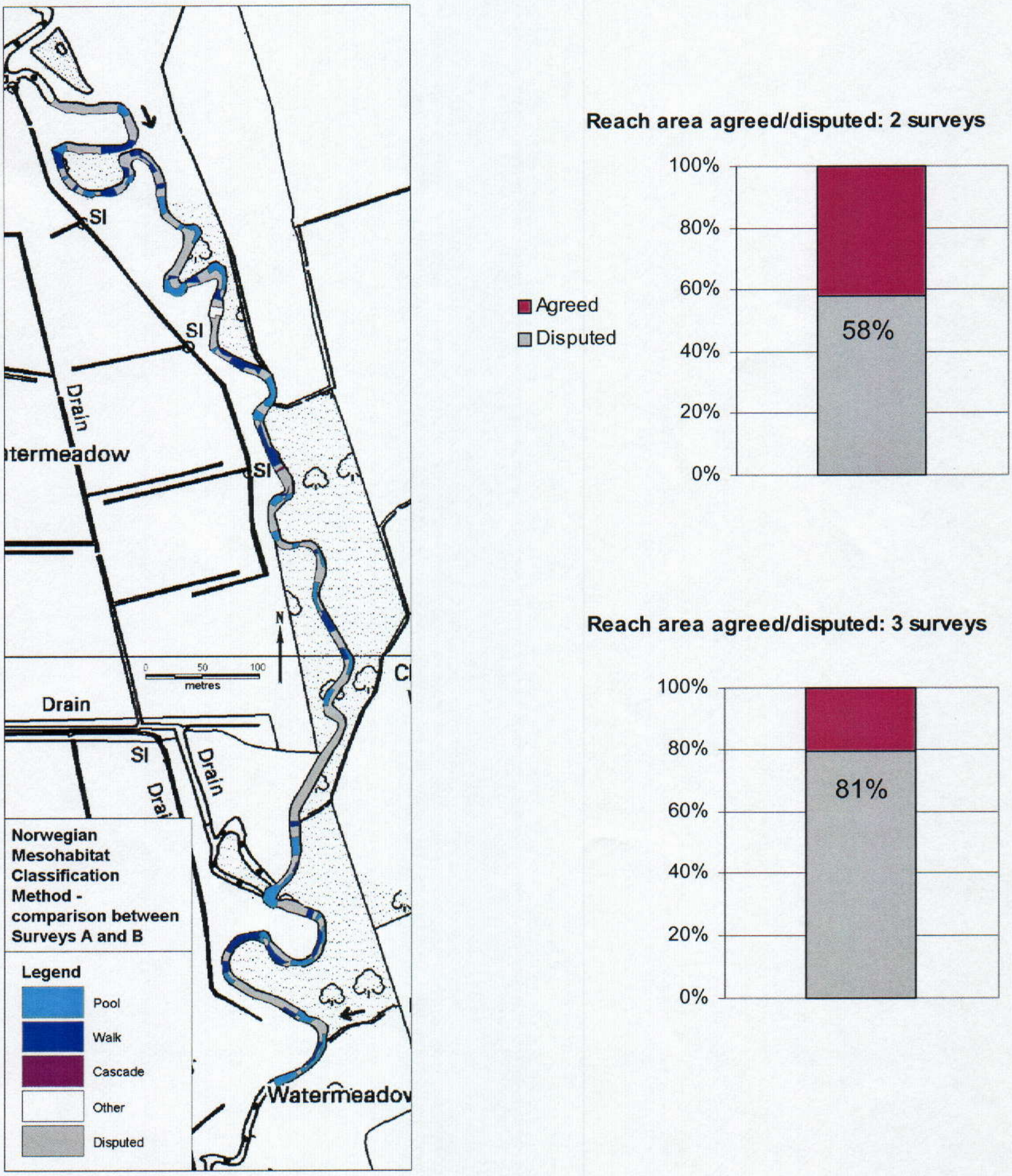


Figure 19. Comparison of habitat agreement between surveys A & B using NMCM.

Rapid Habitat Mapping

Figure 20 shows the location of agreement and disagreement between the two surveys with the greatest degree of similarity and the percentages of the channel area assigned to the habitat units by two and three operators. In the case of two operators, 47% of the channel area was disputed, and that rose to 85% with three operators. Unlike the previous two survey methods, there was agreement on some locations for all three dominant habitat types, i.e. run, glide and pool.

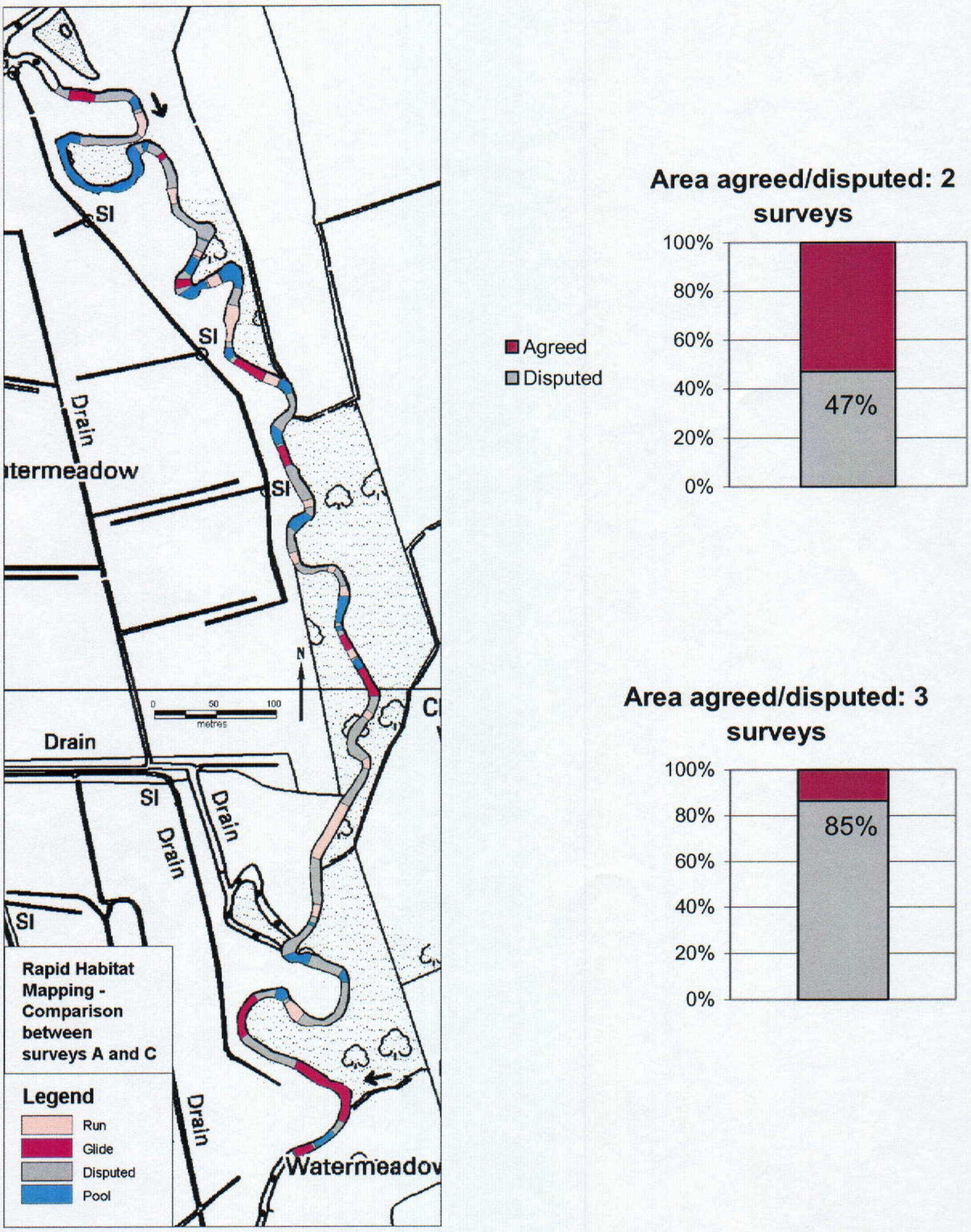


Figure 20. Comparison of habitat agreement between surveys A & B using RHM.

5.3 Inter-method comparison

5.3.1 Habitat classification

A simple comparison of habitat areas between methods is not possible because different methods use alternative habitat classification systems. Some habitat types are unique to one method (e.g. ruffle used by MesoHABSIM), some are used by two but not all methods (e.g. riffle in MesoHABSIM and RHM but not NMCM), and some types are sub-divided by certain methods but not others (e.g. glide for MesoHABSIM and RHM, but shallow and deep glide in NMCM), this is illustrated in table 6.

Table 6. Comparison of habitat descriptions used by three methods.

	MesoHABSIM	RHM	NMCM
Plunge Pool	Area where main flow passes over a complete channel obstruction and drops vertically to scour the streambed.		
Fall		Turbulent & Very Fast. Vertical drops over full width of channel, commonly found in bedrock & step-pool systems.	
Cascade	Stepped rapids with very small pools behind boulders and small waterfalls	Turbulent & Very Fast. Series of short falls & scour pools, frequently with large substrate sizes & stepped profile.	Wave, Steep Fast, Shallow
Chute		Turbulent & Very Fast. Narrow steep slots or slides in bedrock.	
Rapid	Higher gradient than riffle, faster current velocity, coarser substrate, more surface turbulence. Convex bed shape	Turbulent & Fast. Moderately steep, coarse substrate, with planar profile (rather than stepped as in cascade)	Wave, Steep Fast, Deep
Ruffle	Dewatered rapid in transition to either run or riffle		
Riffle	Shallow, moderate current velocity, some surface turbulence, high gradient. Convex bed shape	Turbulent & Moderately fast. Substrate finer than other fast water turbulent Units, less white water, more substrate breaking surface.	
Fast Run	Uniform fast flowing channel		
Run	Deeper with moderate current velocity, no surface turbulence. Laminar flow. Bed longitudinally flat, laterally concave.	Non-Turbulent & Moderately fast. Moderately fast & Shallow gradient with ripples on the water surface. Deeper than riffles, little, if any, substrate breaking surface.	Smooth/Rippled Steep Fast Deep
Deep Glide			Smooth/Rippled Moderate Fast, Deep
Glide	Moderately shallow, laminar flow, lacking pronounced turbulence. Flat bed.	Non-Turbulent & moderately slow. Smooth glassy surface, visible surface movement, relatively shallow, compared to pools	
Shallow Glide			Smooth/Rippled Moderate Fast, Shallow
Deep Splash			Wave Moderate Fast, Deep
Shallow Splash			Wave, Moderate Fast, Shallow
Pool	Deep water impounded by complete channel blockage or partial obstruction. Slow with concave streambed.	Non-Turbulent & Slow. Relatively deep and slow flowing, fine substrate. Usually little surface water movement visible.	Smooth/Rippled Moderate Slow, Deep
Walk			Smooth/Rippled Moderate Slow, Shallow
Rill			Wave, Moderate Slow, Shallow
Ponded		Non-Turbulent & Slow. Water ponded back upstream by and obstruction (e.g. weir, dam)	

MesoHABSIM		RHM	NMCM
Backwater	Slack area along channel margin, caused by eddies behind obstructions.		
Side arm	Channel around an island, smaller than half the width of the river, frequently at a different elevation than the main channel		

5.3.2 Time required to complete habitat mapping

Clear differences exist between the survey methods, habitat classification systems used (MesoCASiMiR has no 'labels' or pre-determined descriptions for habitat types), which habitat attributes are assessed (e.g. water width, depth, velocity etc.), and the amount of measurement employed to record habitat attributes (e.g. subjective versus direct measurement, or one point measurement versus numerous randomly located measurements). As a consequence, the time taken to carry out the surveys differs between methods.

Estimates of the time taken to complete the River Windrush surveys were identified and are plotted below (figure 21). This is based on two people surveying a 1.5km reach. Clearly the time taken will vary depending on the number of personnel, the ease of access) along the bank and in and out of the channel if required), the complexity of the channel morphology etc. Therefore, these values are indicated for a general comparative guide only, for these particular surveys and on this particular river.

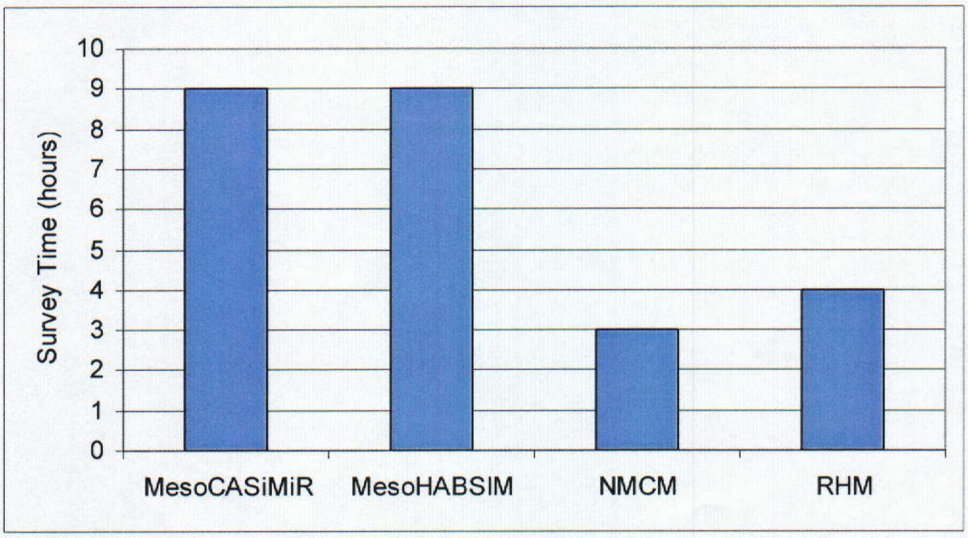


Figure 21. Approximate time taken to complete surveys.

MesoCASiMiR and MesoHABSIM took significantly longer to complete than NMCM and RHM. This is due to the greater number of habitat attributes that are assessed and the greater number of measurements taken (particularly MesoHABSIM). However, it should be reiterated that the former two methods do not require additional field work assessing habitat information in order to complete habitat modelling, i.e. they are the only stage of field data collection required. The latter two, i.e. NMCM and RHM both require additional field data collection and hence a comparison comparing all four methods in terms of the time required for complete data collection should include all stages of field data collection (and possibly subsequent modelling) to provide a true reflection of the time required.

5.3.3 Operator variability

In terms of operator variability, when comparing two surveys for each method, RHM had the least variability between surveys (47%) compared to NMCM (58%) and MesoHABSIM (68%). Because of the nature of the MesoCASiMiR habitat typology (units are not classified) it is not possible to perform a similar comparison for this method. What is clear is that although the extent of variability differs between methods, it is also relatively high for all survey methods. Areas of disagreement increase considerably when all three surveys are compared for the NMCM and RHM methods. This is to be expected as the area of agreement will continue to decrease with increased number of surveys.

One reason for the different amounts of observer variability between methods undoubtedly relates to the complexity of the habitat classification system each employs. To illustrate this point, assume one survey method has only two habitat types in the classification system, and another has 50 habitat types. Repeat surveys using the first method will by chance lead to lower observer variability because observers are selecting habitat types from a choice of two, whereas with the second method the chances of choosing the same type from a list is much longer. RHM has the simplest classification and MesoHABSIM the more complex and hence the findings that RHM has lower observer variability do not necessarily indicate differences in the reliability or consistency of the method, but may reflect the complexity of the habitat classification systems employed by each. What is fundamentally more important is the relevance of the habitat classification system. Habitat units should be defining key morphological and/or hydraulic units, and these must be demonstrated to have some ecological relevance in order to validate the habitat classification system and help determine which is the most appropriate system.

5.3.4 Influence of habitat type on operator variability

The information obtained from the surveys has been used to calculate the proportion of the channel area with habitat type agreement and disagreement. The results have not been analysed in detail to examine the exact amount of observer variability ***for each habitat type*** (in terms of actual area and proportion of the reach) and for each method. However, it seems that by comparing the results of the habitat proportions of reach area and the maps of observer variability, that glide habitats seem to be the habitat type most likely to be misclassified between operators. For example, two surveys using NMCM suggested similar proportions of the reach were occupied by glides, but there were no locations where they were classified in the same place. The fact that glides are misclassified more often than say pools or riffles is not entirely surprising as these are features that are less distinct or less striking than others, (e.g. they don't have substrate breaking the surface, standing waves, etc.) and hence are an 'intermediate' habitat type. Nevertheless, this is critical if glides are deemed to be hydraulically sensitive to abstraction and/or ecologically important, as this implies that they need to be classified with a high level of confidence.

6. Summary and conclusions

This study utilised field data from a 1.5km reach of the River Windrush to examine observer variability (the classification of the same habitat feature varies between different surveyors) when employing four different habitat mapping methods (i.e. MesoCASiMiR, MesoHABSIM, Norwegian Mesohabitat Classification Method (NMCM) and Rapid Habitat Mapping (RHM)). Three methods have been assessed in detail here (MesoHABSIM, NMCM and RHM), and the fourth (MesoCASiMiR) is being analysed by the developer of the method, i.e. Andi Eisner (University of Stuttgart).

With the exception of MesoHABSIM, each survey method was employed once by a pair of surveyors who had field experience with the technique and at least once by a pair of surveyors who had some background knowledge of the method but who had no prior field experience or formal field training with it. Therefore, the field workshop provided an insight into the nature and extent of observer variability when methods are employed by experienced field surveyors versus personnel who have had no formal field training in that specific technique. This may be a common occurrence where habitat mapping methods are developed by research teams and published in the literature but no training courses are provided in their use.

The summary and conclusions are organised below in two sections. The first focuses on issues of observer variability and the second provides brief comments on each survey method based on this study and review comments from surveyors after the workshop.

6.1 Analysis of observer variability

When analysing the results at the most basic level, i.e. non-spatial, the numbers of each habitat units present and the proportion of the reach occupied by each habitat type has been defined. Using this information, clear similarities were evident for all methods between repeat surveys. Similarities between surveys appear greatest when identifying the relative dominance of habitat types. For example, three surveys using NMCM all suggested that walk, pool and shallow glide were the three most common type of habitat units present. However, greater differences were evident between surveys when comparing the actual numbers of units and habitat areas.

Some significant differences occurred in unit size and habitat fragmentation between surveyors. For example, some surveyors would distinguish large numbers of small units, whereas other surveyors using the same technique would map the reach with far fewer and hence much larger units. For example, one survey using MesoHABSIM identified a total of 60 habitat units along the reach; a second only identified 14 units.

The pair of surveyors with the least experience of habitat mapping techniques consistently produced results that were significantly different to the other surveyors. In particular, they tended to designate very long units and hence their reach results contained fewer overall units compared to other survey teams. The significance of this is evident when looking at habitat size and fragmentation. On a practical note too, designating very long habitat units would be particularly problematic when applying MesoHABSIM as the operators would have to estimate long distances when identifying locations to collect random point sampling data. The operator variability in terms of habitat length demonstrates the need to provide guidance to field surveyors on the typical length of habitat units, and the types of visual indicators that should be used to differentiate between habitat types and hence identify habitat boundaries.

Spatial analysis was also completed to examine the locations of agreement and observer variability, and the types of units identified consistently between surveys. Spatial analysis suggested when comparing two surveys for each method, RHM had the least variability between surveys (47%) compared to NMCM (58%) and MesoHABSIM (68%). The high degree of variability in MesoHABSIM results may, in part, reflect the lack of surveyor's experience in the use of this technique. Nevertheless, all survey results indicate a high degree of variability between surveys for all methods when comparing results between those experienced and non-experienced field surveyors. Differences between methods may reflect the complexity of the habitat classification method (and the lack of experienced surveyors for MesoHABSIM) rather than any inherent differences in the reliability or accuracy of the survey method.

The spatial analysis also highlighted critical deficiencies in examining variability using only non-spatial data. For example, non-spatial data seemed to suggest good agreement between surveys using NMCM for glides because the total reach area for this habitat type was similar for each survey (approx. 20%). However, spatial analysis indicated that in fact there were no locations along the reach where there was agreement for this habitat type. Consequently, observer variability is significantly higher than apparent when examining total reach data by habitat numbers or total habitat area.

6.2 Brief comments on each method

The summary below reflects the comments made by the surveyors following the Workshop debrief and from the appraisal of operator variability outlined in this report.

The RHM method is relatively quick to apply, and physical measurements enable the determination of the area of each unit required to locate sites for follow-up fieldwork necessary for detailed habitat modelling. However, criticisms focused on the limited number of habitat units that were distinguished. This factor is also probably responsible for RHM having the lowest operator variability of the three techniques analysed in this report. For example, some felt the run category could be further divided into sub-units. Analysis of operator variability suggests that distinguishing between glides and pools was most problematic. At times the inability to distinguish lateral (cross-channel) diversity also became a limitation.

The use of a 'Decision Tree' that the NMCM applies to identify habitat types, using assessments of surface flow pattern, gradient, velocity and water depth received a positive response from the participants. This enabled surveyors to classify habitats using more rigid guidelines than the RHM method and, based on visual and quantitative information, field surveyors commented particularly favourably about this guidance. Being able to distinguish lateral diversity was also a positive aspect. The main limitation was that the habitat classification was biased towards higher gradient streams, and that greater observer variability occurred with this technique compared to the RHM.

MesoHABSIM enables habitat modelling without any further physical habitat field data collection, but requires considerable additional time during the fieldwork due to the more intense survey work. Surveyors found the definitions of habitat types difficult to interpret and distinguish in the field. The derivation of seven random sampling locations for each unit (to record velocity, depth and substrate) was time consuming and often only covered small areas of the whole unit (i.e. clustered) and were therefore biased. Similar to RHM, no lateral diversity is acknowledged. Calculations on the extent of observer variability are still to be determined.

MesoCASiMiR does not rely on any predetermined habitat classification, but requires the surveyors to distinguish between different units based on their hydraulic and geomorphic properties. Users felt this was a positive benefit, as they were not trying to 'fit' observations into existing classifications, but merely distinguishing between discrete units in the channel. Lateral diversity was incorporated, and visual estimates of velocity were deemed satisfactory. Users felt that estimating channel width was problematic and that use of a simple instrument (e.g. laser rangefinder) would overcome this. This method had the greatest operator variability between surveyors.

In general, the MesoCASiMiR method seemed most appropriate for further research. Despite being one of the slower methods to apply, it incorporated sufficient measurements to instil user confidence in habitat unit discrimination. It also enables subsequent physical habitat modelling without additional fieldwork therefore saving additional time required for follow-up fieldwork. Therefore, MesoCASiMiR provides the basis for a stand-alone rapid habitat assessment technique. However, further research is required to enable the method to become predictive and hence estimate habitat availability at flows other than those surveyed directly, and an analysis of whether the physical data that is collected is appropriate for assessing sensitivity to abstraction is needed.

7. Recommendations for further work

1. Detailed analysis of the MesCASiMiR results should be completed to enable a comparison with the MesoHABSIM, NMCM and RHM methods. Unlike the other techniques, MesoCASiMiR does not use a habitat classification system and hence a comparison is not a simple procedure. However, it may be possible to classify the units identified by the field surveyors based on their hydraulic characteristics, and then compare the location and extent of similar types between surveys to examine observer variability. This warrants further investigation.

2. The preliminary findings of this study suggest that glides are the habitat unit most likely to be mis-classified between observers. This is critically important if glides are hydraulically sensitive to abstraction and/or ecologically relevant. In order to evaluate the exact nature and extent of observer variability by habitat type, survey results should be analysed to calculate the exact areas of agreement and dispute for each habitat type and for each method.

3. Additional analysis of the field data would help identify the nature of mis-classification. For each location where there was disagreement between surveys, the two contradictory habitat types could be identified and the area of misclassification calculated. This would help identify which combinations of habitat types are most often confused with one another. For example, does most confusion occur between glides and pools, glides and runs, runs and pools, runs and riffles? By identifying which habitat types are most often confused, recommendations could be highlighted to provide better descriptions and differentiation between these units in habitat classification systems.

4. This study has focused on rapid physical habitat mapping results. All four of the methods employed are utilised as one part of a several stage process (e.g. subsequent field data collection, hydraulic simulation, habitat suitability calculation) in aquatic habitat modelling studies. To examine the true effect of observer variability of river habitat mapping methods, further studies should utilise these field data to complete habitat modelling predictions, and the modelling results compared between surveys. This would provide an analysis of the impact of observer variability on habitat modelling results.

5. The field workshop enabled the methods to be assessed at one flow. Repeat surveys at different flow levels should be carried out. This would enable an assessment of the sensitivity of each method to detect the influence of flow variability on physical habitat.

6. Whichever method is employed, the relevance of habitat classification systems requires ecological validation. This should ensure that the classification system used is defining habitats that are ecologically relevant and distinct from one another. This could be accomplished by sampling the instream biota (e.g. fish, macroinvertebrates) within and

between habitat units and compare the spatial division of ecological communities with a range of habitat classification systems.

8. References

Booker, D.J., Acreman, M.C., Dunbar, M.J., Goodwin, T.G., Gowing, I.M., Rivas-Casado, M., Hill, G., Maddock I. and Hardy, T.B. 2005 *Rapid Assessment of the Physical Habitat Sensitivity to Abstraction. Interim Technical Report 4 October 04 – March 05*. Report to the Environment Agency and the Centre for Ecology and Hydrology. CEH Wallingford pp 109.

Harby, A., Halleraker, J, H., Sundt, H., Alfredsen, K. T., Borsanyi, P., Johnse, B. O., Foreseth, T., Lund, R. and Ugedal, O. (2004) Assessing habitat in rivers on a large scale by linking microhabitat data with mesohabitat mapping. Development and test in five Norwegian Rivers. In Garcia de Jalon, D. and Martinez, P. V. (eds) *Proceedings, Fifth International Symposium on Hydraulics, Madrid, Spain*. IAHR, Spain.

Eisner, A., Young, C., Schneider, M. and Kopecki, I. (2005) MesoCASiMiR – new mapping method and comparison with other current approaches. In Harby, A. *et al*., (eds). *Proceedings*, Final COST 626 meeting in Silkeborg, Denmark.

Hawkins, C. P., Kershner, P., Bisson, A., Bryant, D., Decker, L. M., Gregory, S. V., McCullogh, D. A., Overton, C. K., Reeves, G. H., Steedman, R. J. and Young, M. K. (1993) A Hierarchical Approach to Classifying Stream Habitat Features. *Fisheries*, 18/6, 3-12.

Jowett, I. G. (1993) A method of objectively identifying pool, run and riffle habitats from physical measurements. *New Zealand Journal of Marine and Freshwater Research* 27, 241-248.

Maddock, I.P. (1999) The importance of physical habitat assessment for evaluating river health. *Freshwater Biology* 41, 373-391.

Maddock, I.P., Bickerton, M.A., Spence, R. & Pickering, T. (2001) Reallocation of compensation releases to restore river flows and improve instream habitat availability in the Upper Derwent catchment, Derbyshire, UK. *Regulated Rivers: Research and Management*, 17, 417-441.

National River Flow Archive (2005) 39142 - Windrush at Bourton on the Water. Available at: http://www.nwl.ac.uk/ih/nrfa/station_summaries/039/142.html [accessed on 24/05/2005].

National Trust (2004) Information Board at Sherborne Watermeadows, Sherborne, Glos.

Newson, M. D. & Newson, C. L. (2000) Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges. *Progress in Physical Geography* 24, 195-217.

Padmore, C.L. (1997) Biotopes and their hydraulics: a method for determining the physical component of freshwater habitat quality. In Boon, P.J. &

Howell, D.L. (eds.), *Freshwater quality: defining the indefinable*. Edinburgh: HMSO. 251-257.

Parasiewicz, P. (2001) MesoHABSIM: A concept for application of instream flow models in river restoration planning. *Fisheries*, 26/9, 6-13.

Tickner, D., Armitage, P.D., Bickerton, M.A. & Hall, K.A. (2000) Assessing stream quality using information on mesohabitat distribution and character. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10, 179-196.

Wadeson, L. A. (1994) A geomorphological approach to the identification and classification of instream flow environments. *South African Journal of Aquatic Sciences* 20, 1-24.

Whited, D., Stanford, J.A. & Kimball, J.S. (2002) Application of airborne multispectral digital imagery to quantify riverine habitats at different base flows. *River Research and Applications* 18: 583-594.