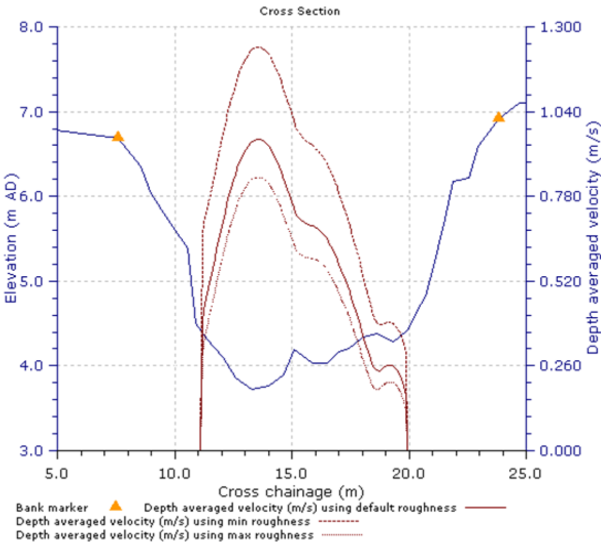
MONITORING OF THE SHOPHAM LOOP RESTORATION PROJECT

Analysis and evaluation



For

Environment Agency

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Prepared by

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Document Revisions

No.	Details	Date
1	Draft Report	July 2010
2	Draft Report	July 2011
3	Final Report	

This assessment has been compiled on the basis of RRC's extensive expertise and the analysis of data collated from a range of sources. RRC seeks to provide advice and suggestions to facilitate river restoration progress, and in the case of this document an assessment of the project based on data collected over 3 years. The information assessment and conclusions are limited by the specific mix, detail and time frame of data collected for this project. Where data limitations have been identified these are noted in the text and it should be borne in mind that the level of feasible analysis has been reliant solely on these data sources.

Executive Summary

Introduction

Following a project to reconnect an 850 m length of bypassed meander (known as Shopham Loop) on the River Western Rother in West Sussex in 2004, it was recognised that there was a need to evaluate and demonstrate the success of the restoration works in terms of:

- Changes in *geomorphology*, as the basic template of physical habitat.
- Changes in the *hydrology and hydraulics*, to ensure no adverse impact on flood levels and also from the point of view of the hydraulic aspects of habitats.
- Changes in the *ecology* of the restored and adjacent reaches, as well as the surrounding landscape.
- The *drivers* of these changes.

As such, a decision was made to implement a comprehensive monitoring programme, and data collected variously between 2002 and 2009 are analysed here.

Objectives of the report

The current report seeks to:

- Establish what the available data can tell us (Section 2).
- Determine whether the monitoring objectives have been met, and to what extent (Section 3).
- Identify and address particular successes and shortcomings of the programme, summarizing lessons learnt (Section 3).
- Provide specific recommendations for future monitoring programmes both at Shopham Loop and more generally (Section 4).

Evaluation and lessons learnt

Key challenges encountered are identified, particularly in terms of the importance of developing clear measurable objectives; consistency in data collection; and pre-project planning and design. Not having these aspects explicitly considered within the project at all – and especially the very first – stages of the project has significantly reduced the confidence associated with the analysis of some of the datasets. This has, in turn, limited the number of definitive conclusions relating to the success of the restoration project.

Conclusions from the data

In spite of the obstacles mentioned, several reasonably firm conclusions regarding the trajectory of the project in terms of the specific aspects of geomorphology, hydraulics, etc. mentioned above can be made, including the following:

1. The most significant changes in morphology occurred very quickly after construction, likely owing to the high flows which occurred in this period, as well as the unconsolidated channel bank and bed material. A much more complex and varied set of cross-sections than the design sections followed has formed.

2. Whilst small-scale adjustment is in evidence throughout the loop, the most significant changes have occurred on the main Rother immediately downstream, where the loop re-enters at a fairly sharp angle. This was the only practical planform option, however, owing to the need to protect valued historic stonework.

3. By 2007, most of the initially bare banks had established a good cover of vegetation, whilst mature woody vegetation retained during the works had begun to contribute to morphological change within the channel.

4. In-channel macrophytes quickly established and continue to develop a varied community, though somewhat dominated by a few key species.

5. Minnow and 3-Spined Stickleback initially dominated the loop and scrape, respectively, during fisheries surveys, though the dominance of these species has been decreasing, with the new scrape habitat in the floodplain being colonised quite dramatically.

6. The fish community of the loop was comparable with the wider catchment, though Bullhead, Chub, Brown Trout, Grayling, Sea Trout and Barbel were consistently found to be more common in the loop than sites up- and downstream (the latter three species found only in the loop). Gudgeon, Dace, Roach, Lamprey, Pike, Bream and Carp were consistently under-represented.

7. The range of macro-invertebrate communities reflected the diversity of meso-habitats which developed within the loop, and generally, invertebrate biomass and species richness have increased. The loop also now supports a much less pollution-tolerant community than the pre-project baseline, with the 'vegetation' and 'cobble' habitats particularly important from this point of view.

Recommendations

General recommendations for similar monitoring programmes relate directly to the points identified in the *Evaluation* section – namely, to define measurable objectives; to plan fully in advance, explicitly considering experimental design and adequate control data; and to ensure effective central coordination of data collection.

The remaining recommendations are of a technical nature, relating to the specific types of data collection adopted within the programme. Recurring themes are consistency; control and baseline data; building in redundancy and planning for unforeseen problems; timeframes; sample sizes; and collecting sufficient data to allow further analysis should additional resources become available.

Those recommendations which could be applied to a continuation of monitoring at Shopham Loop are clearly identified.

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1. Introduction

In 2004, a project to reconnect an approximately 850 m length of river meander, which had been bypassed by a navigation cut, was completed. In recognition of the rarity of post-project appraisal on river restoration and enhancement ventures such as this at the time, a second phase was initiated, aimed at determining its success, or otherwise, via an integrated programme of monitoring which extended over 5 years.

This report presents an analysis not only of the data collected and the success of the works, but also the approach taken to monitoring and its implementation. Lessons learnt through the exercise are identified, so as to inform the holistic design of future river restoration projects and their appraisal processes.

1.1 The site

Known as the ‘Shopham Loop’, this meander is part of the natural course of the Western River Rother, in West Sussex, England, between national grid references (NGRs) SU9804619061 and SU9830018825 (see Figure 2). The reach was bypassed in the 18^{th} century with a gated channel, to allow the passage of boats upstream to Midhurst. The lock gate structures later fell into disrepair, however, with the result that the majority of the Rother’s flow took the shorter, straighter route of the canal cut. The limited and slow flows remaining within the loop caused it to silt-up gradually.

With the overall aim of restoring the diverse physical habitat associated with a naturally meandering lowland river, without adversely affecting hydraulic performance, the Environment Agency (EA), in cooperation with the River Restoration Centre (RRC), led a project to excavate and divert flow back through this meander.

1.2 Objectives

Post-project appraisal should always be undertaken with reference to the project’s original objectives. Those for both phases of the Shopham Loop scheme are presented below.

1.2.1 Restoration project objectives

Though these were not defined sufficiently explicitly from the outset to provide the framework for post-project appraisal, the following have been identified retrospectively as encapsulating the main ambitions:

- Restore 1 km of degraded watercourse and its associated floodplains.
- Restore natural river processes to provide additional habitat diversity to benefit the ecology of the river.
- Enhance and diversify the fishery of the lower river Rother catchment.

1.2.2 Monitoring objectives

The monitoring programme sought to identify, over three years:

- Changes in *geomorphology* (as the basic template of the physical habitat) of the restored and adjacent reaches, looking at the evolution of features (banks, sidebars, point bars, flow types, vegetation establishment, etc.), using a time sequence to give rates of morphological change.
- Changes in the *hydrology and hydraulics* of the restored and adjacent reaches, to ensure the project has no adverse impact on flood levels, as well as to enable detailed analysis of the in-channel hydraulic conditions within the restored reach.

- The *ecological response within the restored and adjacent reaches*, to document how flora and fauna adjust to the changing physical habitat over time. This would also be supplemented with the application of habitat suitability models to analyse the mechanisms driving observed changes.
- The *ecological response of the surrounding landscape* and species influenced by the restoration of the river and the floodplain, and through changes in management.
- The *drivers of changes* (e.g. response to faulty design, influence of extreme events, etc) in channel morphology, substrate composition and the establishment/evolution of flora and fauna. It was intended to compare the nature of the restored physical habitat (i.e. the project outcomes) with those anticipated at the design phase of the project.

1.2.3 Report objectives

This document seeks to:

- Establish what the available data can tell us about the success and sustainability of the project (Section 2).
- Determine whether the monitoring objectives have been met, and to what extent (Section 3).
- Address any shortcomings of the monitoring, identify further data requirements and discuss what could be done to add value to the information (also Section 3).
- Summarize lessons learnt and provide specific recommendations for future monitoring strategies both at Shopham Loop and more widely (Sections 3 and 4).

1.3 Methods

1.3.1 Restoration methods

In terms of planform, the reference point for restoration was relatively clear, from that of the loop as surveyed in 2002. The designed course does deviate slightly from the pre-existing at the upstream end, with a new entry channel cut to bypass the flume in front of the gate structure remnants (Figure 1).

The loop was excavated to one of two cross-section designs (for bend apices and straight reaches), or a point on the transition between them (Figure 5), with the assumption that the banks would erode to a more natural form in higher flows. It was the original intention to cut only to the evident historic bed level, but this could not be identified upon excavation, possibly owing to historic dredging.

In order to prevent undermining of the remnant stonework (with high archaeological value) at the downstream confluence, sheet piling was sunk across the river and a ‘bed check’ created from a base layer of coarse, locally-sourced sandstone. This downstream feature fixed a minimum bed elevation, and was intended to mimic bedrock. At the entry to the loop, a similar technique was employed so as to minimize the impact on water and bed levels in the upstream reach of the river (which had adjusted to the backwater effect of the collapsed gate structure), as well to create a crossing point for farm traffic. This was dressed with gravel, to mimic a natural riffle. It is acknowledged that these features have limited the opportunity for the channel to adjust its course naturally over longer timescales.

Finally, to divert the flow and create a backwater intended to be both a sediment trap and novel habitat type (e.g., for fish refuge in high flows), a large bund was constructed in the downstream portion of the canal cut, using spoil from the loop. The embankment of this straight cut was repaired, and an upstream bank portion (at the ford) lowered and set back, to encourage inundation of the floodplain in high flows. An approximately 1.5 m deep hollow scrape was also excavated on the floodplain.

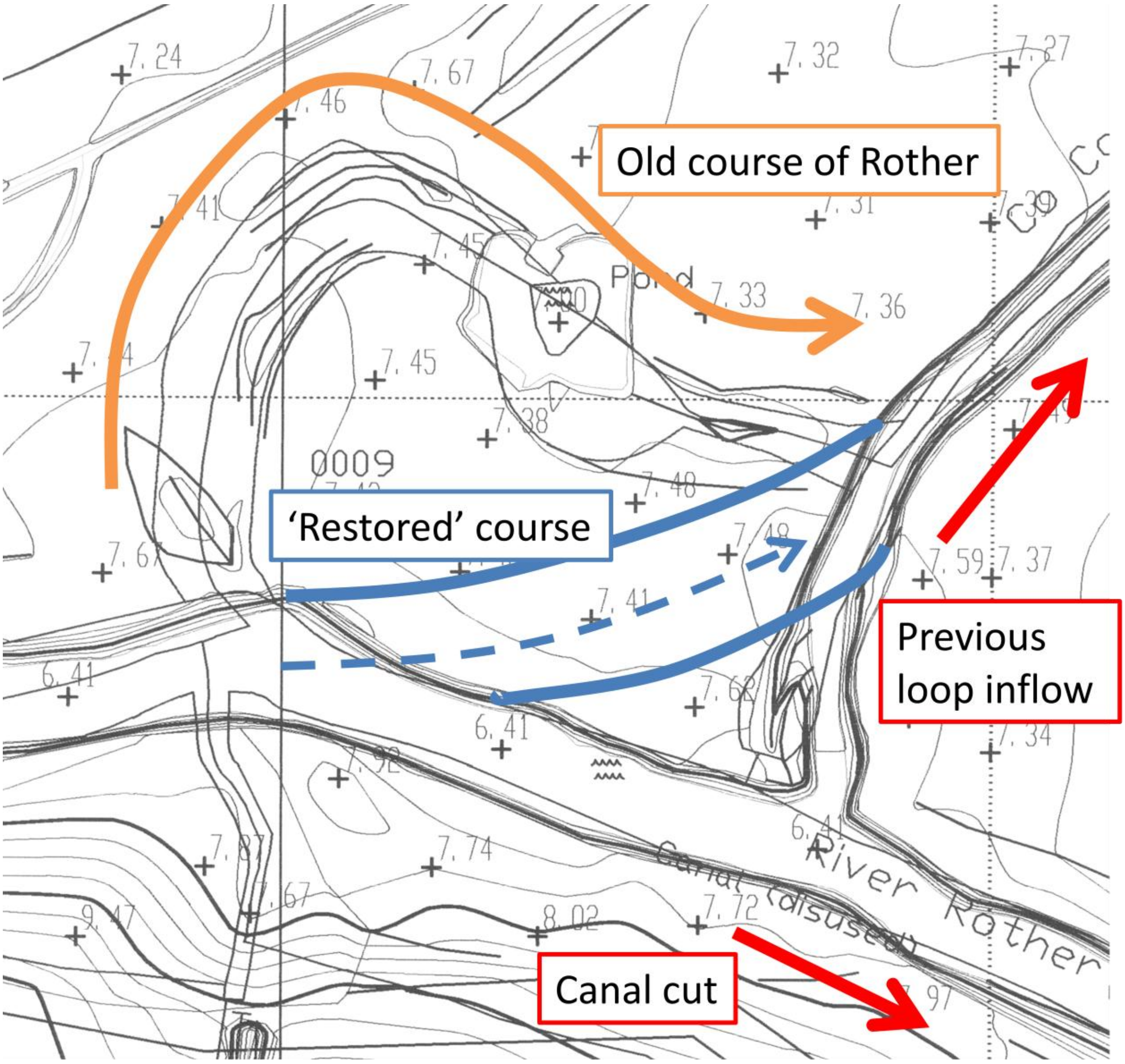

Figure 1: Upstream entrance to Shopham Loop, showing the pre-project arrangement (red), the designed course (blue) and a smaller meander remnant (orange). Overlaid on excerpt of survey by Halcrow Geomatics.

1.3.2 Monitoring methods

Between 2002 and 2009, the following datasets were generated:

- Topographic survey
- Fixed-point photography
- 15-minutely water levels
- Macro-invertebrate kick samples
- Electro-fishing
- Macrophyte survey

Topographic survey

A complete total station topographic survey, with channel cross-sections in the canal cut and in the loop as it existed, was undertaken by Halcrow Geomatics in December 2002 (before any work had commenced). This was followed up by an 'as-built' survey in October 2004. Three further surveys, including up to 24 cross-sections in the loop, and thalweg surveys on 2 occasions (see Table 1), were conducted by Southampton University in 2005, 2006 and 2009. The layout of the surveys is given in Figure 2.

Data	2002	As-built	2005	2006	2009
Loop thalweg	No	No	Yes (91)	Yes (307)	No
Canal cut thalweg	Yes (14)	Yes (dam only – 84)	No	No	No
Loop sections	14 (unknown)	14 (358)	24 (440)	17 (423)	20 (451)
Non-loop sections	18 (unknown)	5 (132)	2 (30)	3 (105)	3 (74)

Table 1: Topographic survey datasets. Numbers in brackets refer to number of points within the channel. Note that where a complete thalweg survey is absent, this can be approximated using the lowest elevation points from the cross-sections.

Fixed-point photography

The site was recorded photographically from 24 fixed angles, with coverage quite variable between years, and increasing to more than 28 angles over the last few sampling sessions. Images are available taken during and soon after construction, twice in 2005, three times in 2006 and once in 2007. 35 mm colour slide film was used, because of its fine resolution.

15-minutely water levels

Three pressure transducers were installed in and around the loop to monitor water levels. The data were logged at 15 minute intervals. Sensor 1 was mounted from an overhanging tree in the middle of the loop in 2005 (NGR: SU9833919060); sensor 2, approximately 240 m upstream (NGR: SU9783219147); and sensor 3, approximately 430 m downstream, at Shopham bridge at a later date, in 2006 (NGR: SU9847718555), as illustrated in Figure 3.

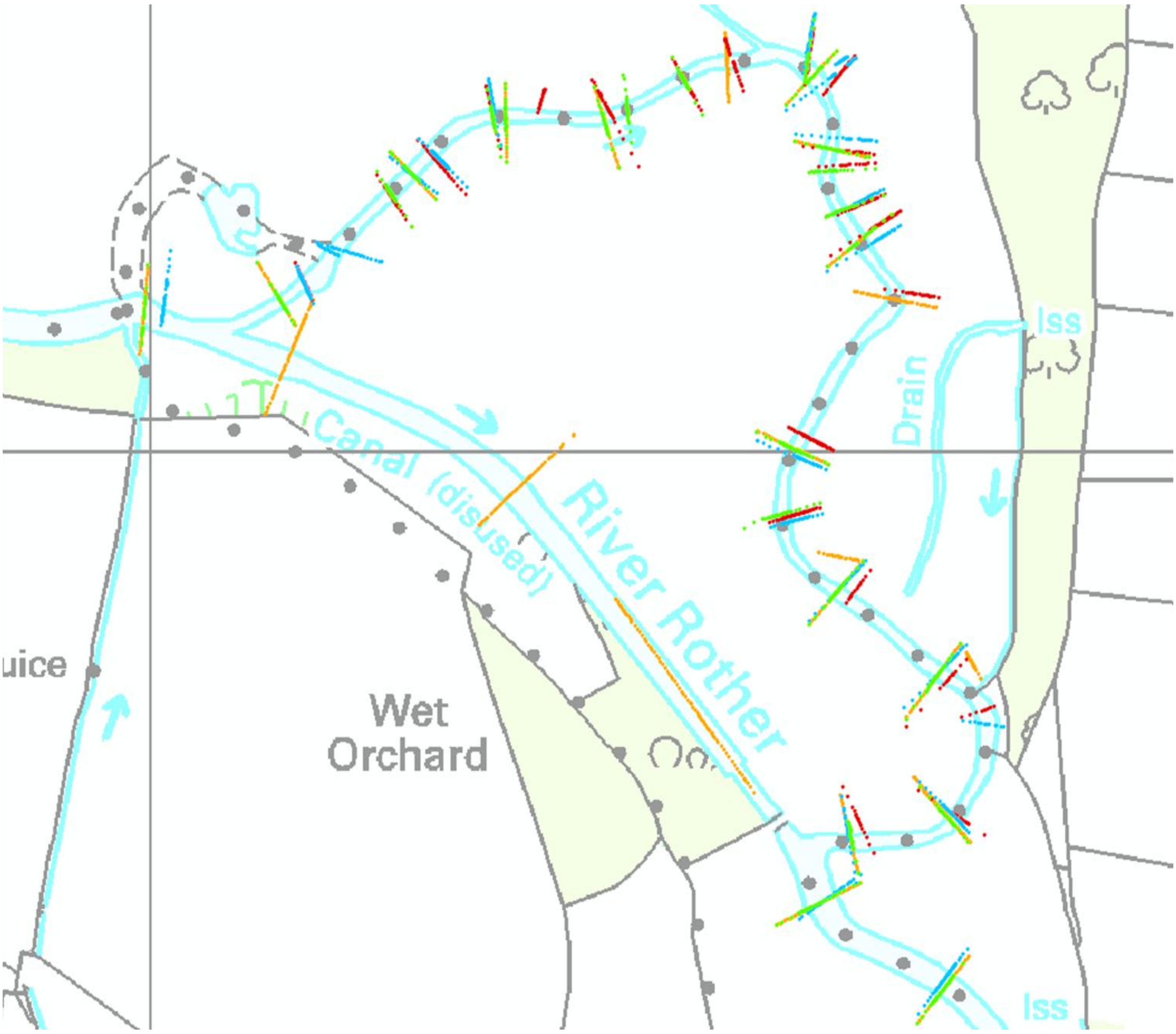

Figure 2: Position of cross-sections and thalweg survey points.
Orange: 2004 (as-built); Red: 2005; Blue: 2006; Green: 2009; Black: thalweg, 2006 © Crown Copyright and database right 2011. All rights reserved. Ordnance Survey Licence number 100026380

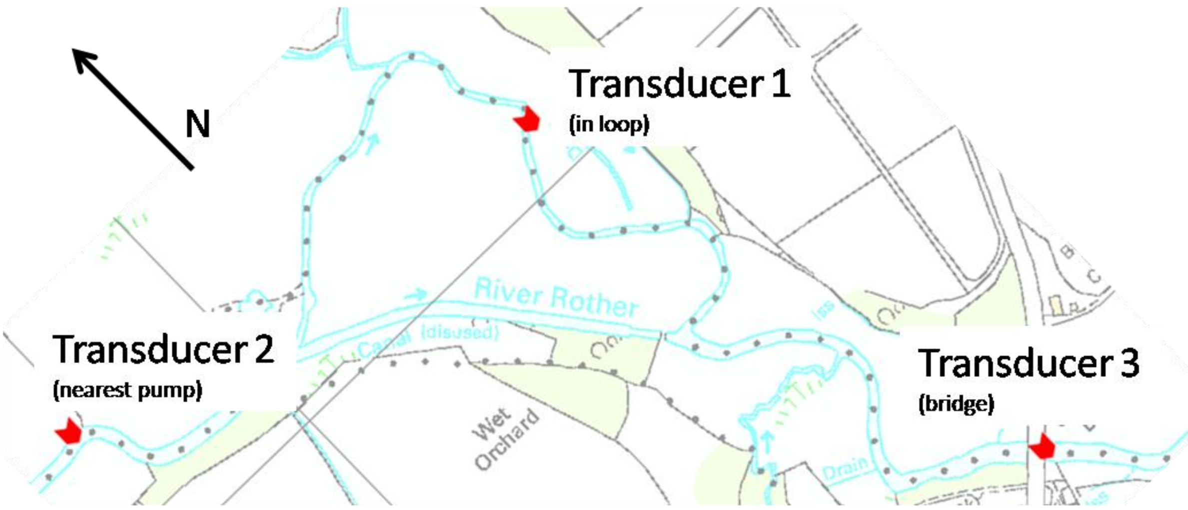

Figure 3: Position of logging pressure tranducers within the study area. © Crown Copyright and database right 2011. All rights reserved. Ordnance Survey Licence number 100026380

Macro-invertebrate kick samples

Standard 3 minute benthic kick samples were performed once pre-project, both in the loop and canal cut in September 2002, and post-project in August 2009 in the loop only. 1 minute samples were also taken in 2005, 2006 and 2007.

Kick samples were stratified by 'mesohabitats' (defined by substrate type, including vegetation), with approximately 3 replicates per year for each type. The position of these samples on the reach varied from year to year to account for any migration of features and bed material, and also because of access issues (Figure 4).

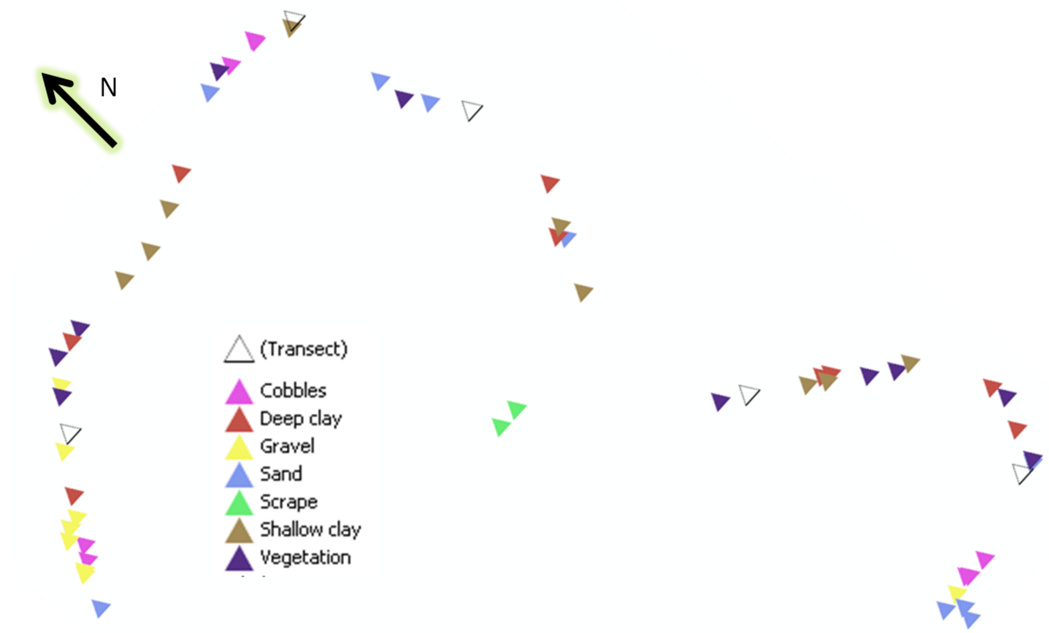

Figure 4: Layout of macro-invertebrate kick samples around the loop.

In addition, 3 minute samples were taken at 5 fixed points around the loop, intended to coincide with survey cross-sections 2, 4, 7, 9 and 13A. The aim here was to investigate the relationship between the evolution of channel form and channel biota.

<table>
<tr><th>Sampling point/type</th><th>2002</th><th>2005</th><th>2006</th><th>2007</th><th>2009</th></tr>
<tr><td>Transects</td><td></td><td></td><td>5</td><td>5</td><td>1</td></tr>
<tr><td>Scrape</td><td></td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Cobbles</td><td></td><td>3</td><td>3</td><td>3</td><td></td></tr>
<tr><td>Gravel</td><td>2</td><td>3</td><td>2</td><td>3</td><td>2</td></tr>
<tr><td>Sand</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td></tr>
<tr><td>Woody debris/Vegetation</td><td></td><td>3</td><td>3</td><td>3</td><td></td></tr>
<tr><td>'Deep clay'</td><td rowspan="2">3 (depth unspecified)</td><td>3</td><td>1</td><td>3</td><td>3</td></tr>
<tr><td>'Shallow clay'</td><td>3</td><td>3</td><td>3</td><td></td></tr>
</table>

Table 2: Number of kick sample replicates by type and year.

Comparable 3 minute data are available for EA surveillance monitoring stations at:

- Selham, approximately 7.8 km upstream (NGR: SU9350021260; May & Sep 2005, Apr & Sep 2006, Oct 2007 and May 2009)
- Shopham bridge, just 430 m downstream (NGR: SU9847018500; May & Sep 2005, Apr & Aug 2006, Apr & Oct 2007 and August 2009)
- Fittleworth, approx. 3.6 km downstream (NGR: TQ0088018239; Apr & Sep 2002, Apr & Nov 2005, Apr 2006, and May 2007)

Fisheries surveys

EA standard electro-fishing methods were applied through the length of the loop and in the scrape in 2005, 2006, 2007 and 2009. The loop data were stratified by position along the reach, aggregated into six 100 m sections and two shorter (approx. 40 m each) sections covering the bed-checks. Some basic information about size classes is available for 2005 and 2007, and for the scrape only in 2006 and 2009.

Comparable data are available for EA surveillance monitoring stations at:

- Coultershaw, approx. 1.3 km upstream (NGR: SU9729819058; Jul 2006, and Aug 2007 and 2008)
- Fittleworth, approx. 3.6 km downstream (NGR: TQ0088018239; Jul 2006, 2007 and 2008)

In addition, species larvae present and their approximate location were recorded in 2005 in the canal cut.

Macrophyte survey

Coarse vegetation in the channel and on the banks of the loop was recorded in July 2005, June 2006, summer 2007 and August 2009. Species and approximate coverage were mapped.

2. Summary of results and conclusions

The results of analyses and conclusions emerging from the monitoring data are presented in this section, grouped according to the monitoring objectives as set out in Section 1.2.2.

There are a number of complicating factors placing limits on the confidence with which conclusions can be asserted, and the contents of this section should be interpreted with this in mind. Further discussion of the data collection and monitoring design, including explanation of these limitations, is presented in Section 3.

In recognition of this, conclusions are presented at three levels of confidence:

High degree of confidence – These conclusions are completely supported by the evidence collected and the analyses performed within the context of this evaluation. In many cases they are broad and general in nature, but all are intended to be unequivocal.

Reasonable confidence – These statements are highly likely to be true, but there may not be complete data in support of them. Though further investigation may find otherwise, the great weight of evidence supports the claim.

Tentative conclusions – These are suggested by the data, but cannot be definitively asserted. Typically, some data support the conclusions but the bulk of the data is inconclusive, or the data collection was likely to produce artefacts.

2.1 Geomorphology

2.1.1 Topographic survey

Dr. Steve Darby (Darby, 2007) examined the first two post-project surveys ('05 and '06) in January 2007, and concluded that *overall, channel adjustments observed to 2006 indicated that the channel morphology remained consistent with the design concept. Some local channel adjustments had occurred, particularly within the curved reaches. However, these adjustments appeared to be mostly minor and had introduced an increasing (but small, up by that point) degree of morphological variability into the restored reach, both in terms of the long profile and cross-sectional morphology. This variability was anticipated to be a key factor in underpinning habitat diversity, and therefore a priority for monitoring.* These conclusions still hold true in light of the analysis of further evidence presented in the current study.

More specifically, Dr. Darby concluded the following:

- *Morphological changes within the loop were generally of small scale. Moreover, observed changes seemed to be reflecting inter-annual variability rather than a systematic temporal trend, but this needed to be verified as the duration of monitoring increased.*
  The 2009 survey suggests this still to be partly true, but some changes, particularly local scour, appeared to be continuing in the same trajectory in some cross-sections (see overlays, below).
- *Straight reaches of Shopham Loop appeared to be less sensitive to morphological change than the curved reaches.*
  This was no longer clear in the sections included in the analysis below, but this is likely owing to the decreased distinctiveness between straight and curved sections due to small

morphological adjustments. See particularly Section 4 (Figure 8), which is likely to have been considered a straight reach (this is not explicitly stated in the report), but has adjusted significantly, most likely as a result of considerable adjustment of the upstream curved reach (Section 4A; Figure 9).

- *Within straight reaches of the loop, variations in* mean *width relative to the design concept had been negligible. However, the* variability *of the channel width in these straight reaches (as quantified using the standard deviation), had increased markedly during the period 2005 to 2006.*
  (no subsequent analysis of width standard deviation has been undertaken)
- *Within straight reaches of the loop by 2005 the channel had considerably enlarged its cross-sectional area (by deepening) relative to the restoration design. Some recovery of cross-sectional area had subsequently (2005-2006) occurred, as the channel (on average) narrowed in this period. However, the cross-section surveys indicated that localised scour was continuing in some sections. The net effect was that the cross-section area of straight reaches remained in 2006 larger than the restoration design value.*
  In the sections examined below, cross-sectional area continued to increase to 2009. Local areas of scour have also persisted since 2006.
- *Curved reaches of the loop had, on average, widened significantly (25% increase relative to design value by 2006). The variability of width had also increased in these curved reaches.*
  (it has not been possible to determine any further major conclusions relating to channel width)
- *Within curved reaches, the* variability *of most of the key morphological parameters had increased substantially during 2005-2006.*
  This conclusion holds (see also section on perimeter length, below).
- *Some localised changes in the morphology of the Rother cross-sections immediately downstream of Shopham Loop were observed, but the change appeared to involve a degree of channel migration, rather than a systematic shift in morphology* per se*.*
  Section B, the closer of the Rother sections to the loop outflow, has been the site of the greatest change, with substantial erosion of the bank on the outside of the bend (right bank) occurring between 2006 and 2009. This is indeed a form of channel migration resulting from the introduction of a tight curve where there was none before. There has also been morphological change, however, in that the thalweg has moved from being close to the left bank in the 'as-built' survey, to being close to the right bank in 2009, though this is a predictable adjustment (even if perhaps not anticipated to such a degree in the design process) and is consistent with the design concept.

Cross-section overlays

Visual comparison of a time series of coincident cross-sections can give an indication of the occurrence, direction and approximate rate of any changes in the channel's transverse morphology. There were just under 40 original design sections, broadly based on those illustrated in Figure 5, or a linear transition between the two quasi-trapezoidal forms.

These results are limited by the complications discussed in Section 3, but the loop cross-sections which match most closely between years are presented in Figures 6-18, below. Note the vertical exaggeration in the section plots.

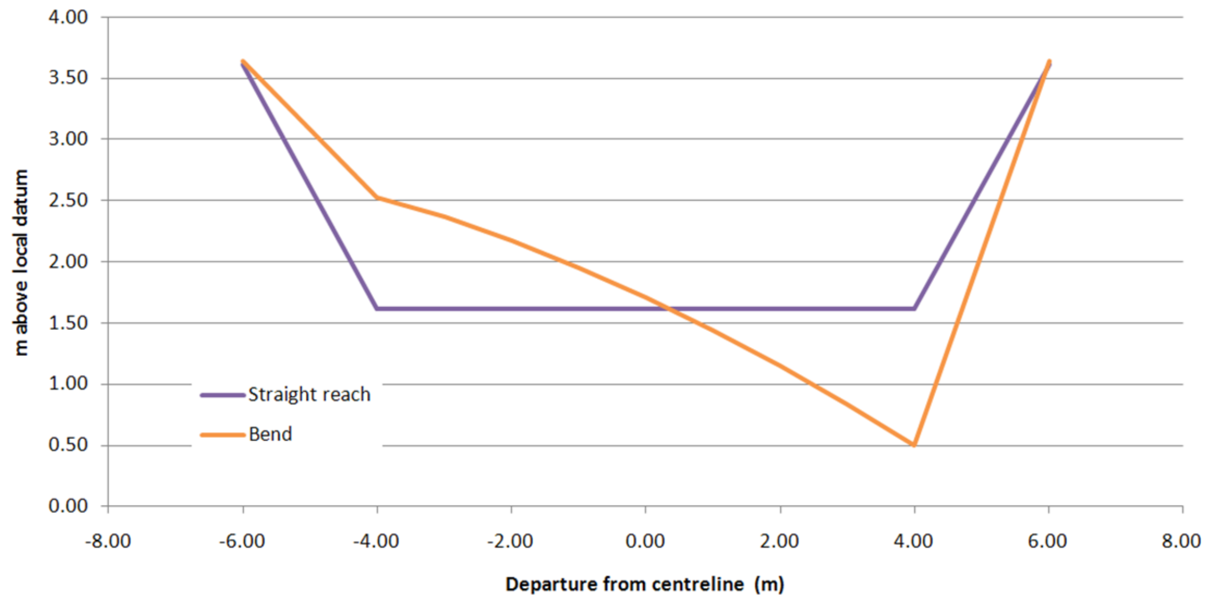

Figure 5: Schematic design cross-sections for straight reaches or meander cross-overs and bend apices.

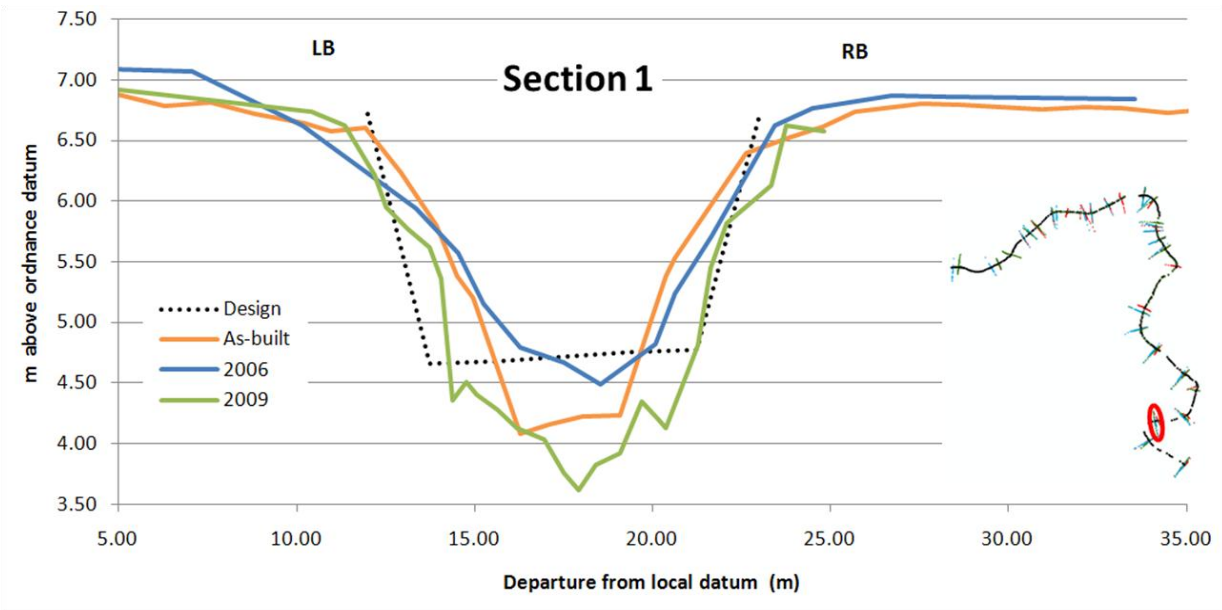

Figure 6: Overlays from surveys of loop section 1 (at downstream bed check). LB: left bank (facing downstream); RB: right bank (position on planform inset).

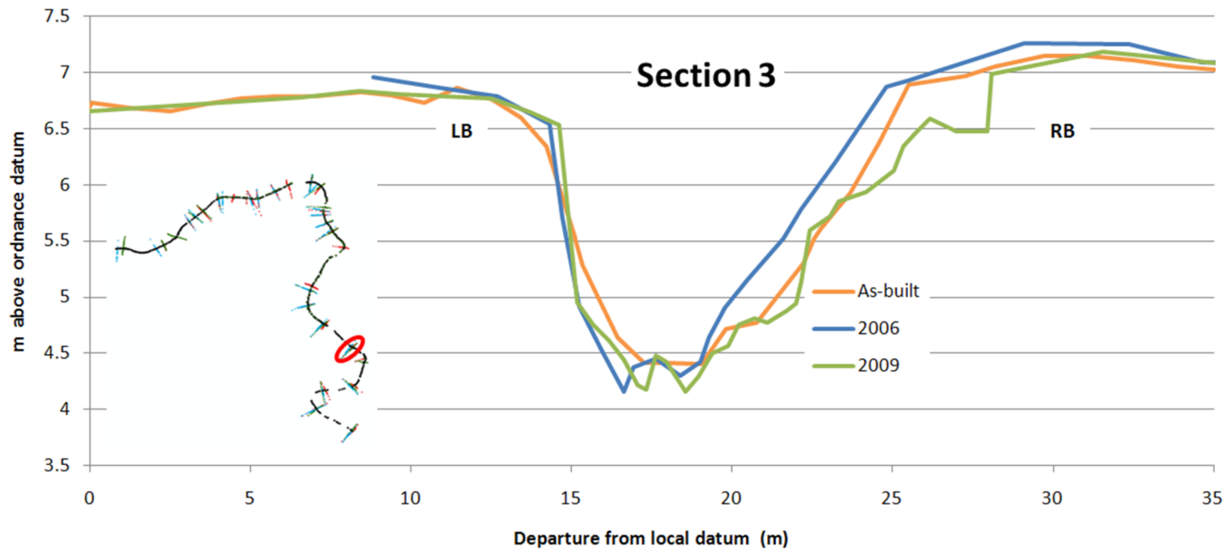

Figure 7: Overlays from surveys of loop section 3. LB: left bank (facing downstream); RB: right bank (position on planform inset).

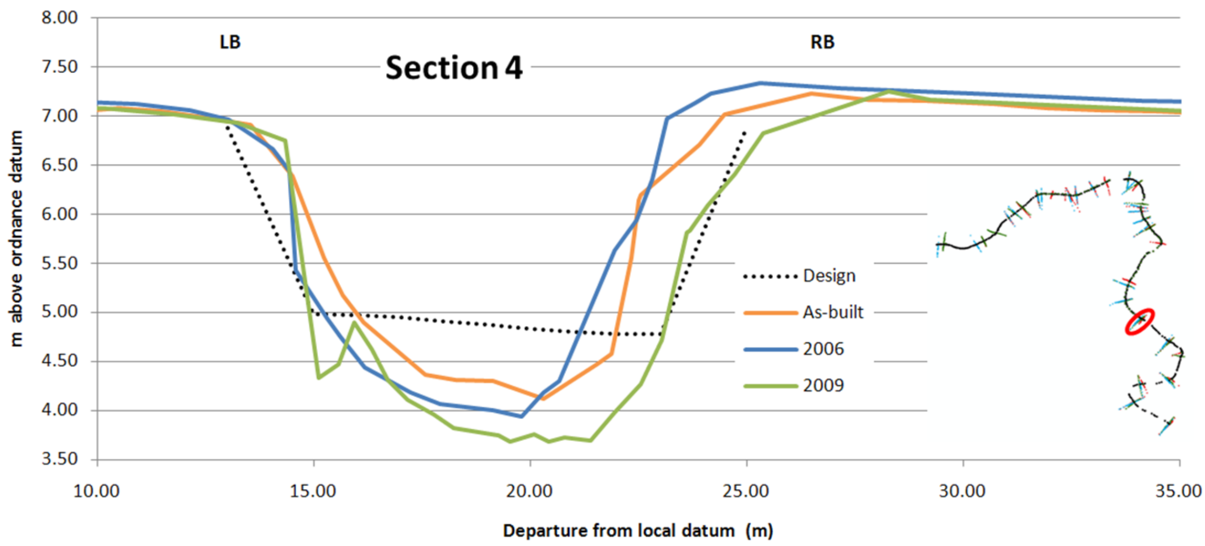

Figure 8: Overlays from surveys of loop section 4. LB: left bank (facing downstream); RB: right bank (position on planform inset).

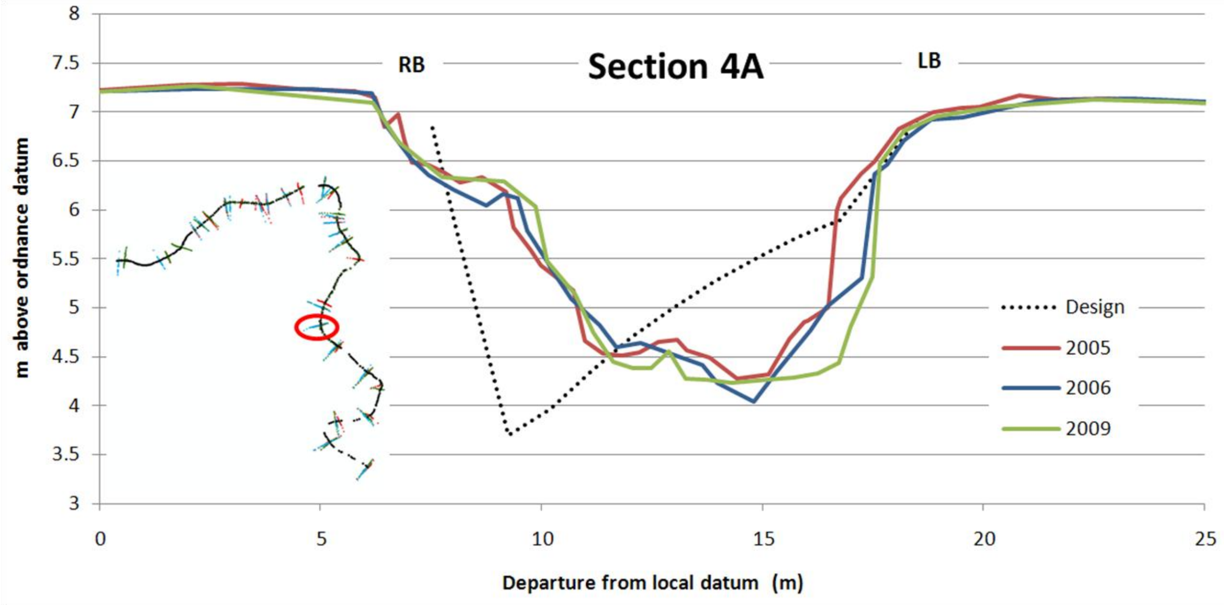

Figure 9: Overlays from surveys of loop section 4A. LB: left bank (facing downstream); RB: right bank (position on planform inset).

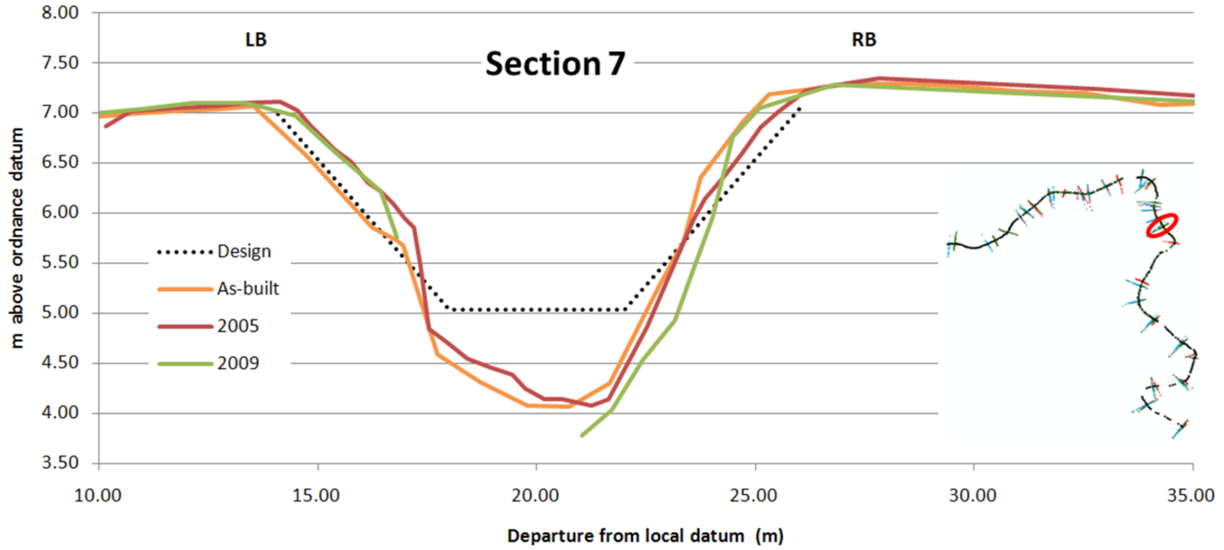

Figure 10: Overlays from surveys of loop section 7. LB: left bank (facing downstream); RB: right bank (position on planform inset).

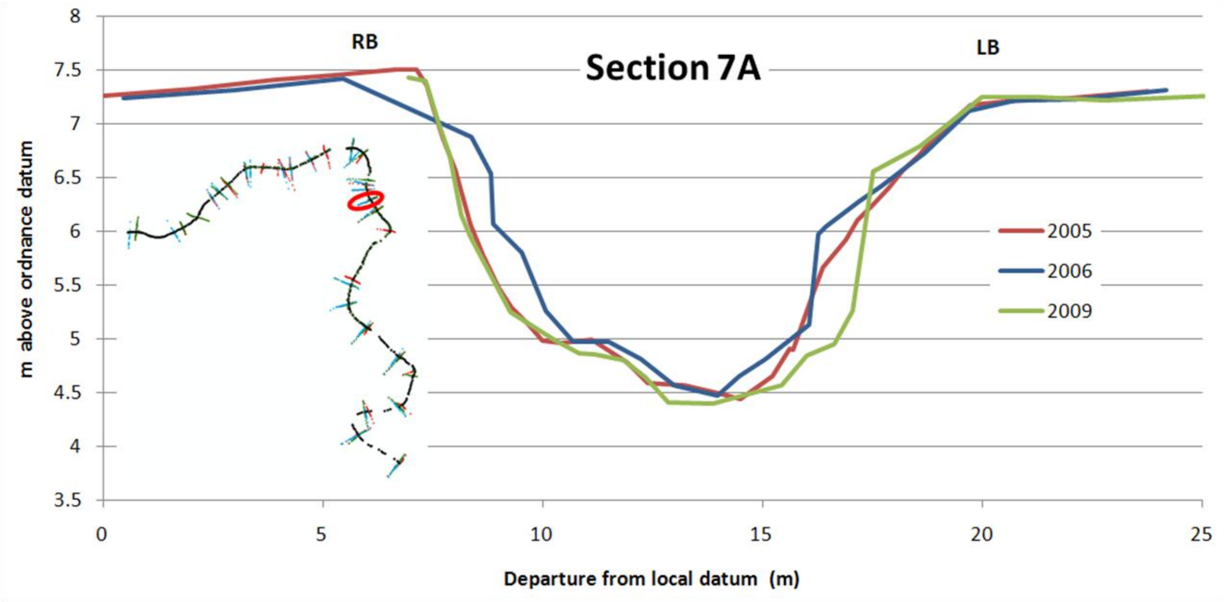

Figure 11: Overlays from surveys of loop section 7A. LB: left bank (facing downstream); RB: right bank (position on planform inset).

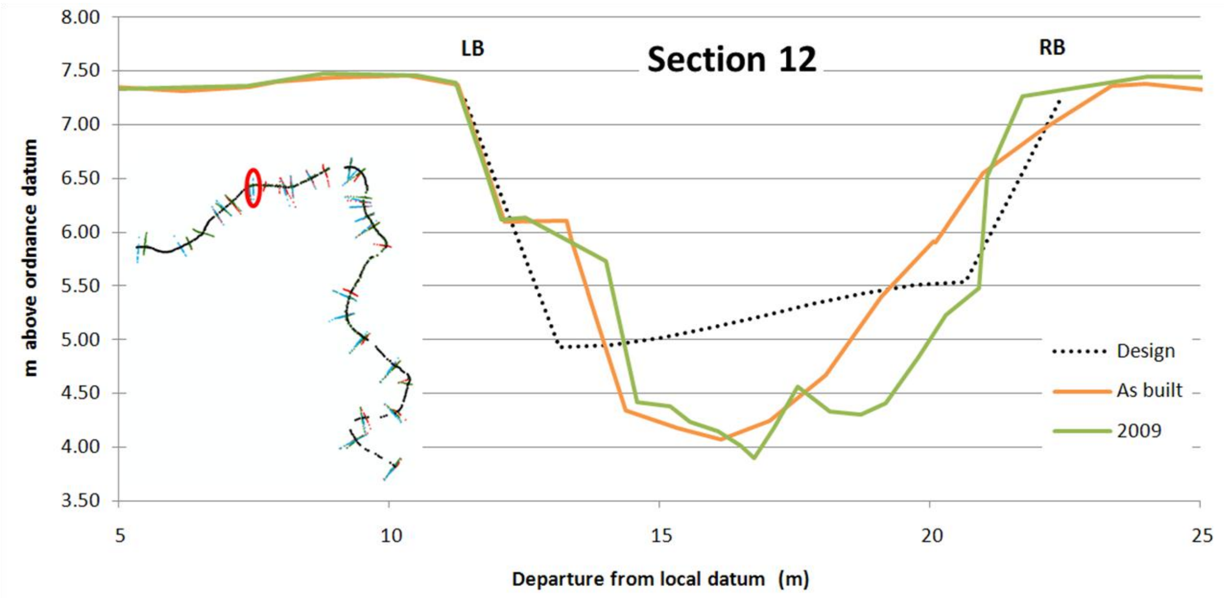

Figure 12: Overlays from surveys of loop section 12. LB: left bank (facing downstream); RB: right bank (position on planform inset).

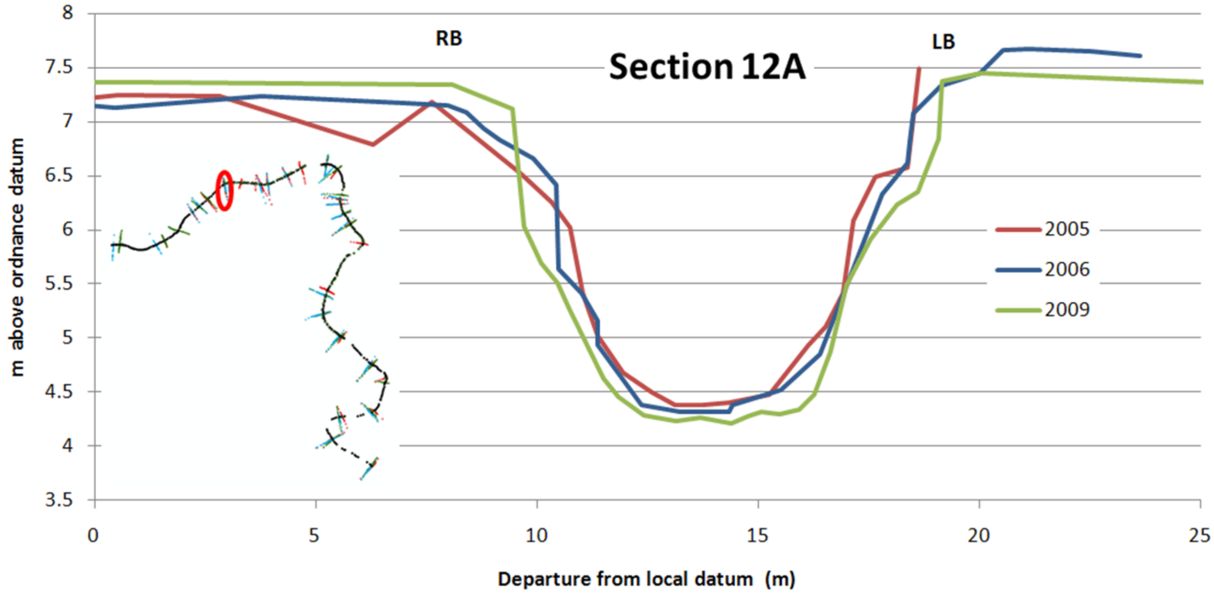

Figure 13: Overlays from surveys of loop section 12A. LB: left bank (facing downstream); RB: right bank (position on planform inset).

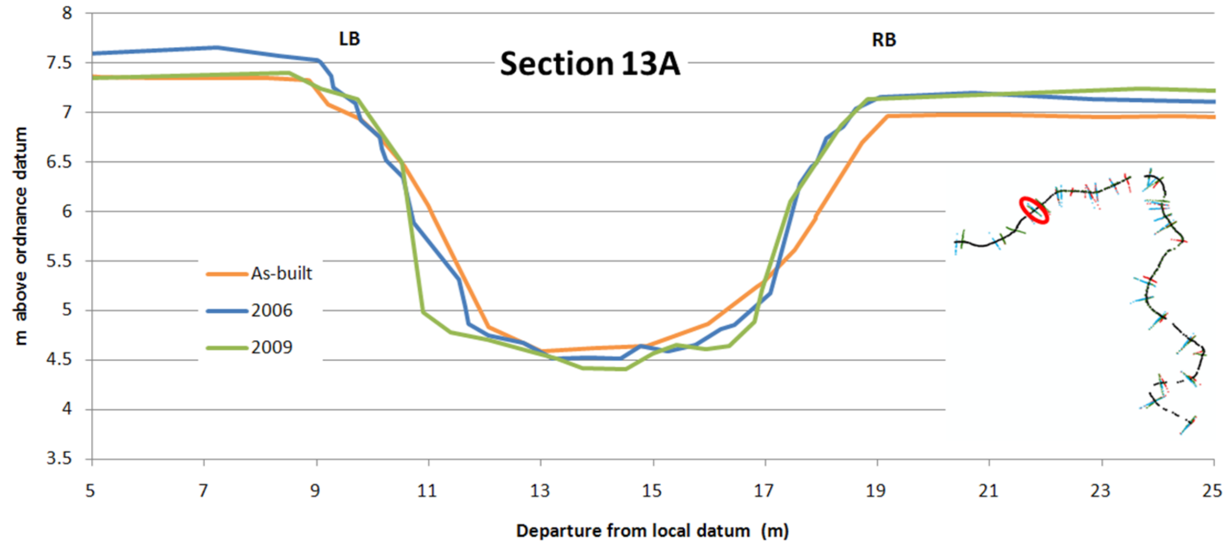

Figure 14: Overlays from surveys of loop section 13A. LB: left bank (facing downstream); RB: right bank (position on planform inset).

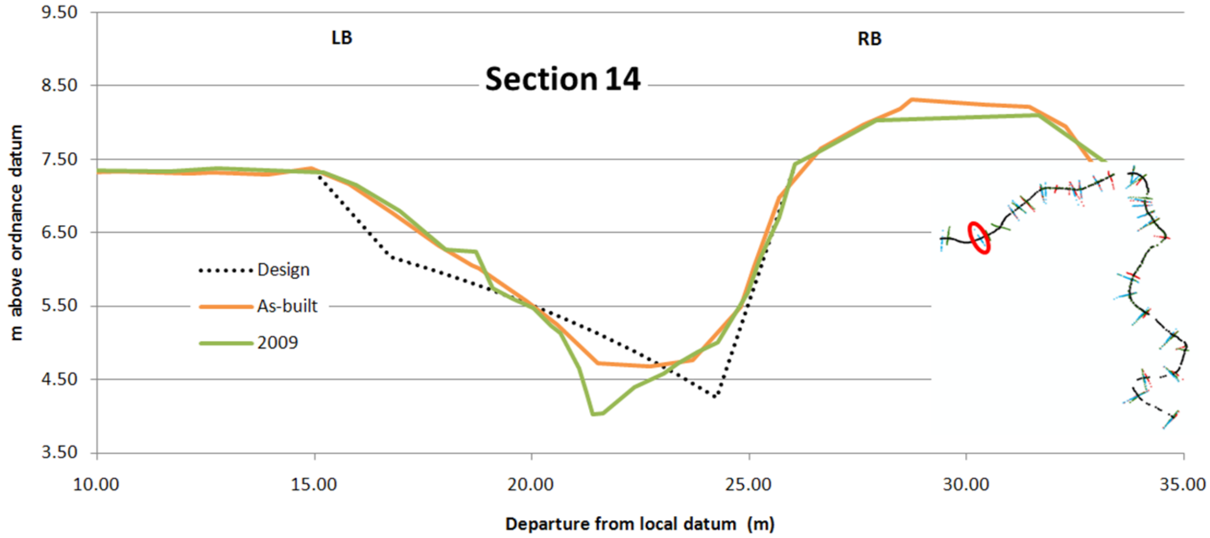

Figure 15: Overlays from surveys of loop section 14. LB: left bank (facing downstream); RB: right bank (position on planform inset).

Sections surveyed on the main course of the Rother give an indication of the wider impact of the works, and are presented in Figures 16-18, below.

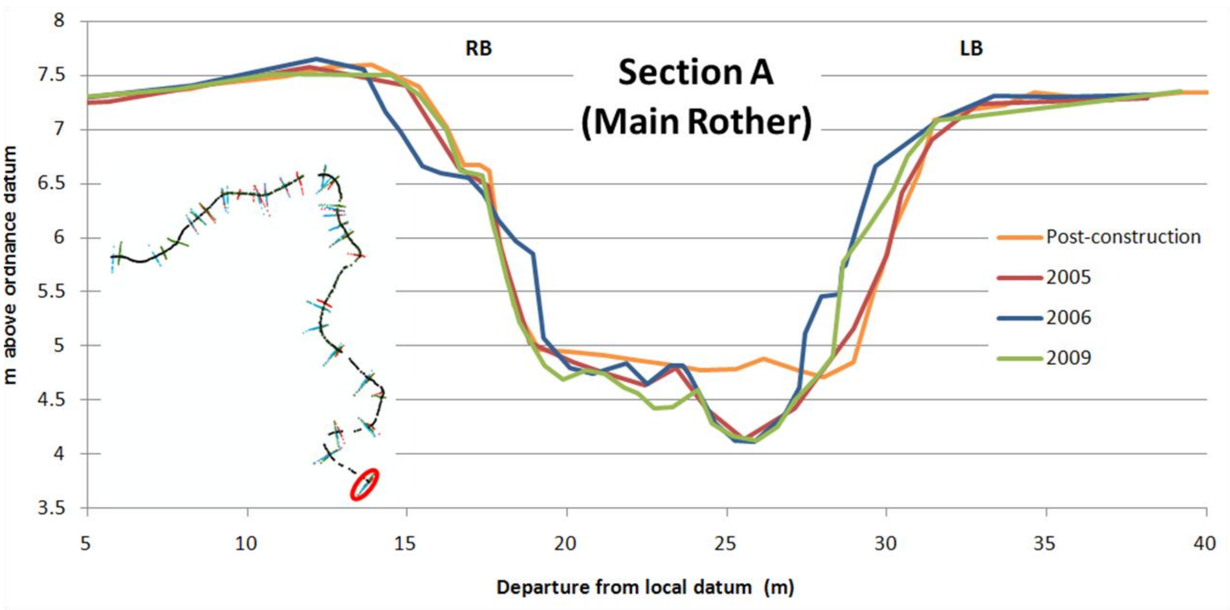

Figure 16: Overlays from surveys of main river section A. LB: left bank (facing downstream); RB: right bank (downstream of loop - position on planform inset).

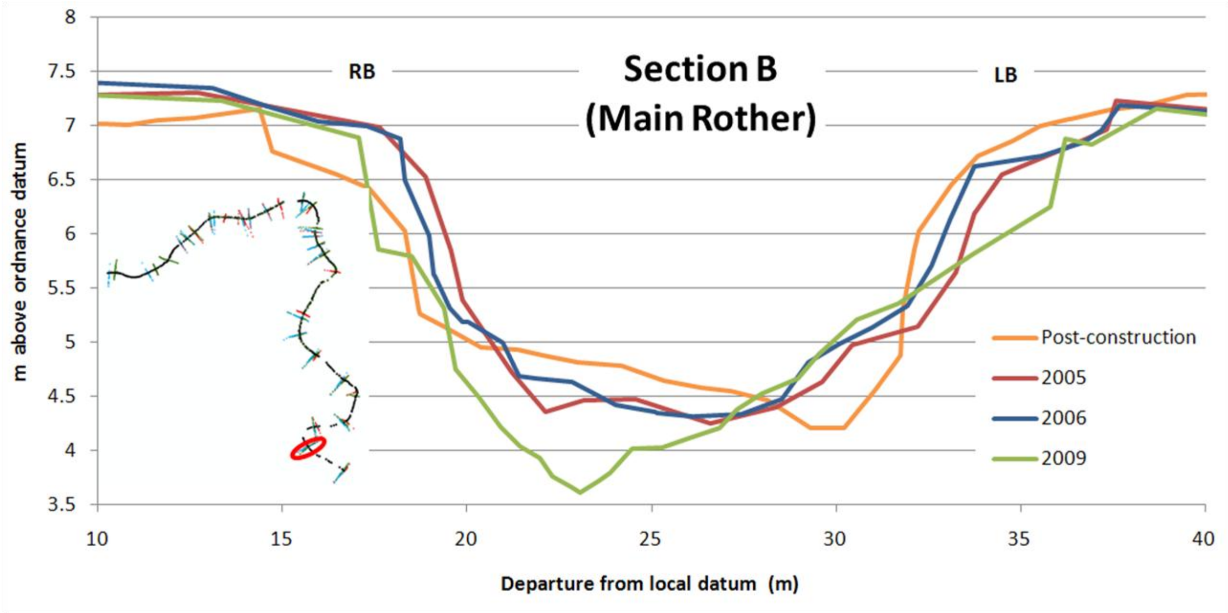

Figure 17: Overlays from surveys of main river section B. LB: left bank (facing downstream); RB: right bank (downstream of loop - position on planform inset).

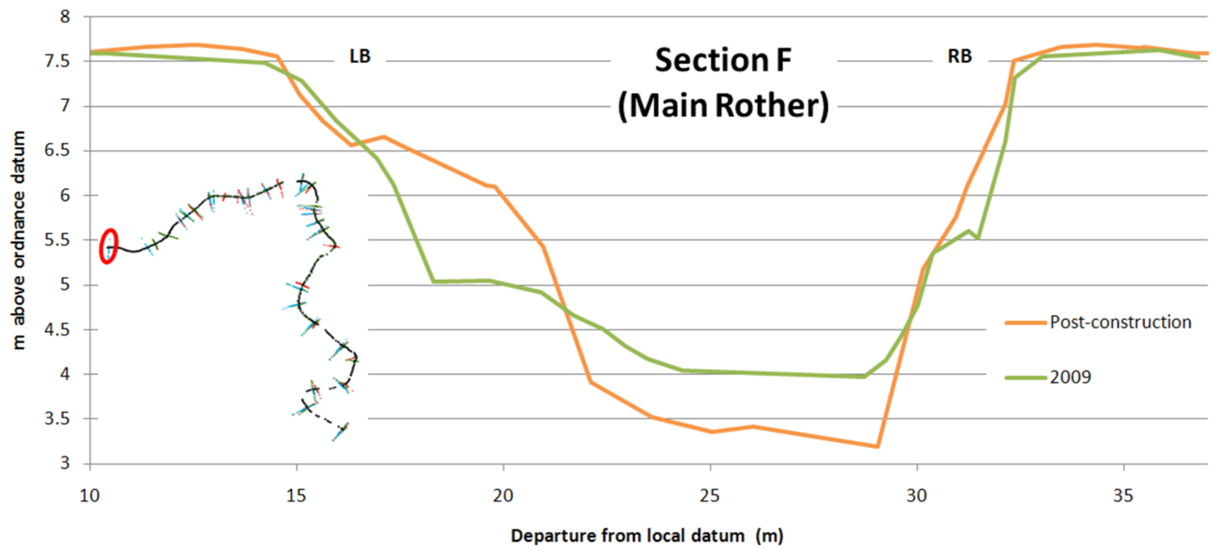

Figure 18: Overlays from surveys of main river section F. LB: left bank (facing downstream); RB: right bank (upstream of loop - position on planform inset).

High confidence conclusions:

- There was no significant (> 1 m) lateral channel migration between autumn 2004 and the survey in 2006.
- Small-scale channel adjustment is widespread.
- *Apart from in the vicinity of sections 4 and 4A,* the most significant changes in sectional morphology since the 2004 survey have occurred in the original channel, immediately downstream and upstream of the connection to the meander loop.
- Bed levels are consistently lower than those designed (this was already known, however – see Section 1.3.1, 2nd paragraph).
- The design section morphology is not strongly evident.

Reasonable degree of confidence:

- The increases observed in cross-sectional area suggest the dominance of erosion over deposition over the period of observation, and that the pre-restoration concern of sedimentation in the loop has been resolved.
- The outer bank appears to have slumped into the channel at section 4A.
- Assuming the design sections were followed in construction[1], the most significant changes occurred very quickly – indeed, before the as-built survey was conducted. The report accompanying this survey states that there were high flow conditions in the loop, which supports this conclusion.
- Imported coarse material on the downstream bed-check (cross-section 1) appears to be somewhat mobile, resulting in significant changes in bed level at the surveyed section.

Thalweg data

Figure 19 presents an overlay of the 2005 and 2006 surveys of the maximum channel depth data (longitudinal section), including regressions giving the mean bed gradient.

The following can be concluded with a ***high*** degree of confidence from these results:

- The depth variability is very much greater than that of the channel design.

Tentative conclusions:

- The average bed gradient appears to be exhibiting small oscillating changes from the design value of 0.00083, rather than any long-term trend (this was also a preliminary observation from the initial report in 2007 (Darby, 2007))
- Depth variability may have increased between 2005 and 2006, though there is a significant probability that this is an artefact of lower sampling density in the former.

[1] The actual bed is likely to have been more deeply excavated (see 1.3.1 (restoration methods))

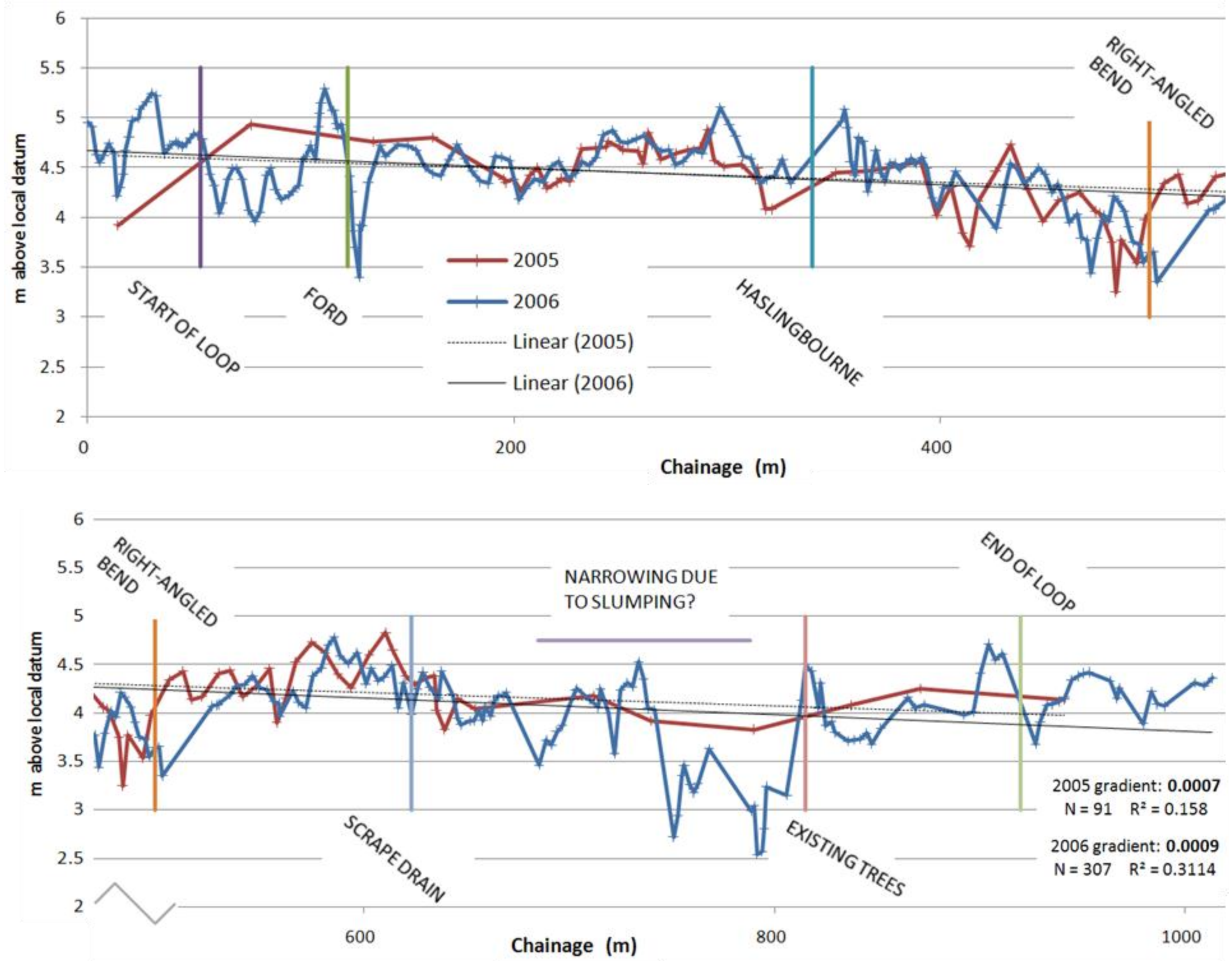

Figure 19: Overlay of 2005 and 2006 thalweg survey data, annotated with selected features and including linear regressions approximating the mean bed gradient (bottom left). Please note caveats in Section 3.

Section perimeter length

Cross-section shape complexity (and, by extension, assumed habitat diversity) may be measured by the length of the sections' perimeters from the cross-section dataset. Table 3 presents the data from coincident sections and years.

Section	2005	2006	2009
4A	14.3 (33)	14.4 (25)	14.6 (24)
7A	12.1 (27)	11.6 (17)	13.0 (20)
12A	15.4 (17)	12.2 (18)	11.0 (21)
A	15.9 (15)	19.5 (34)	16.4 (28)
B	17.0 (15)	15.9 (24)	20.7 (27)

Table 3: Estimated channel cross-section perimeters from survey data. Number of measurements in brackets.

The following ***tentative*** conclusion can be drawn from this analysis:

- All the sections analysed except 12A appear to have increased in complexity between 2004 and 2009.

2.1.2 Fixed point photography

The repeat images recorded may be used to detect local changes in channel forms above the water's surface. However, as more conclusions may be drawn about the *ecological* response from these photographs, these are presented later, under 'Channel ecology', in Section 2.3.1.

2.2 Hydrology and hydraulics

2.2.1 15-minutely water levels

The position of the three pressure transducers is given in Figure 3. Time series of the data are presented in Figures 20-22.

It was the objective of these datasets to enable change detection in flooding. As such, a number of the peak flow events for each time series were examined in more detail. The assumption of bank overtopping was made where a marked decrease in the gradient of the rising limb of the hydrograph was observed. These rising limbs are graphed in Figures 23-25.

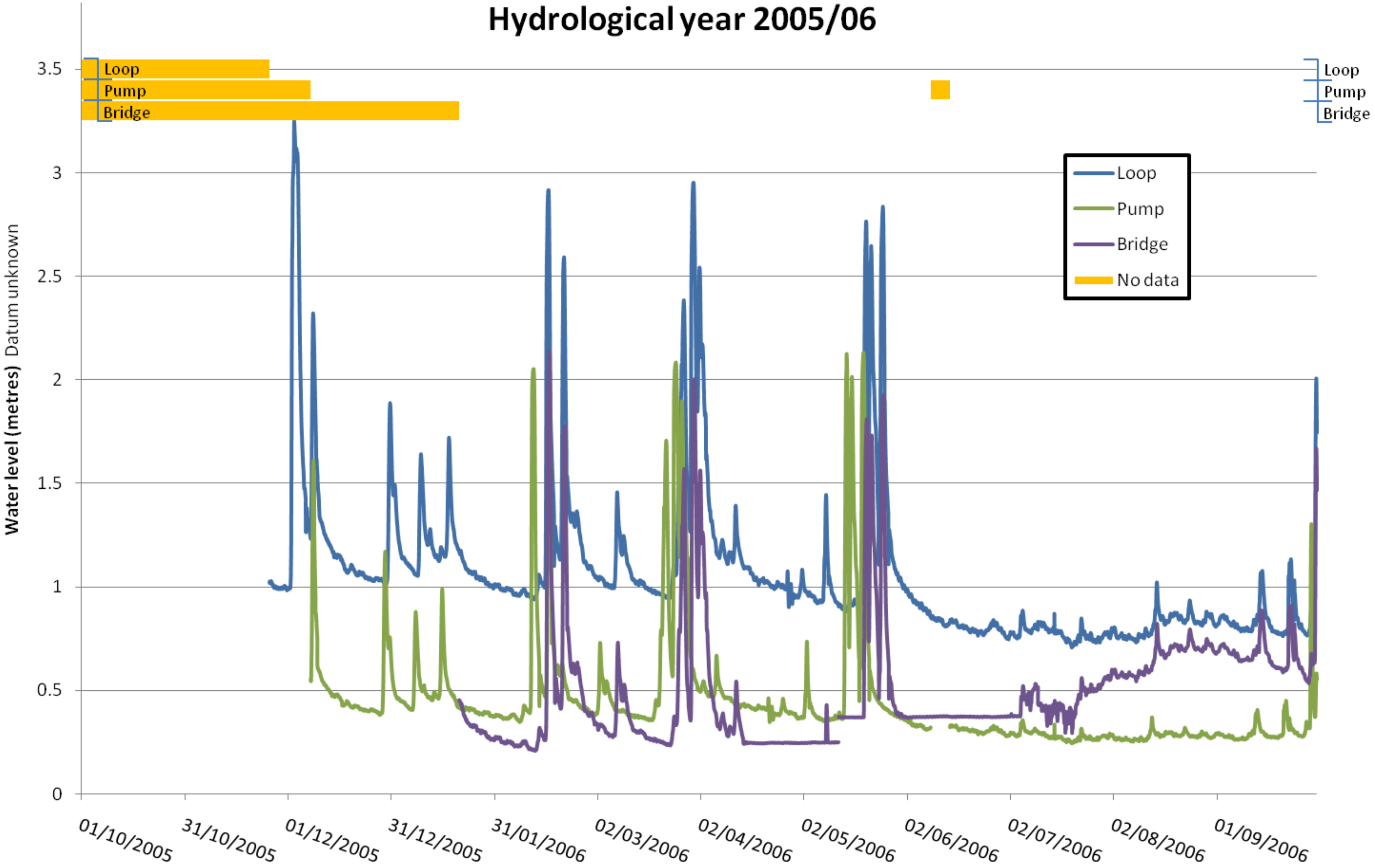

Figure 20: Time series with quality information from the three water level loggers for the 2005/06 hydrological year.

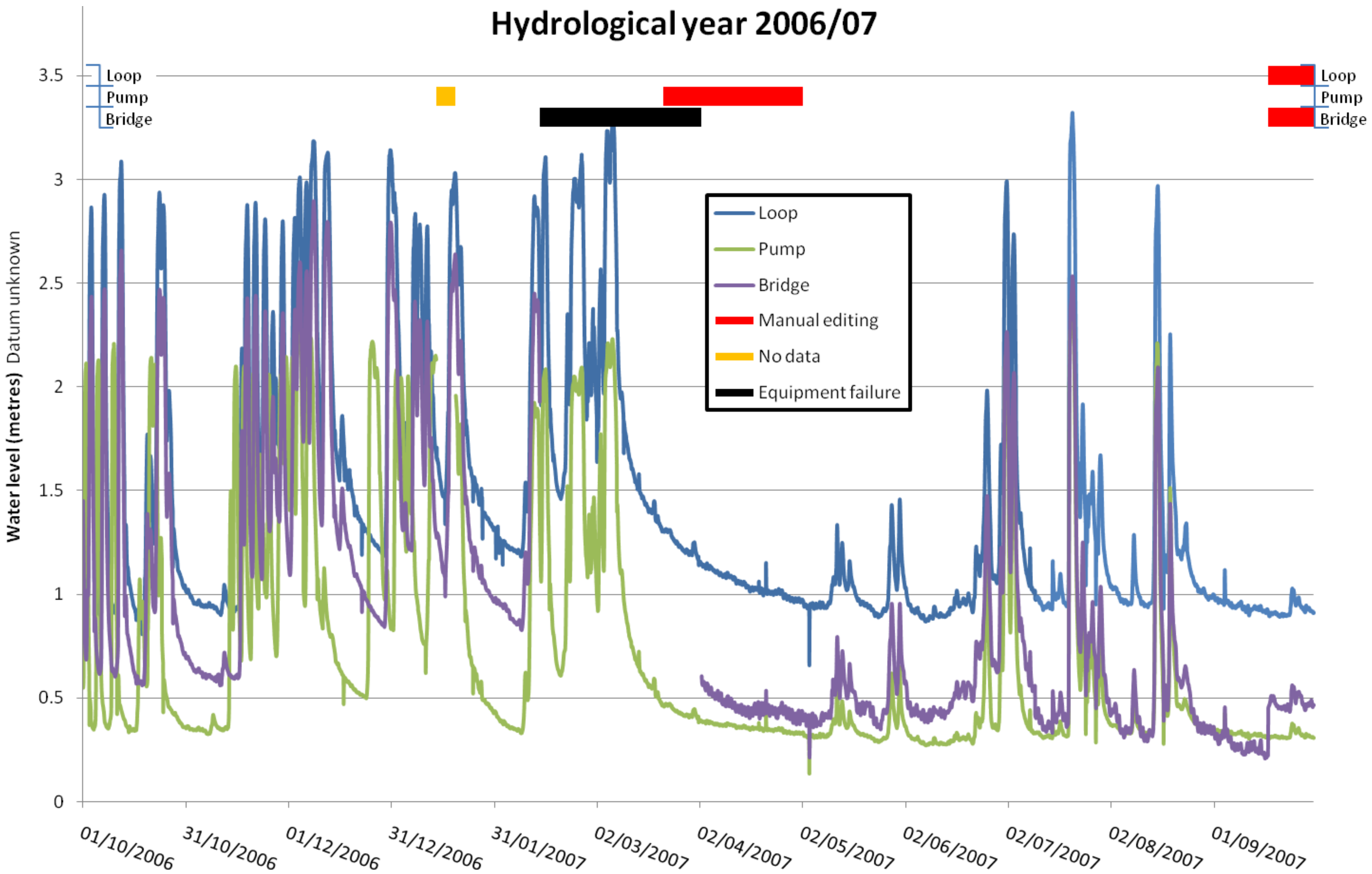

Figure 21: Time series with quality information from the three water level loggers for the 2006/07 hydrological year.

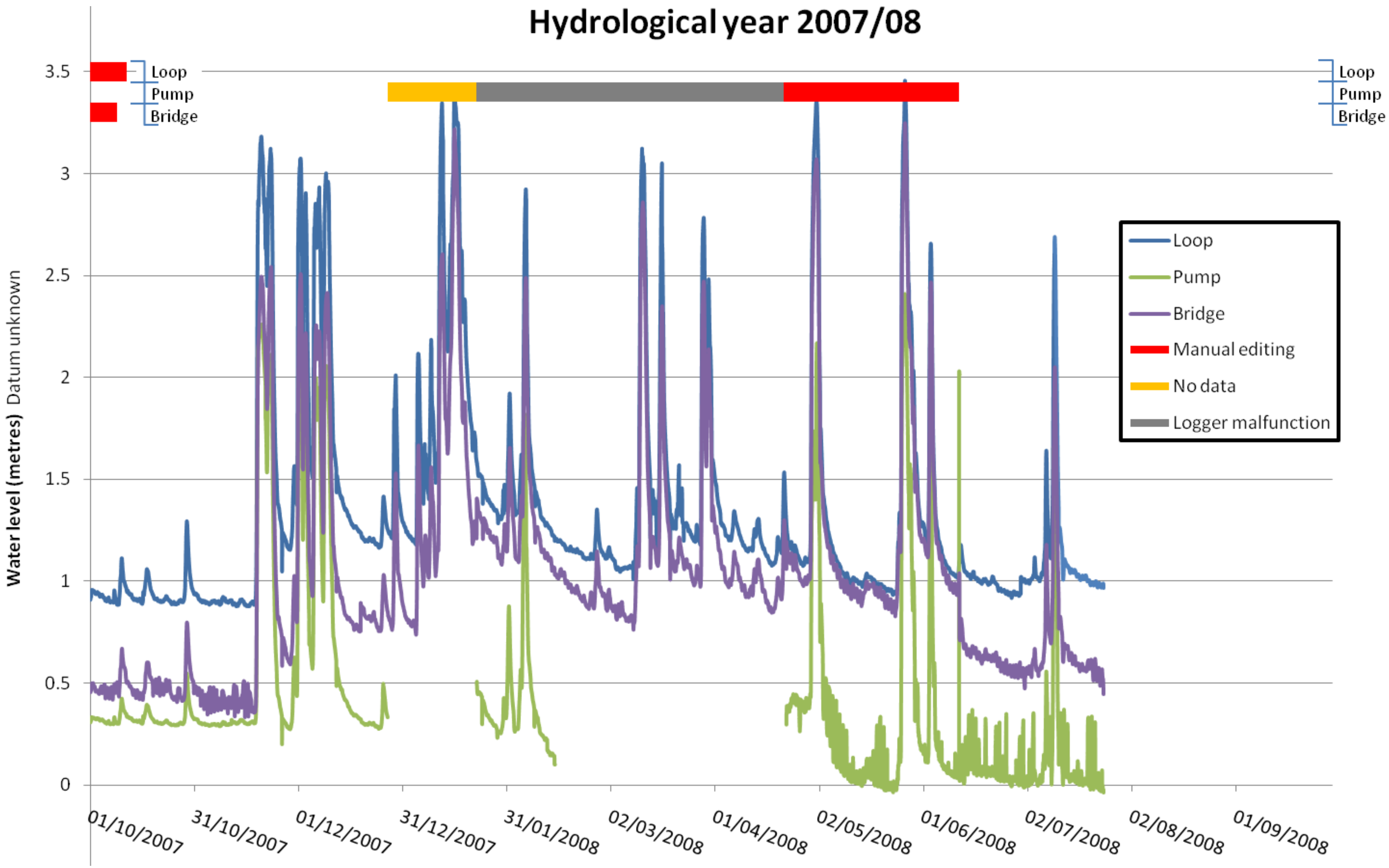

Figure 22: Time series with quality information from the three water level loggers for the 2007/08 hydrological year.

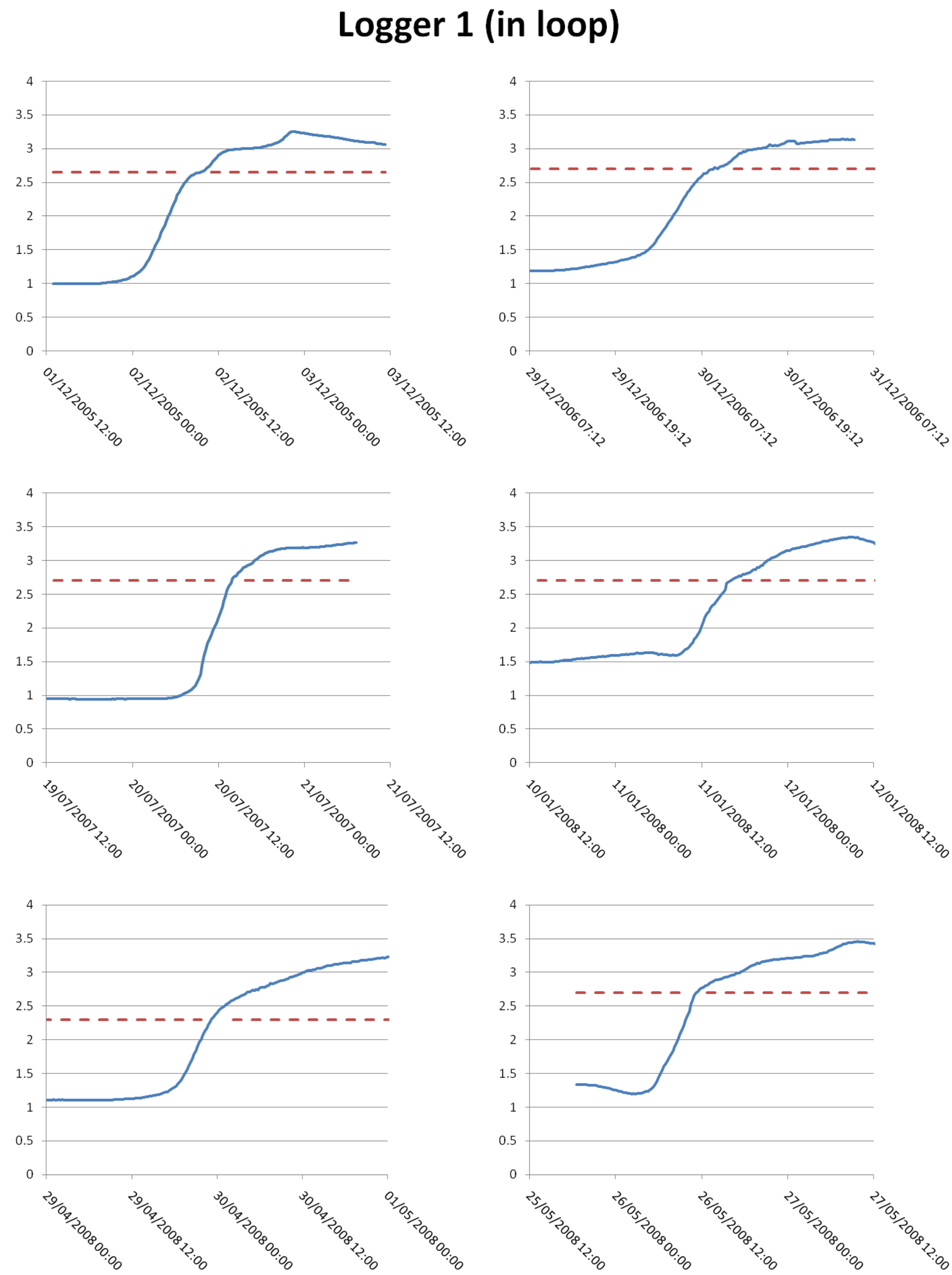

Figure 23: Rising limbs of hydrographs of some peak flow events as recorded by logger 1. Dashed lines represent estimated bank top. Scale is metres above an arbitrary datum.

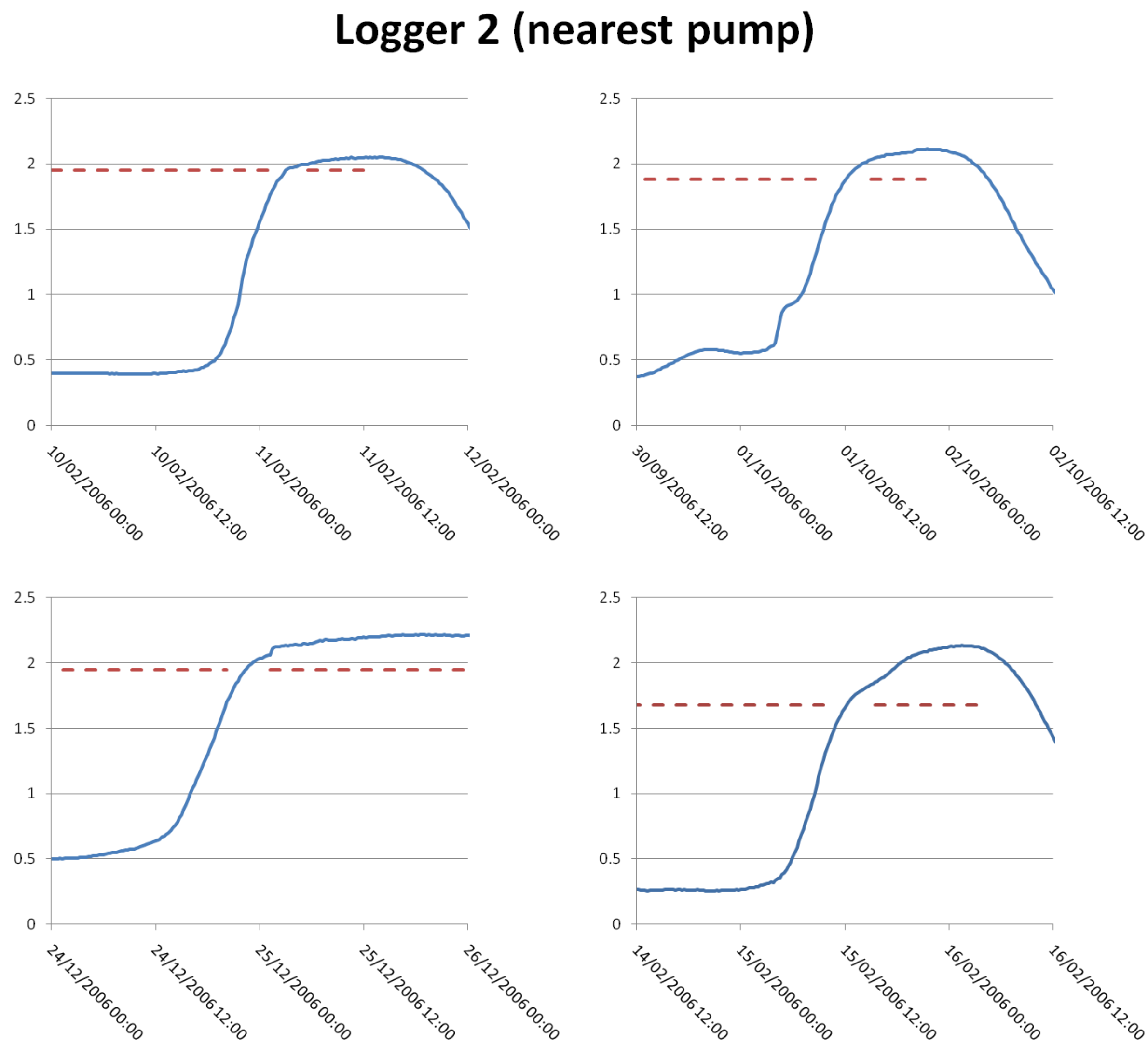

Figure 24: Rising limbs of hydrographs of some peak flow events as recorded by logger 2. Dashed lines represent estimated bank top. Scale is metres above an arbitrary datum.

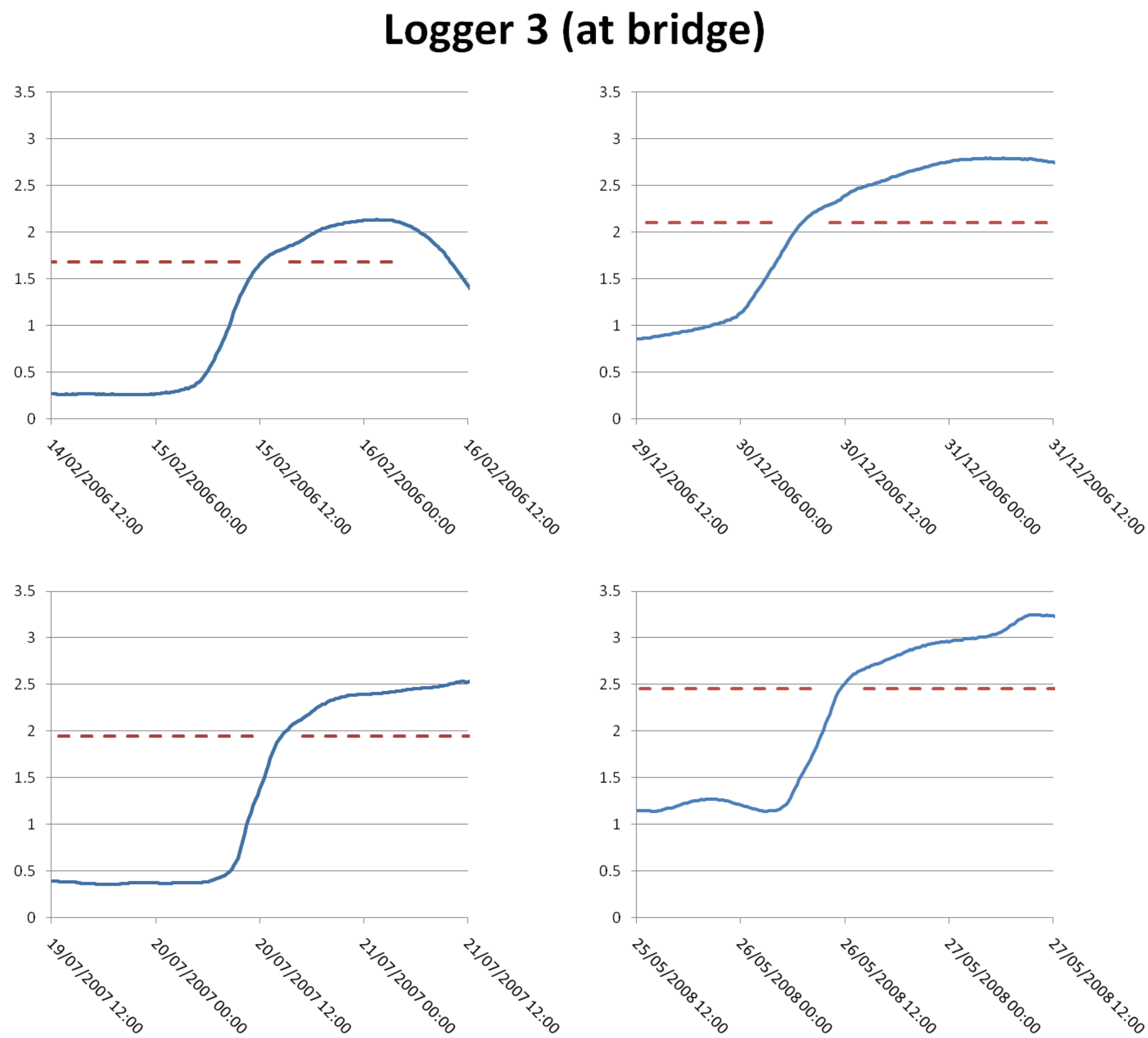

Figure 25: Rising limbs of hydrographs of some peak flow events as recorded by logger 3. Dashed lines represent estimated bank top. Scale is metres above an arbitrary datum.

It can be assumed with a ***high*** degree of confidence that:

- At the very broadest level, the water level and, by extension, flow and flooding dynamics in the restored loop are comparable to the up- and downstream monitoring points.

With a ***reasonable*** degree of confidence, one can say that the data demonstrate:

- The river came out of its banks many times at all three monitoring points.

It can be ***tentatively*** concluded from analysis using the rising limbs of the hydrograph of logger #1 (in the loop, assuming a bank top (flood threshold) level of 2.7 m) that, over the full period covered by the data:

- There were 48 flood events.
- The total time in flood was 1306 hours (54.4 days), which amounts to 5.6 % of the monitoring period.
- The mean flood event duration was 28.4 hours, with a similar median of 23.4 hours.

2.3 Channel ecology

2.3.1 Fixed point photography

Conclusions not only relating to the ecological response within the restored reach, but also that of the floodplain and those relating to geomorphological effects of the reinstatement of the loop are presented in this section. Note that the evaluation of this dataset is presented in Section 3.2.2 under ‘Geomorphology’, as there are more opportunities for adding value from this perspective, as opposed to that of assessing channel ecology.

Complete sets were not recorded at each of the 24 main positions, and a large number of photographs do not properly match, so a selection of the best results is presented below. The full collection of images is provided in Appendix C. Analysis here is limited to the main 24 positions (red symbols in Figure 26), as these have the best temporal coverage.

Year	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2004	June				✓			✓														✓				
2004	Nov					✓						✓			✓	✓	✓	✓								
2005	Jan	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
2005	May	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
2006	Feb	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓				✓	✓	✓	✓	✓				
2006	May	✓					✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓				✓
2006	Nov		✓	✓	✓	✓										✓	✓	✓	✓	✓	✓	✓				
2007	Jul	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓		✓	✓	✓	✓	✓				
2007	Nov	✓	✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓				
Total images		6	5	6	7	6	5	7	5	6	6	5	2	4	5	7	5	8	7	7	6	8	2	2	2	2
		Channel																	Floodplain							

Table 4: Coverage of main fixed point photography positions. Selected positions presented here are highlighted.

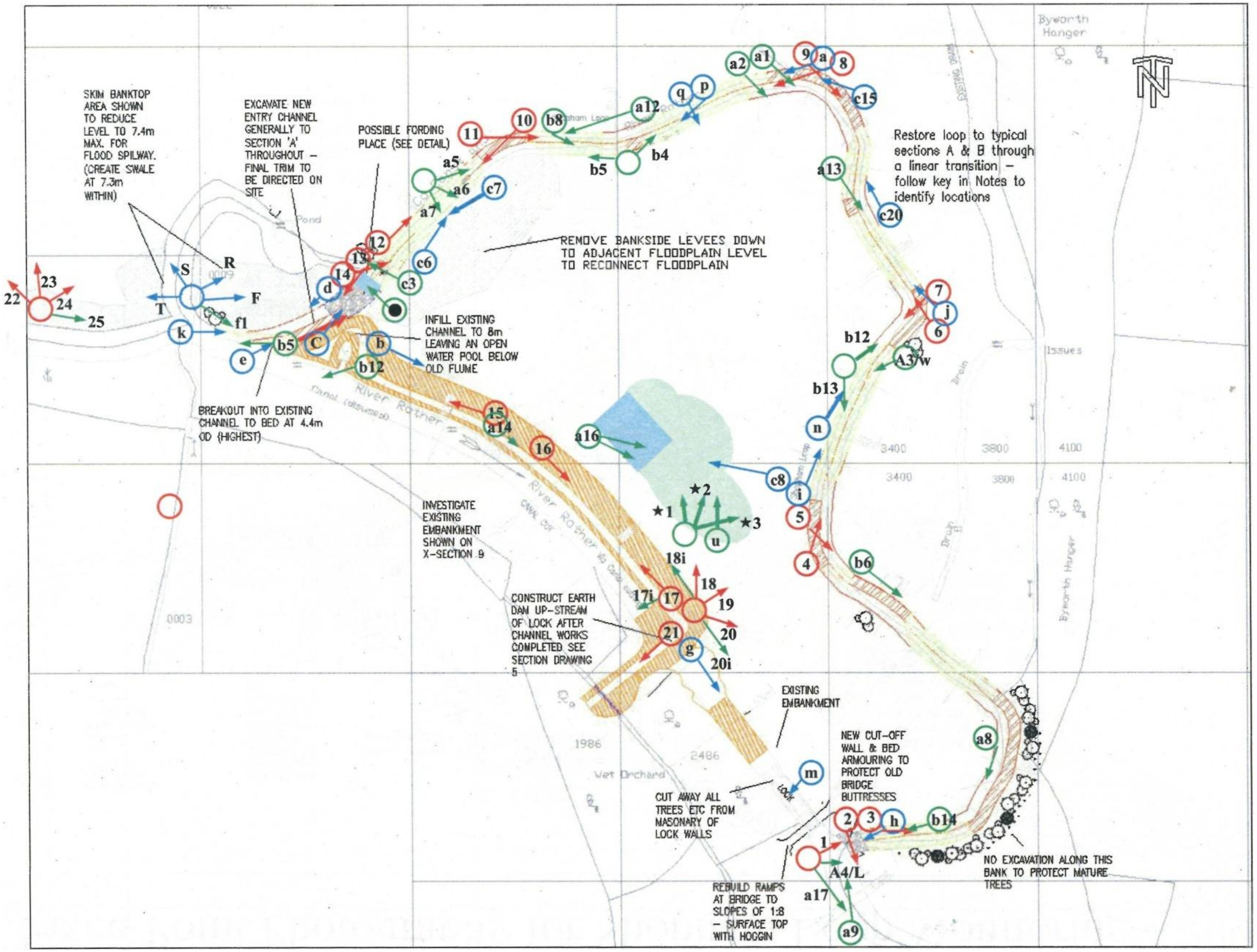

Figure 26: Plan of positions from which repeat images were taken. Main positions analysed here are in red circles

Figure 27: Repeat photo set from position 2

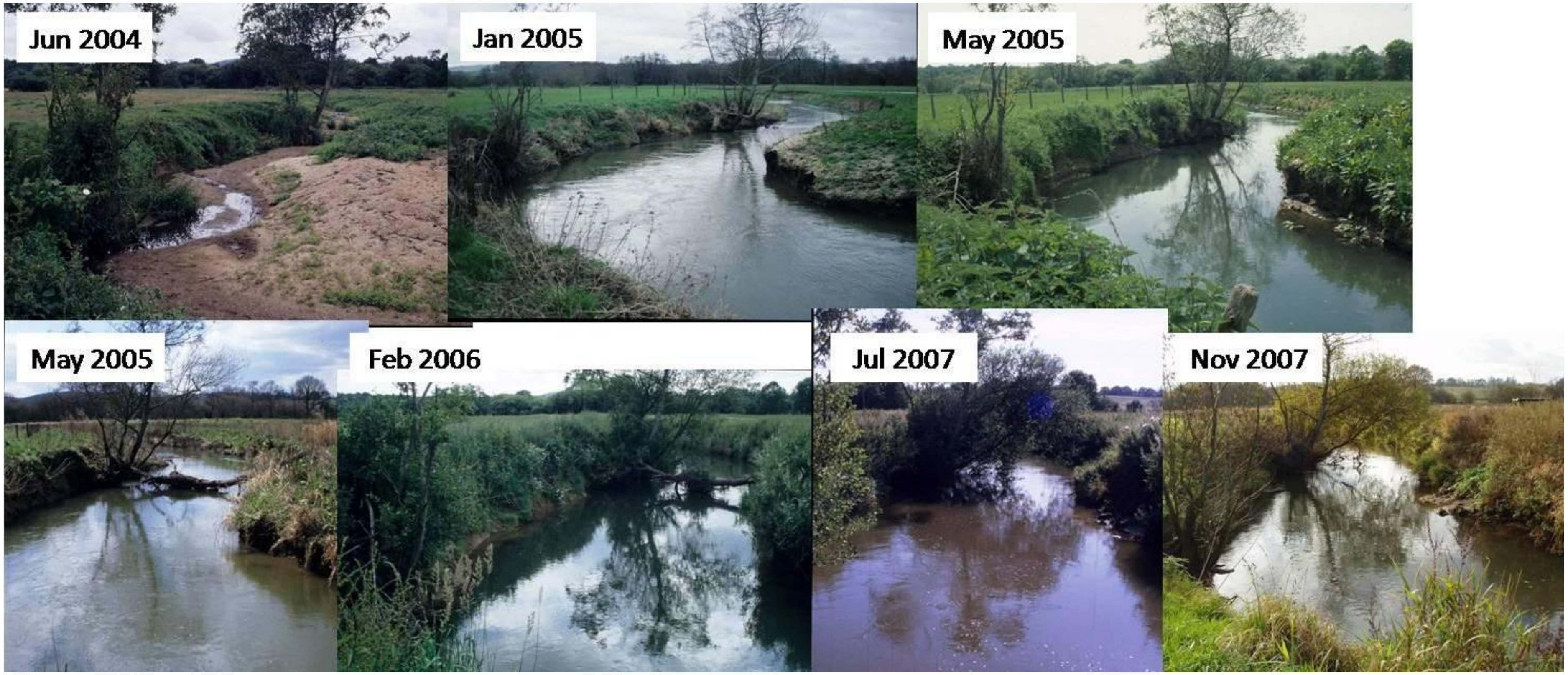

Figure 28: Repeat photo set from position 7

Figure 29: Repeat photo set from position 9

Figure 30: Repeat photo set from position 16

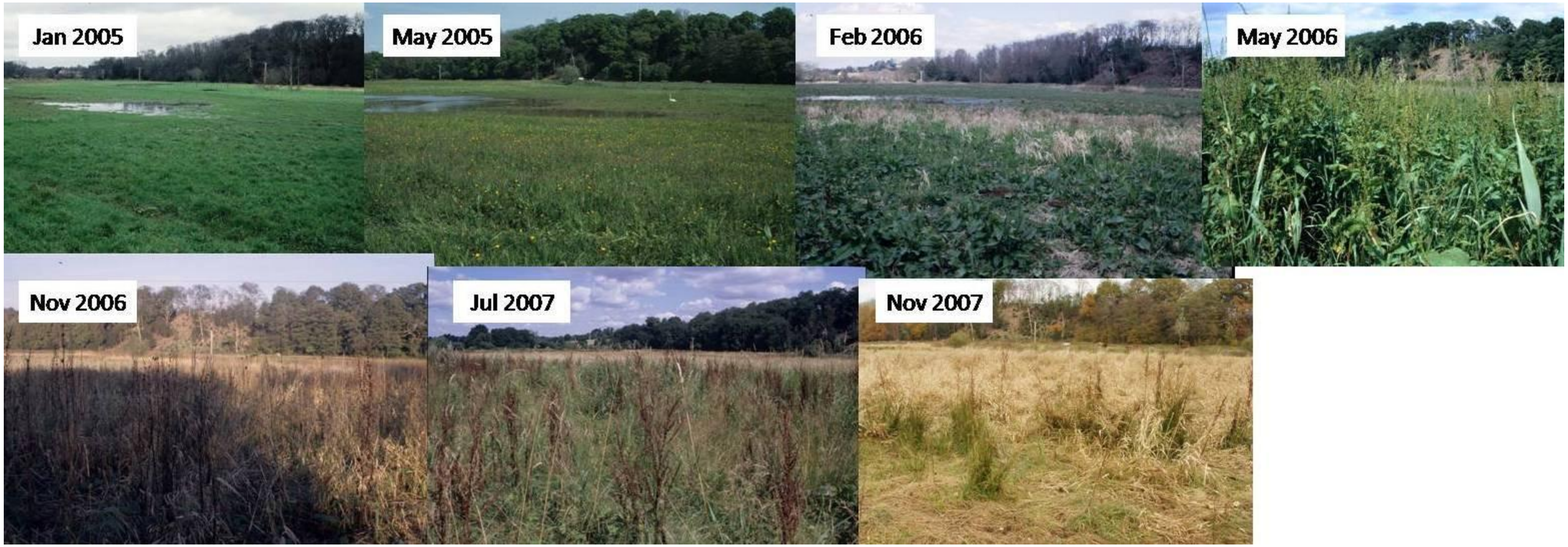

Figure 31: Repeat photo set from position 19

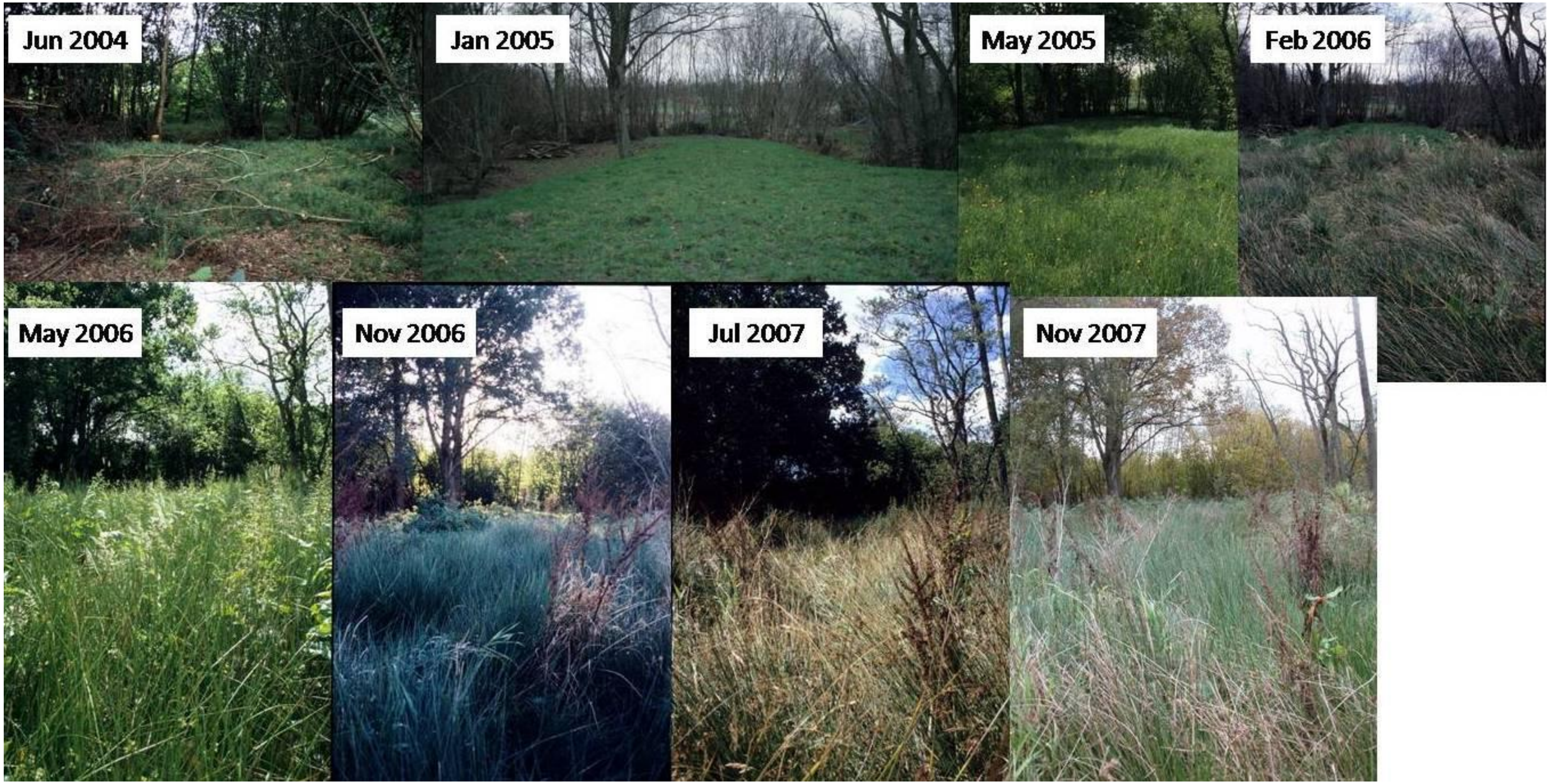

Figure 32: Repeat photo set from position 21

The following conclusions can be drawn with a ***high*** degree of confidence from these image comparisons:

- Virtually all originally bare banks had established a good cover of vegetation by the 2007 growing season.
- Mature woody vegetation retained during the project is contributing woody debris to the channel (e.g., position 7).
- The plant structural and species diversity of the floodplain has increased significantly (e.g., position 19).
- The change in cross-section 4A can be confirmed to be attributed to extensive slumping (presumably following under-cutting) on the outside of the bend (positions 4 and 5 (not shown)).

One can conclude with ***reasonable*** confidence that:

- The greatest morphological changes have been attributed to localized bank erosion and collapse following the first winter high flows. These events have declined sharply in frequency.
- The canal cut appears to be holding significantly more suspended sediment than the restored loop (from the turbidity of the water in the photos).

2.3.2 Macrophyte survey

Summary data from the surveys are presented in Table 5, below, with more detailed information about plant cover in 2006 presented in Table 6.

Statistic / Species	2005	2006	2007	2009
Summary statistics				
Number of species	**23**	13	13	18
Number of genera	**18**	13	11	17
Total estimated % cover	7-10	8	**13**	n/a
Species present and % cover (where available)				
Achillea millefolium				+
Alisma plantago-aquatica	+		< 0.1	
Amblystegium sp.		+		
Apium nodiflorum	+			
Bidens sp.				+
Callitriche hamulata	+			
Carex acuta		**+**		**+**
Heracleum sp.				**+**
Impatiens glandulifera	**+**			**+**

Statistic / Species	2005	2006	2007	2009
Iris pseudacorus	+	+		+
Juncus spp.	(+)	+		(+)
Juncus articulatus	+			
Juncus effusus	+			+
Juncus inflexus	+			
Lemna minor	+		< 0.1	
Lemna trisulca		+		
Lycopus europaeus			< 0.1	+
Lythrum salicaria	+		0.1	+
Myosotis spp.	(+)	+		
Myosotis scorpioides	+		< 0.1	
Oenanthe crocata	+	+	< 0.1	
Persicaria amphibia	+		0.1	
Persicaria hydropiper	+	+	< 0.1	+
Phalaris arundinacea	+	+	6.2	+
Polygonum amphibium				+
Potamogeton berchtoldii			0.2	
Potamogeton pectinatus	+			
Potamogeton pusillus		+		
Rorippa amphibia	+			
Rumex spp.	(+)	+		
Rumex hydrolapathum	+		< 0.1	
Sagittaria sagittifolia	+			
Scrophularia auriculata				+
Senecio sp.				+
Sparganium emersum	+		4.3	+
Sparganium erectum	+	+	0.8	+
Stachys palustris				+
Urtica dioica				+
Veronica anagallis-aquatica	+			

Statistic / Species	2005	2006	2007	2009
Veronica beccabunga	+			
Veronica catenata		+		

Table 5: Species and cover data from aquatic plant surveys. + indicates presence, and species-level coverage data are available and presented for 2007

U/s limit of sub-reach	100 m	200 m	300 m	400 m	500 m	600 m	700 m	800 m	900 m
Estimated cover (%)	n/a	n/a	5 - 10	15	15	<5	10 - 15	10 -15	5

Table 6: 2006 cover estimates by sub-reach (measured from the downstream confluence)

The following conclusions can be drawn with a ***high*** degree of confidence:

- Macrophytes quickly colonized and established themselves within the newly excavated loop.
- *Sparganium* spp. and *Phalaris arundinacea* are among the most common and ubiquitous plants.
- There was a significant range (>125 % of average for whole loop) of spatial variation in macrophyte cover in 2006.

The following can be concluded with a ***reasonable*** degree of confidence:

- Total macrophyte cover appears to be increasing.
- The loop was initially colonized by a diverse macrophyte community, which has since stabilized at lower species richness.

2.3.3 Fisheries surveys

Numbers and biomass

Summary results of numbers, comparison with results from monitoring outside of the study reach, dominance of the most frequently recorded species and fish length, where available, are presented in Table 7, below.

	2005	2006	2007	2009
Loop: all species excluding Minnow				
No. individuals	294	**318**	225	186
% Fit-Coul avg.	69	45	**87**	n/a
Loop dominant species: Minnow				
No. individuals	**1527**	375	190	165
B-P dominance	**0.84**	0.54	0.46	0.47

	2005	2006	2007	2009
Scrape: all species excluding 3-Spined Stickleback				
No. individuals	n/a	7	179	**714**
Total length (cm)	n/a	45	1038	**4650**
Avg. fish length (cm)	n/a	6.43	6.48	**6.51**
Scrape dominant species: 3-Spined Stickleback				
No. individuals	n/a	**1000**	612	7
B-P dominance	n/a	**0.99**	0.77	0.01

Table 7: Summary of fisheries totals. '% Fit-Coul avg': area-normalized percent of mean of catches from Fittleworth (d/s) and Coultershaw (u/s). B-P (Berger-Parker) dominance index is fraction of whole sample due to the most frequently occurring species. Highest values are in heaviest type.

The following conclusions can be drawn from these results with a ***high*** degree of confidence:

- Minnow has been the dominant species in the loop, particularly in 2005, when they were observed spawning on the cobble and gravel bed-checks.
- 3-Spined Stickleback has been the dominant species in the scrape in 2006 and 2007.
- The dominance of these two species has been decreasing.
- Reports of the sampling in 2005 and 2007 show that the lower limit of the age classes of sampled fish increased for Dace (from 0+ to 4+) and Chub (from 3+ to 4+) over this period.
- Total numbers of fish other than Stickleback in the scrape have been increasing significantly.
- The average length of fish in the scrape has been increasing.

The following can be concluded with a ***reasonable*** degree of confidence:

- Total numbers of fish other than Minnows in the loop appear to have peaked in 2006 and declined since. However, accounting for wider trends (% Fit-Coul avg.), catches within the loop appear to have increased between 2006 and 2007.
- Biomass of fish other than Stickleback (represented by total length) in the scrape appears to be increasing dramatically, though is fairly stable when accounting for this dominant species (assuming average length of 5cm).

It can be ***tentatively*** suggested that:

- Recruitment to the scrape is being maintained by regular flooding

Community structure

Species-specific catch numbers for the loop are presented in Figure 33 and as a proportion of catches at nearby surveillance monitoring sites in Figure 34. Diversity indices[2] for the sampled loop and scrape communities are given in Table 8, in which 'β-diversity' is between samples from different 100 m stretches of the loop.

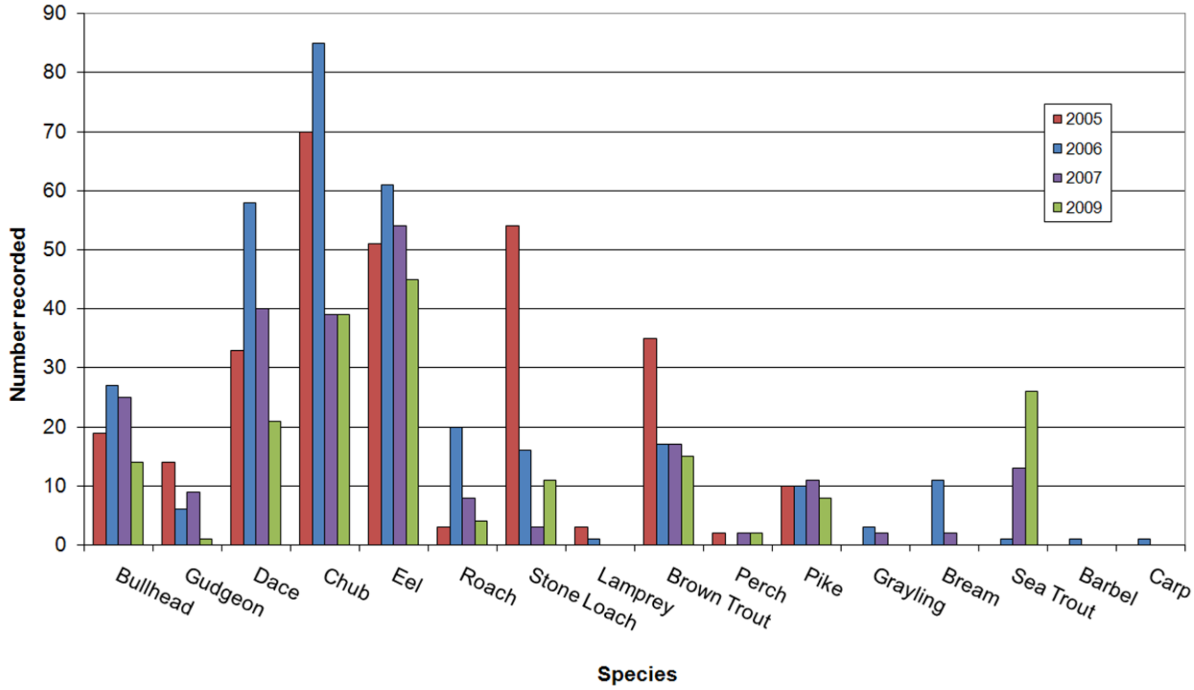

Figure 33: Fish numbers recorded, by species, in samples from the restored reach (excluding Minnow).

[2] α-diversity is a measure of heterogeneity within a sample, and β-diversity, between samples.

The α-diversity index used in this report is Simpson's diversity index (the probability that two randomly selected individuals will be of different species: $1 - D$, where $D = \sum (n/N)^2$, in which n is the number of individuals of one species and N is the total number of individuals)

The β-diversity index used is Whittaker's measure: $\beta = (S / \bar{a}) - 1$, where S is the total number of species recorded and $\bar{a}$ is the average number of species per community.

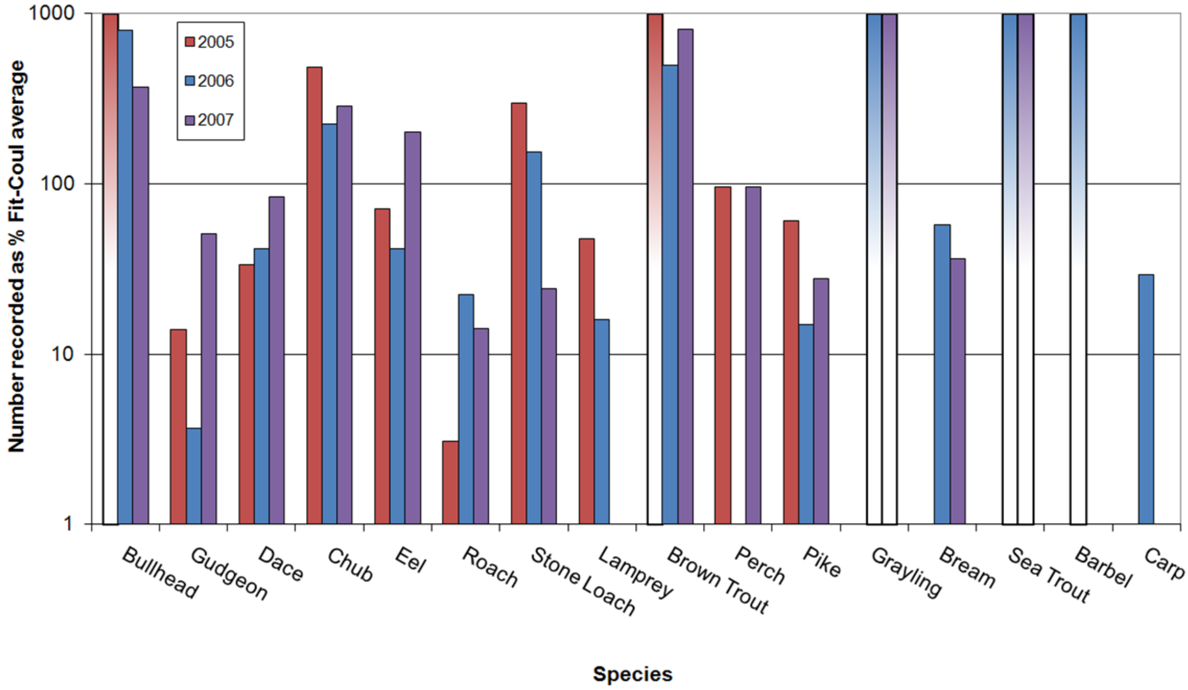

Figure 34: Area-normalized catches displayed as a percentage of the mean of those from surveillance monitoring down- and upstream at Fittleworth and Coultershaw. Gradient-filled bars represent species not found at either of these sites. Note logarithmic scale.

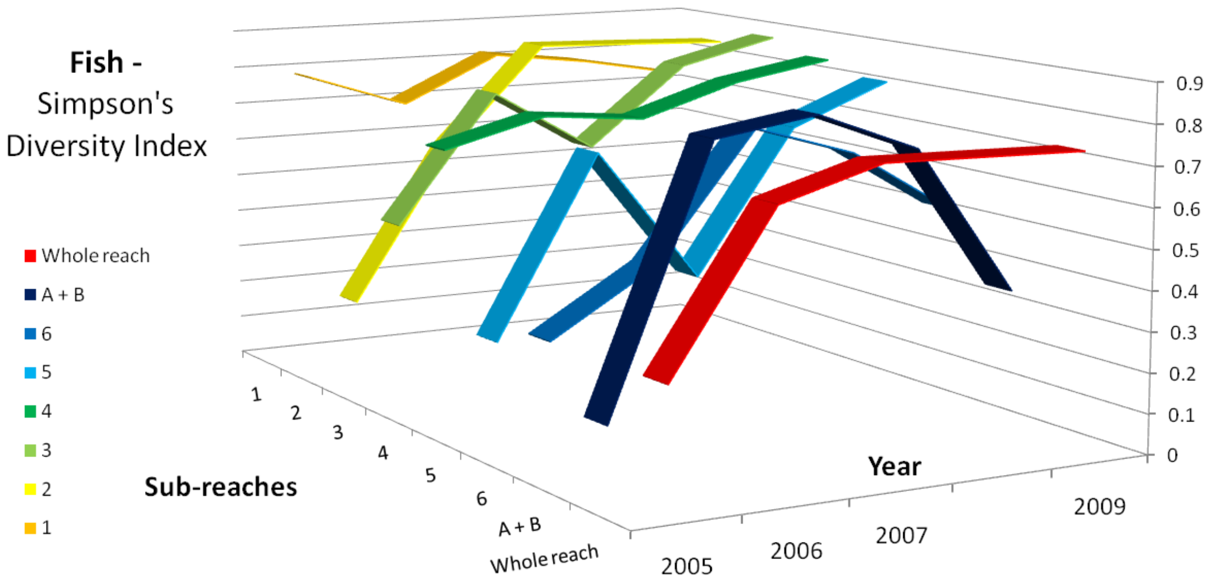

Figure 35: α-diversity of electro-fishing samples, by sub-reach.

	2005	2006	2007	2009
Loop (including Minnow)				
Number of species	12	**16**	15	12
α-diversity (Shannon-Wiener H)	0.77	1.64	**1.83**	1.76
α-diversity (Simpson's D)	1.41	3.06	**3.96**	3.79
β-diversity (Whittaker's β)	0.66	**0.94**	0.62	0.60
Scrape (including 3-spined Stickleback)				
Number of species	n/a	3	10	**11**
α-diversity (Shannon-Wiener H)	n/a	0.04	0.78	**1.52**
α-diversity (Simpson's D)	n/a	1.01	1.56	**3.44**

Table 8: Diversity measures for fish samples.

These data yield the following conclusions with a ***high*** degree of confidence:

- The loop is particularly favoured by Bullhead, Chub, Brown Trout, Grayling, Sea Trout and Barbel, relative to Fittleworth and Coultershaw.
- Diversity of the fish community (α-diversity) in the loop increased to peak in 2007, though the decline to 2009 levels appears to be minor.
- Diversity of the scrape community appears to be increasing significantly, developing a more robust community structure.

The following conclusions can be drawn with a ***reasonable*** degree of confidence:

- The four most common species (Chub, Eel, Dace and Bullhead), as well as Roach, appear to reflect the trend in total numbers, peaking in 2006 and then declining. This pattern is not apparent when trends outside the loop are taken into account (Figure 34).
- Relative to the control sites, Gudgeon, Dace, Roach and Pike are consistently under-represented, and Eel and Bream numbers appear to be low in the loop.

Tentatively, it may be suggested that:

- Relative to wider trends, Bullhead and perhaps Stone Loach may be declining, whilst Sea Trout and Dace may be on the increase in the loop.
- The increase in Sea Trout numbers may indicate improving continuity of fish passage in the Western Rother/Arun system.
- Fish habitat diversity in the loop (β-diversity) has been relatively stable except for a peak in 2006.

2.3.4 Macro-invertebrate kick samples

Kick sample results, where possible, were evaluated in terms of:

Outputs generated by the EA BIOSYS system[3]:

- Biological Monitoring Working Party (BMWP) score – a cumulative index of the pollution sensitivity of the families recorded and, by extension, the water quality.
- Average Score Per Taxon (ASPT) – a meta-statistic from the BMWP method, indicating the average pollution sensitivity of the invertebrate community.
- Community Conservation Index (CCI) – an integrated measure of community species richness and presence of locally and/or nationally rare species, constituting conservation value.
- Lotic-invertebrate Index for Flow Evaluation (LIFE) score – an index for inferring flow characteristics (typical velocity and frequency of flow) from macro-invertebrate communities. The species-level method was used here.

Other calculated (non-BIOSYS) variables:

- Total number of individuals.
- Number of taxa recorded.
- Simpson's diversity index (see Footnote 2 in Section 2.3.3 for explanation).
- Berger-Parker Dominance (fraction of whole sample contributed by most frequent species)

Note:

Owing to differences in data collection (discussed in Section 3.4.3), comparisons can only be made between 2002 and 2009, and between 2005, 2006 and 2007.

For the '05-'07 (1 min) samples, up- and downstream surveillance monitoring (3 min) is not directly comparable, and the data are presented on separate axes or qualified in the caption.

For certain non-BIOSYS variables, the stratified samples have been aggregated to inspect for overall trends.

The format convention for up- and downstream surveillance monitoring sites is as follows (this is difficult to read from some axis labels):

Shopham Bridge

Fittleworth (downstream)

Selham (upstream)

[3] NB. Outputs for the 2005, 2006 and 2007 samples are not true index values as these were 1 min (as opposed to the standard 3 min) kicks, hence they are referred to as 'pseudo-' values. It is however assumed that comparisons can be made between them within these years.

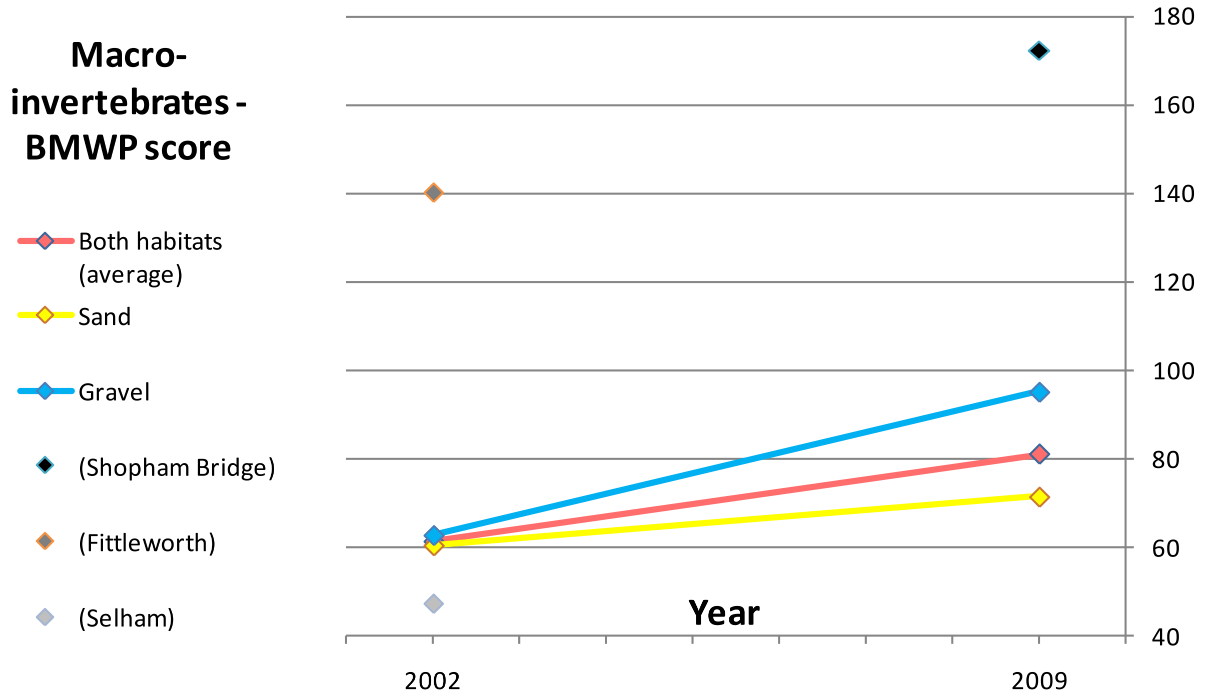

Figure 36: Average BMWP scores for 3 minute kick samples in 2002 and 2009. Results for EA surveillance monitoring sites up- and downstream are also plotted where available.

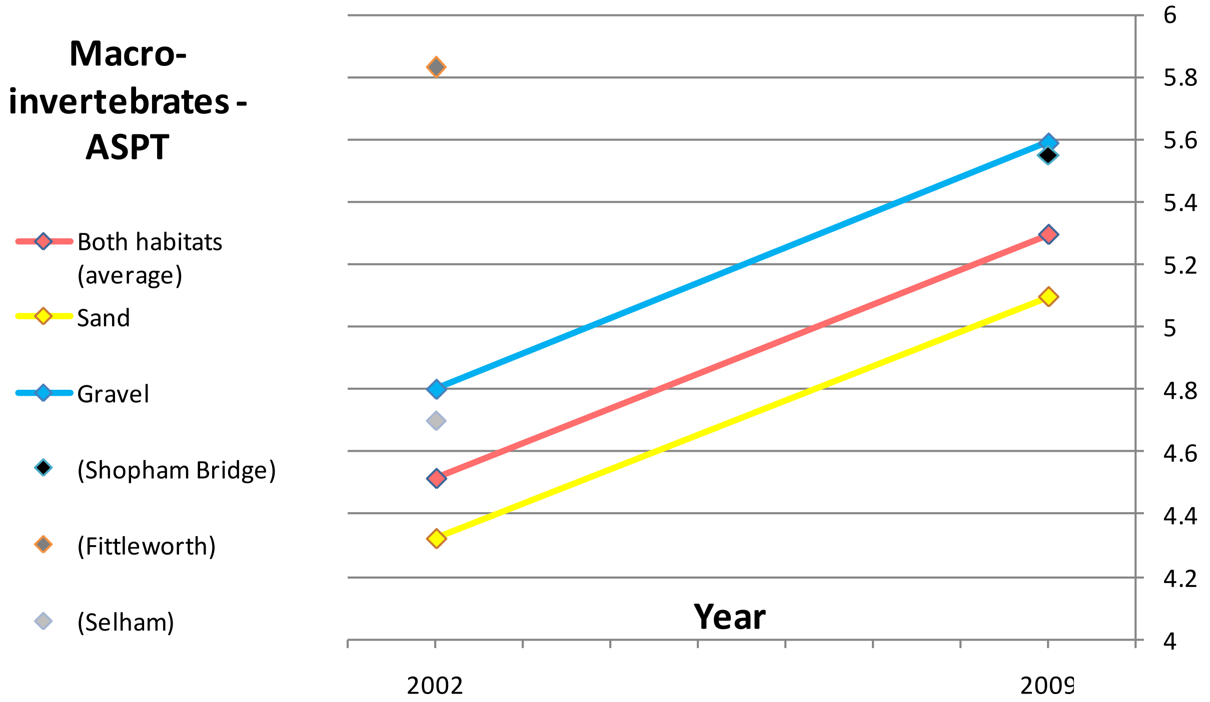

Figure 37: Average ASPT scores for 3 minute kick samples in 2002 and 2009. Results for EA surveillance monitoring sites up- and downstream are also plotted where available.

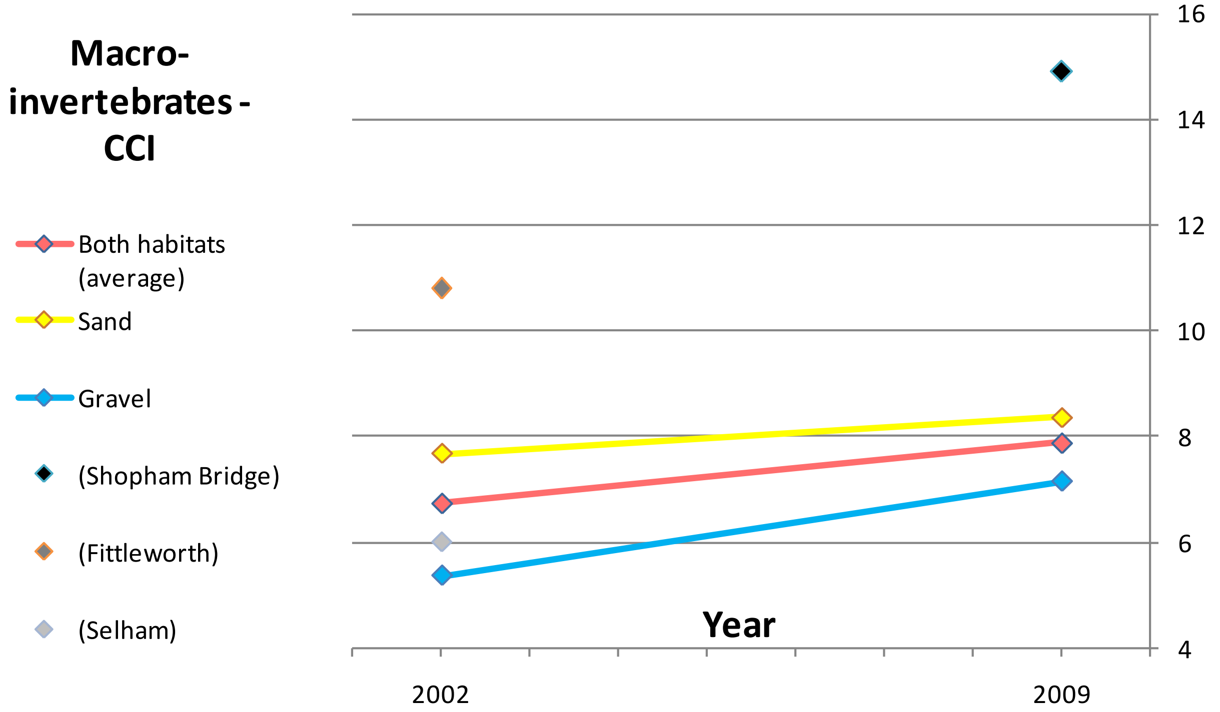

Figure 38: Average CCI scores for 3 minute kick samples in 2002 and 2009. Results for EA surveillance monitoring sites up- and downstream are also plotted where available.

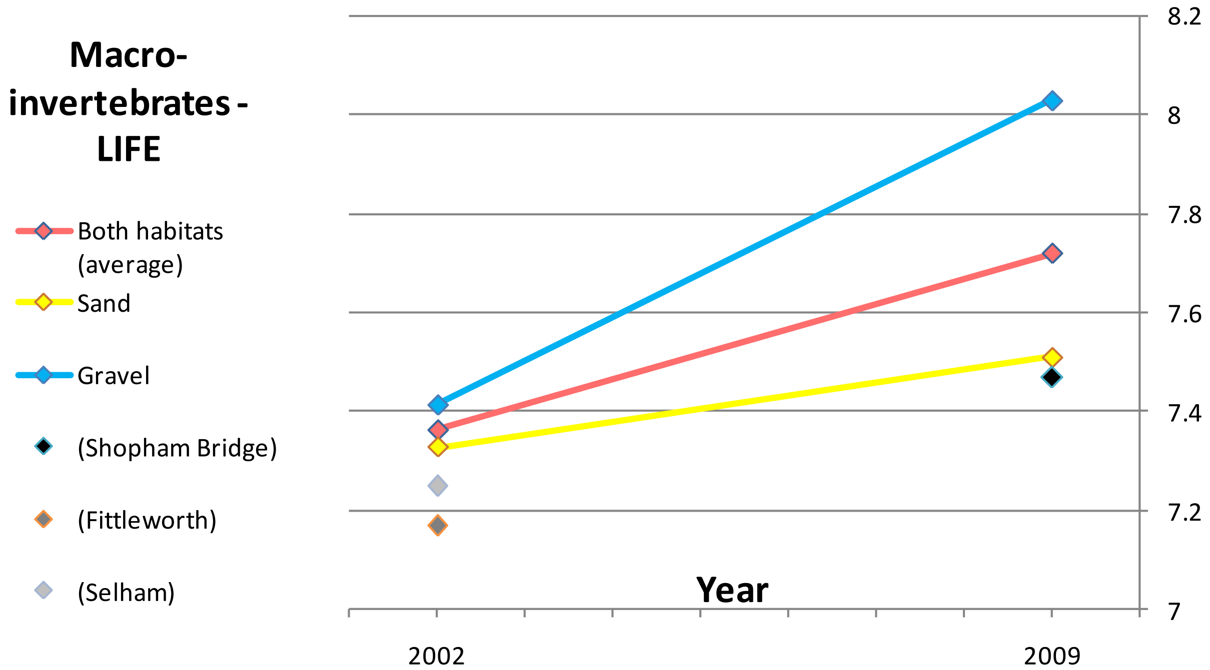

Figure 39: Average species LIFE scores for 3 minute kick samples in 2002 and 2009. Results for EA surveillance monitoring sites up- and downstream are also plotted where available, but note that these are Family LIFE scores.

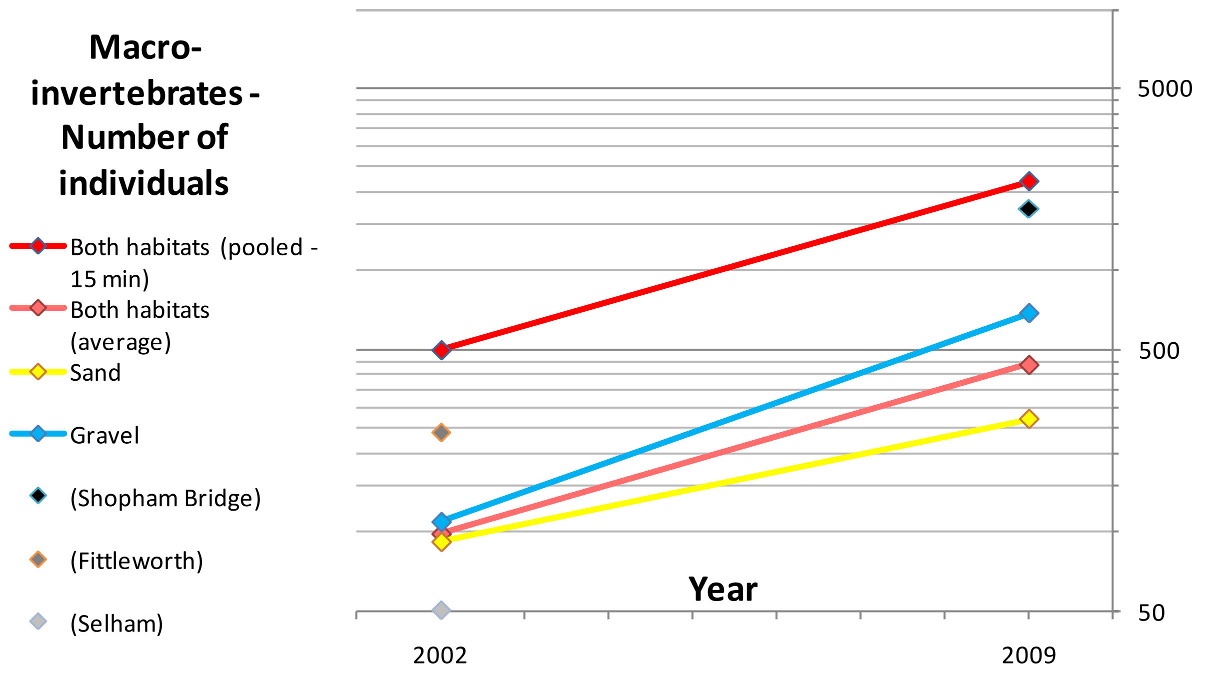

Figure 40: **Average numbers of individual organisms recorded in kick samples in 2002 and 2009. Note logarithmic scale. Numbers are also presented for the average of both habitats and an aggregate of samples, as well as for EA surveillance monitoring sites up- and downstream where available.**

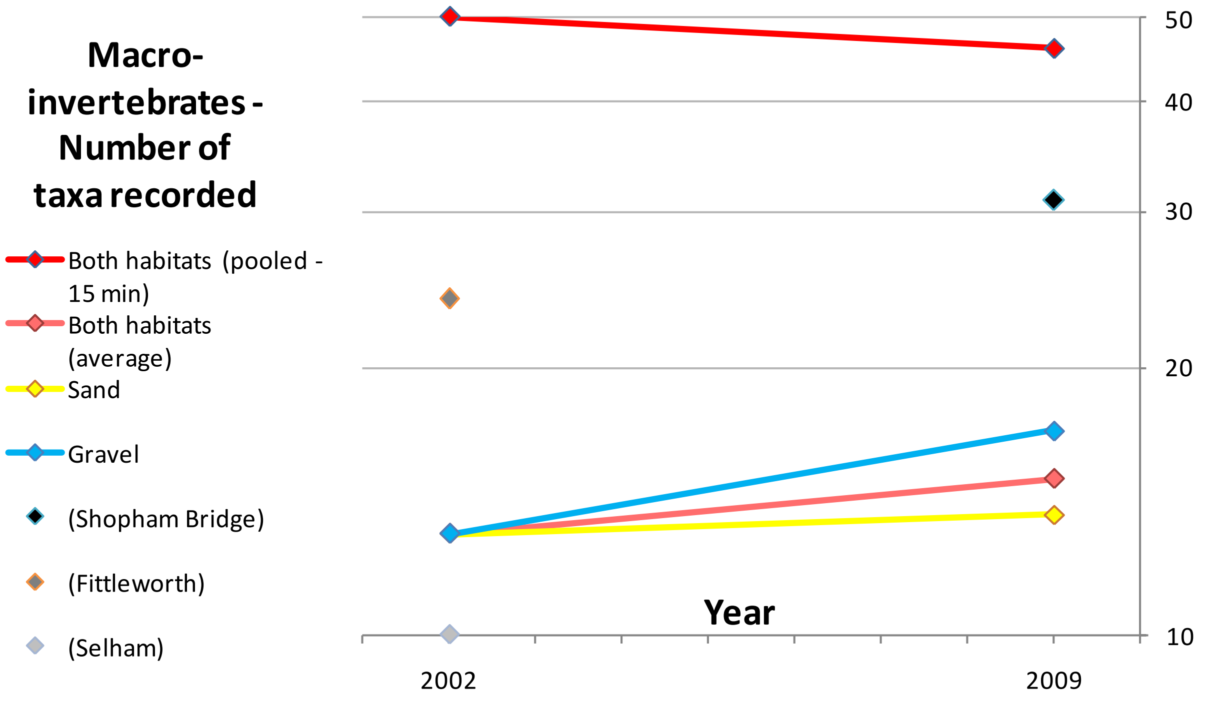

Figure 41: **Average numbers of taxa recorded in kick samples in 2002 and 2009. Note logarithmic scale. Numbers are also presented for the average of both habitats and an aggregate of samples, as well as for EA surveillance monitoring sites up- and downstream where available.**

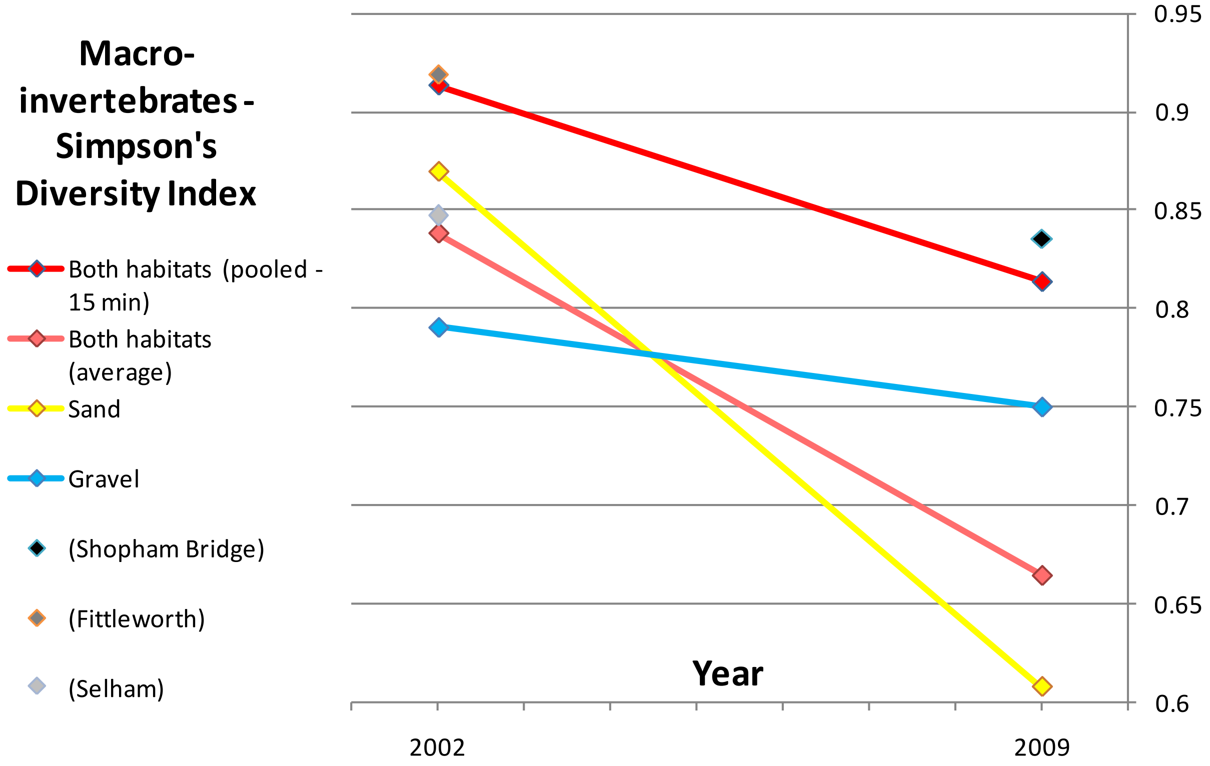

Figure 42: Average α-diversity (Simpson's 1-D) for kick samples in 2002 and 2009. Numbers are also presented for the average of both habitats and an aggregate of samples, as well as for EA surveillance monitoring sites up- and downstream where available.

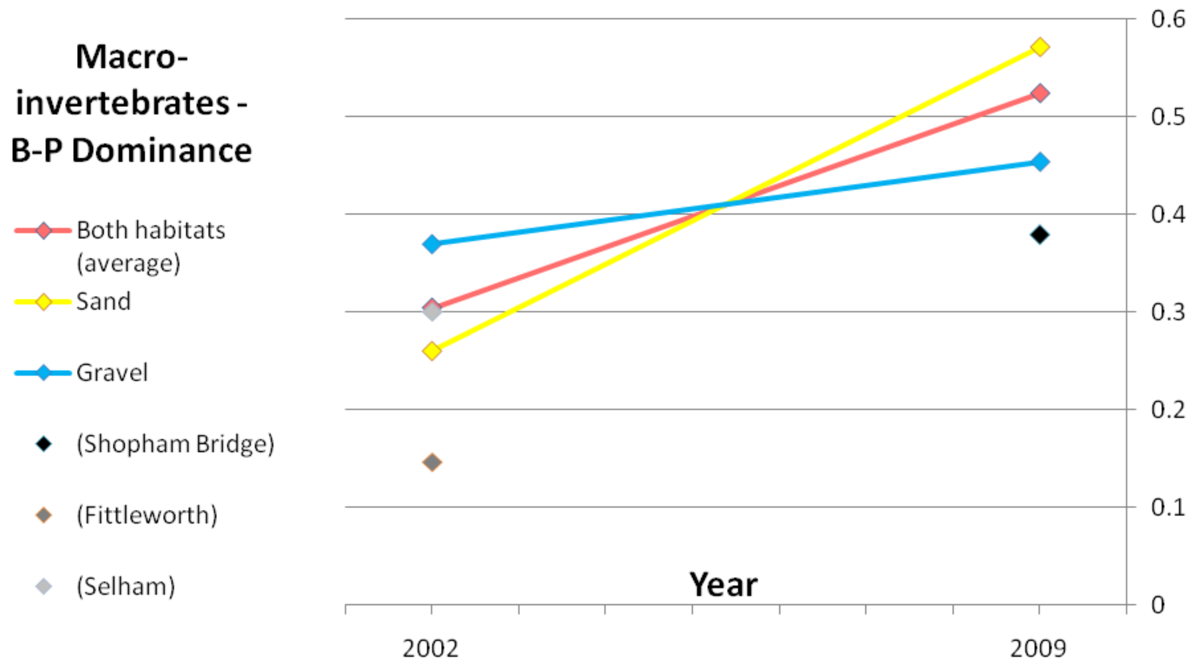

Figure 43: Average Berger-Parker Dominance Index for kick samples in 2002 and 2009. Numbers are also presented for the average of both habitats and an aggregate of samples, as well as for EA surveillance monitoring sites up- and downstream where available.

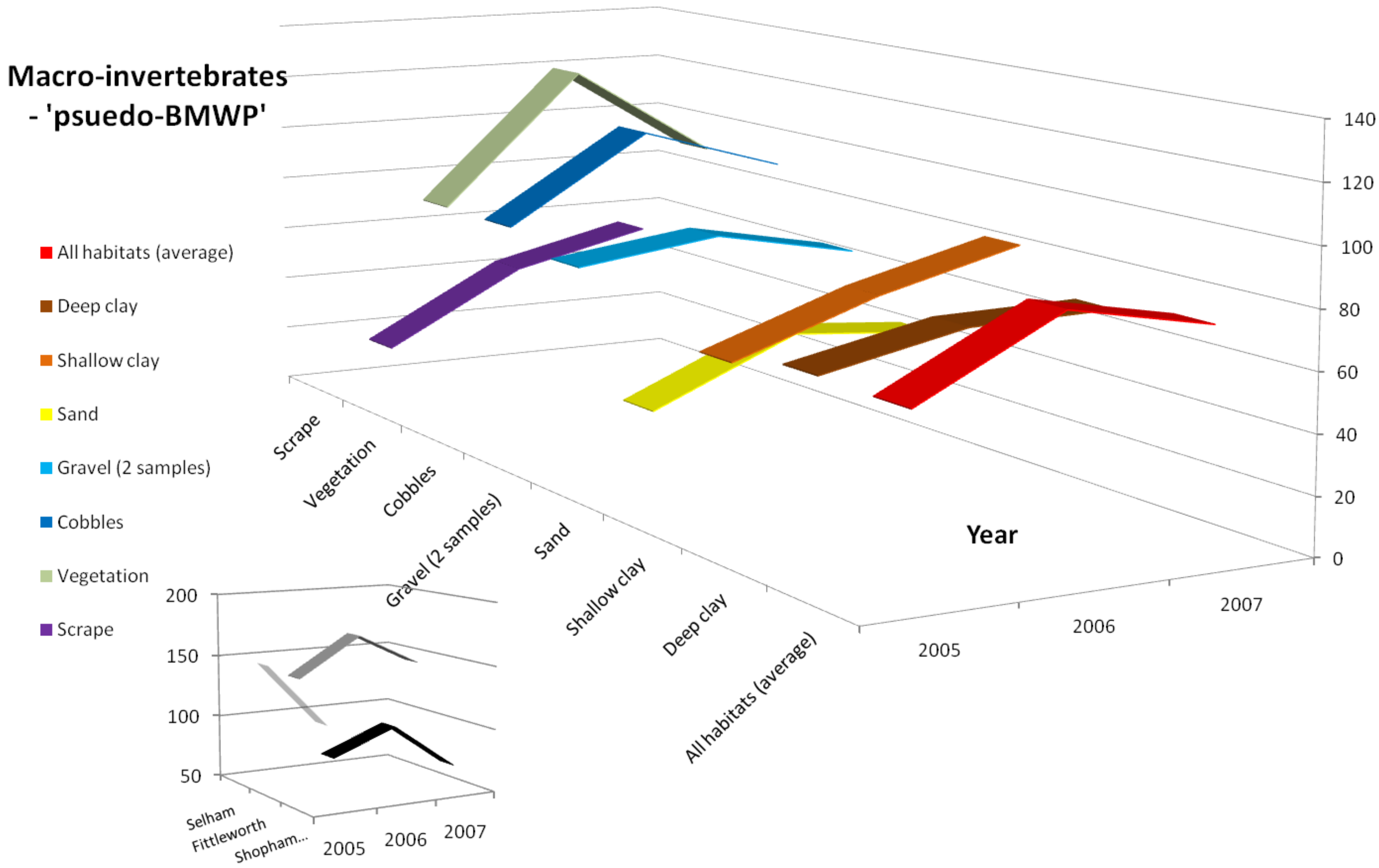

Figure 44: BMWP BIOSYS outputs for kick samples between 2005 and 2007. Note that for the loop samples, these are not true BMWP values as they are an average of values for 1 minute of sampling effort. Inset are true BMWP (1x 3 min) values for EA surveillance monitoring outside the study site.

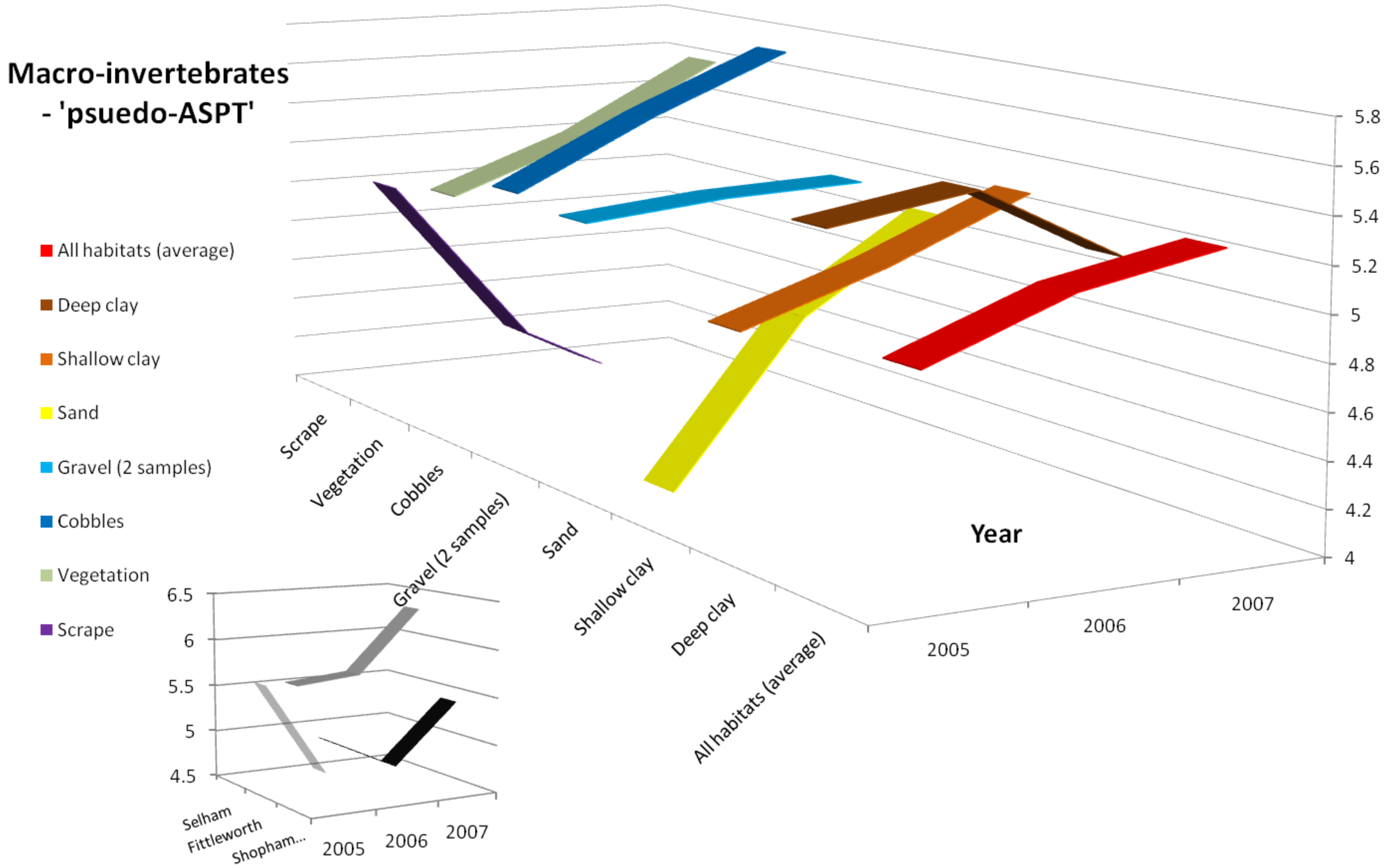

Figure 45: ASPT BIOSYS outputs for kick samples between 2005 and 2007. Note that for the loop samples, these are not true ASPT values as they are an average of values for 1 minute of sampling effort. Inset are true ASPT (1x 3 min) values for EA surveillance monitoring outside the study site.

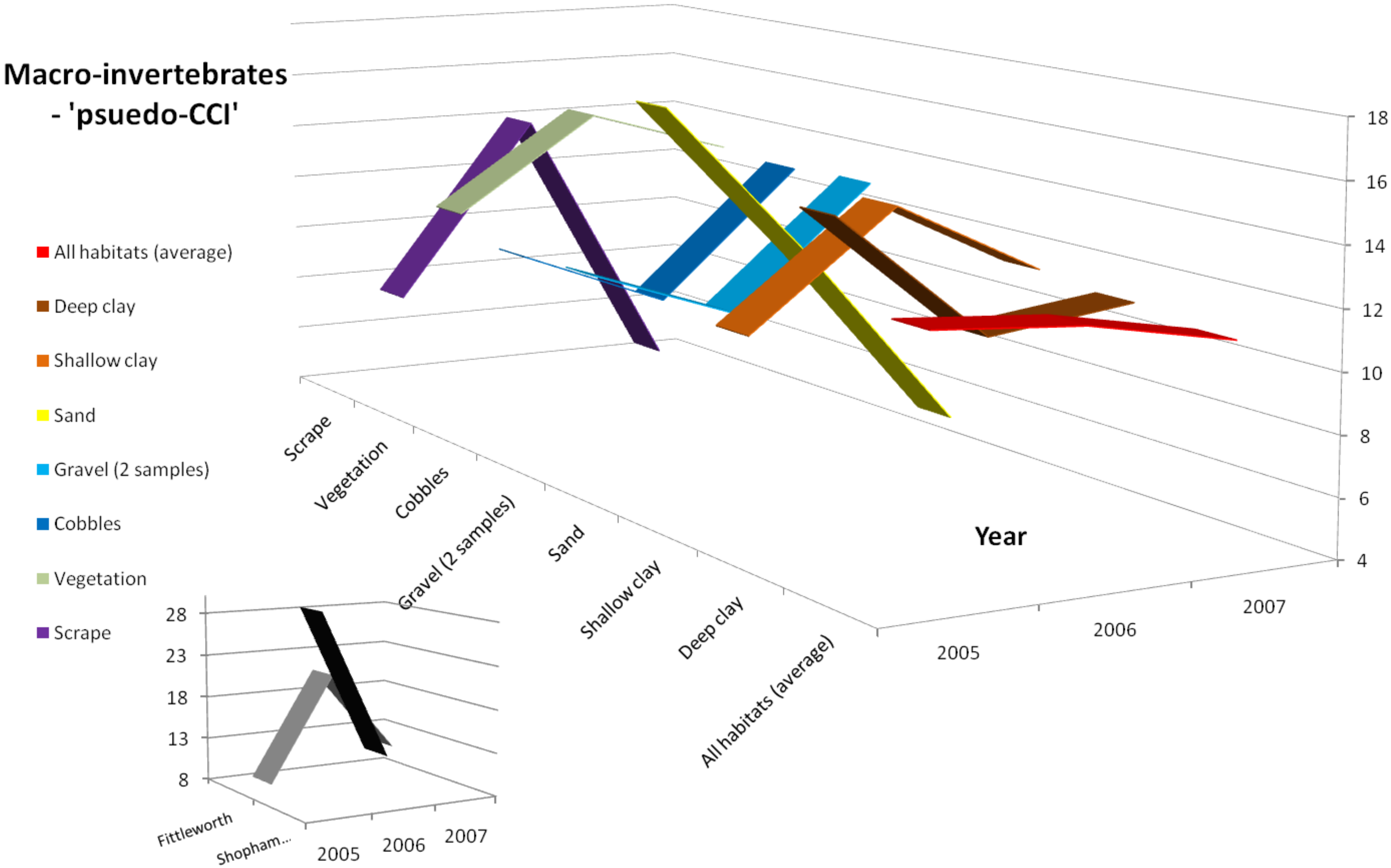

Figure 46: CCI BIOSYS outputs for kick samples between 2005 and 2007. Note that for the loop samples, these are not true CCI values as they are an average of values for 1 minute of sampling effort. Inset are true CCI (1x 3 min) values for EA surveillance monitoring outside the study site, where available.

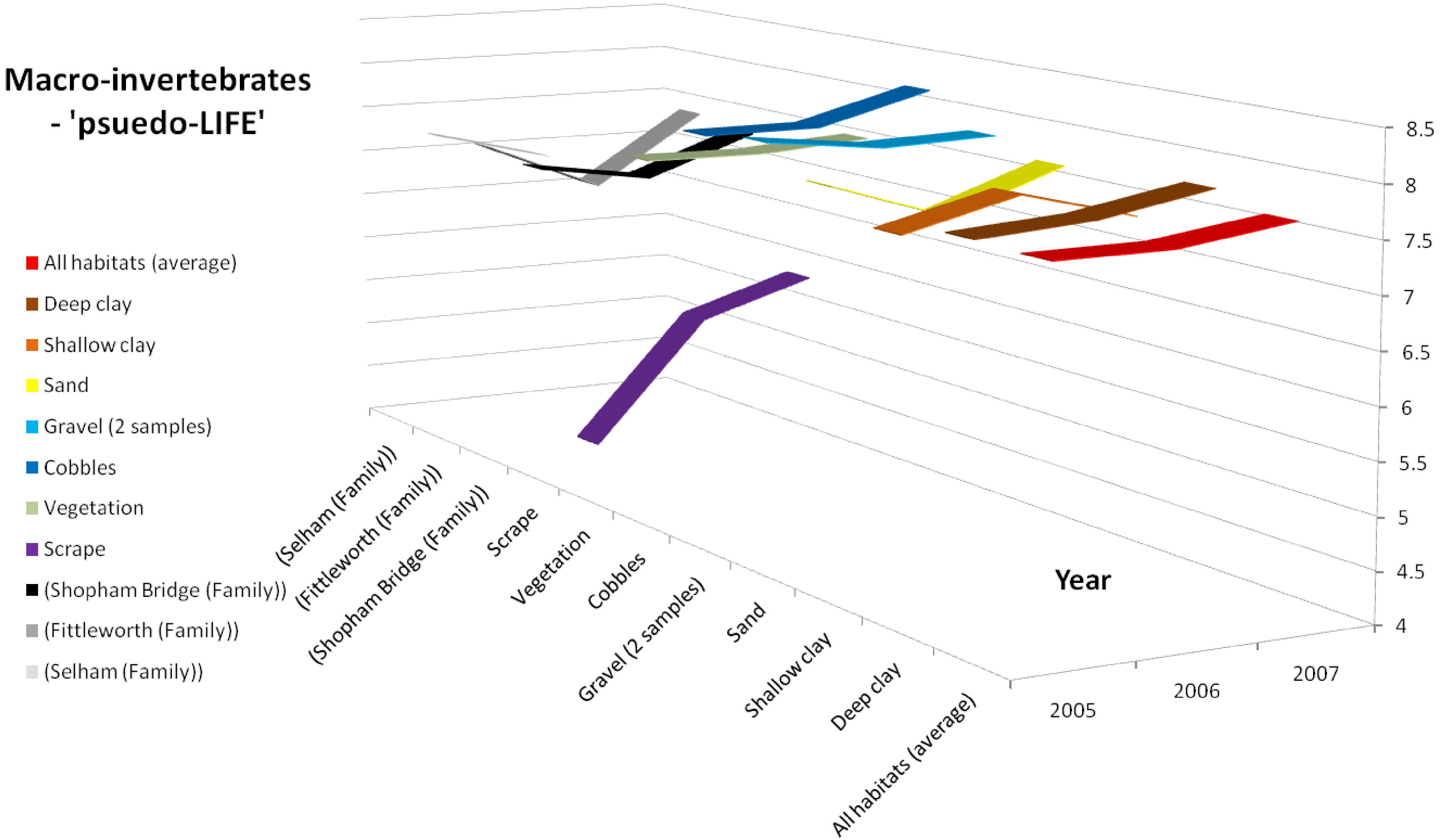

Figure 47: LIFE BIOSYS outputs for kick samples between 2005 and 2007. Note that for the loop samples, these are not true LIFE (species) values as they are an average of values for 1 minute of sampling effort. True LIFE (1x 3 min) values are given for EA surveillance monitoring outside the study site, but these are derived from family, not species scores.

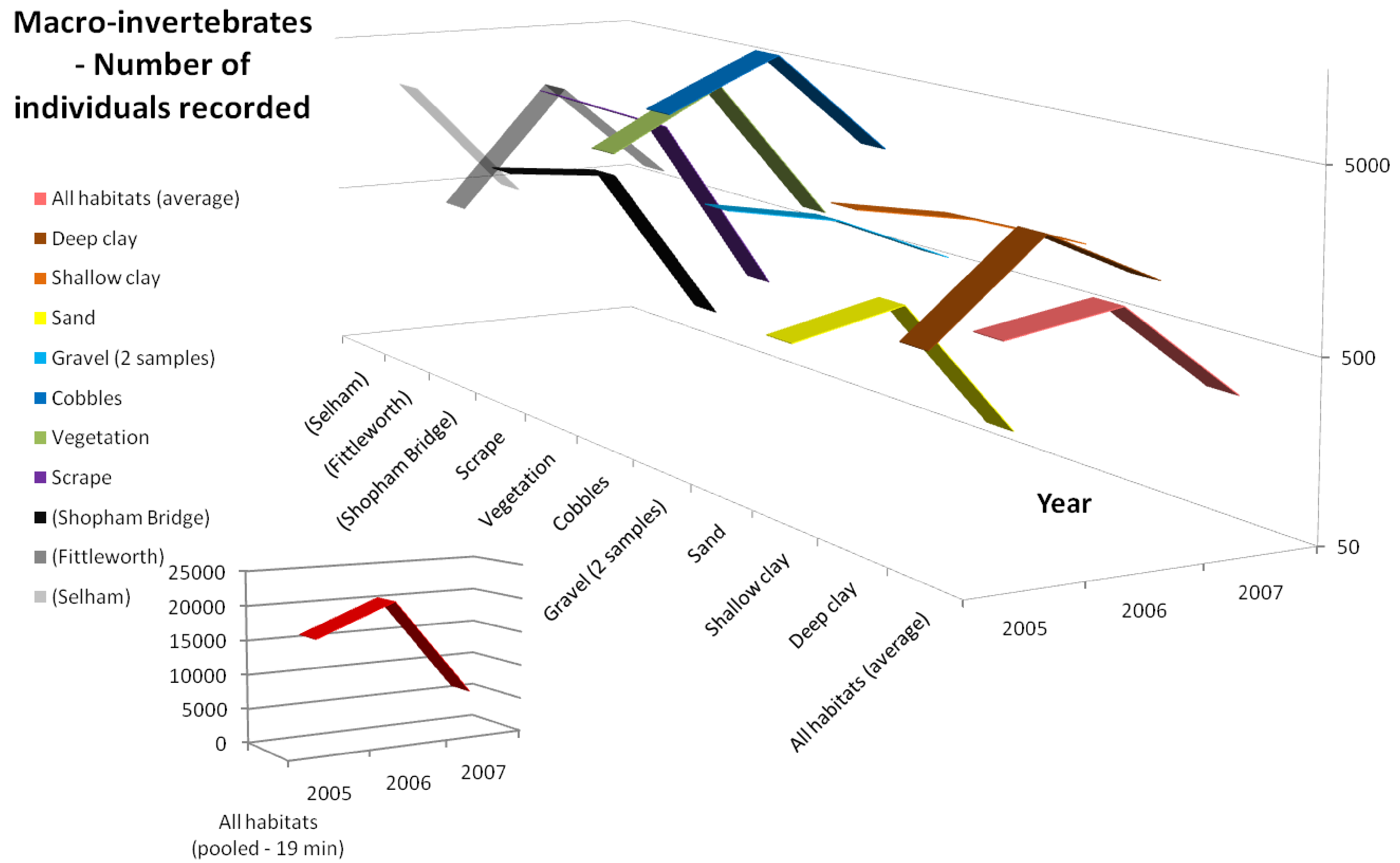

Figure 48: Number of individual organisms recorded for kick samples between 2005 and 2007. Note logarithmic scale. Sampling effort is 3 minutes except for Gravel (2x 1min), and note that outside the loop (Selham, Fittleworth and Shopham Bridge) these are 1x 3 min samples each. The graph inset represents the number of taxa when the loop samples are aggregated.

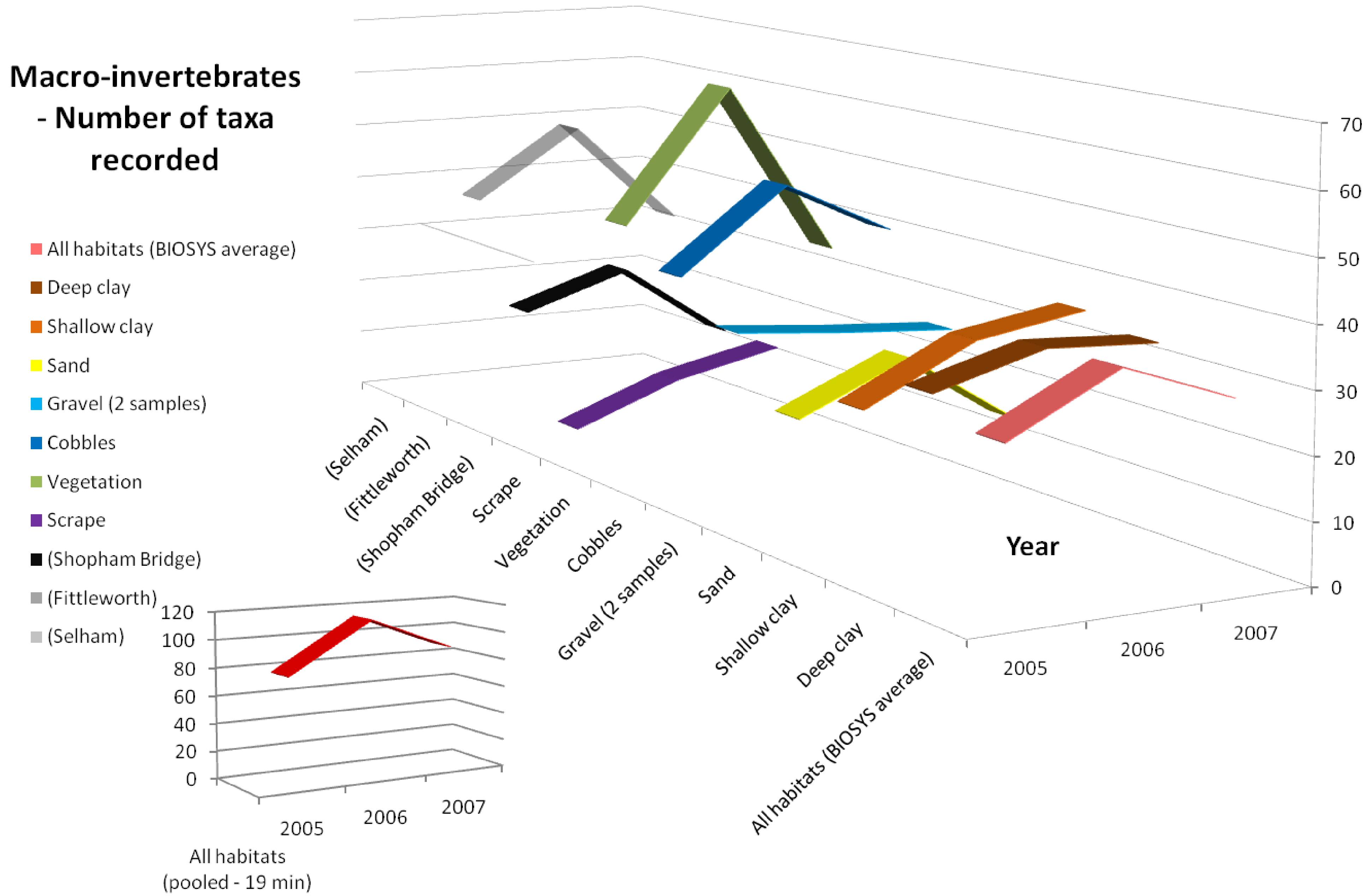

Figure 49: Number of taxa recorded for kick samples between 2005 and 2007. Sampling effort is 3 minutes except for Gravel (2x 1min), and note that outside the loop (Selham, Fittleworth and Shopham Bridge) these are 1x 3 min samples each. The graph inset represents the number of taxa when the loop samples are aggregated.

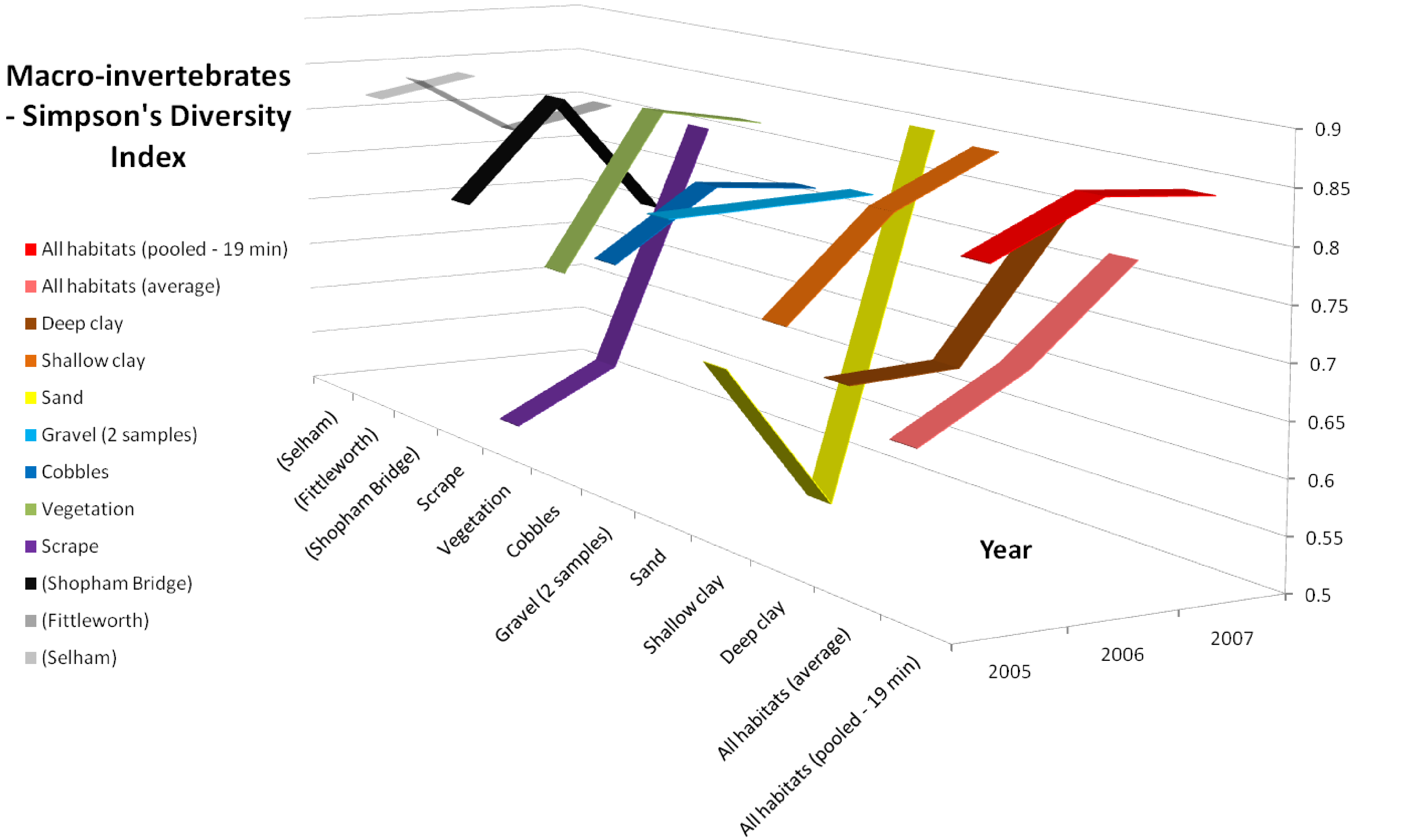

Figure 50: α-diversity (Simpson's 1-D) for kick-samples between 2005 and 2007. Sampling effort is 3 minutes except where aggregated (All habitats - 19x 1 min) and for Gravel (2x 1min), and note that outside the loop (Selham, Fittleworth and Shopham Bridge) these are 1x 3 min samples each.

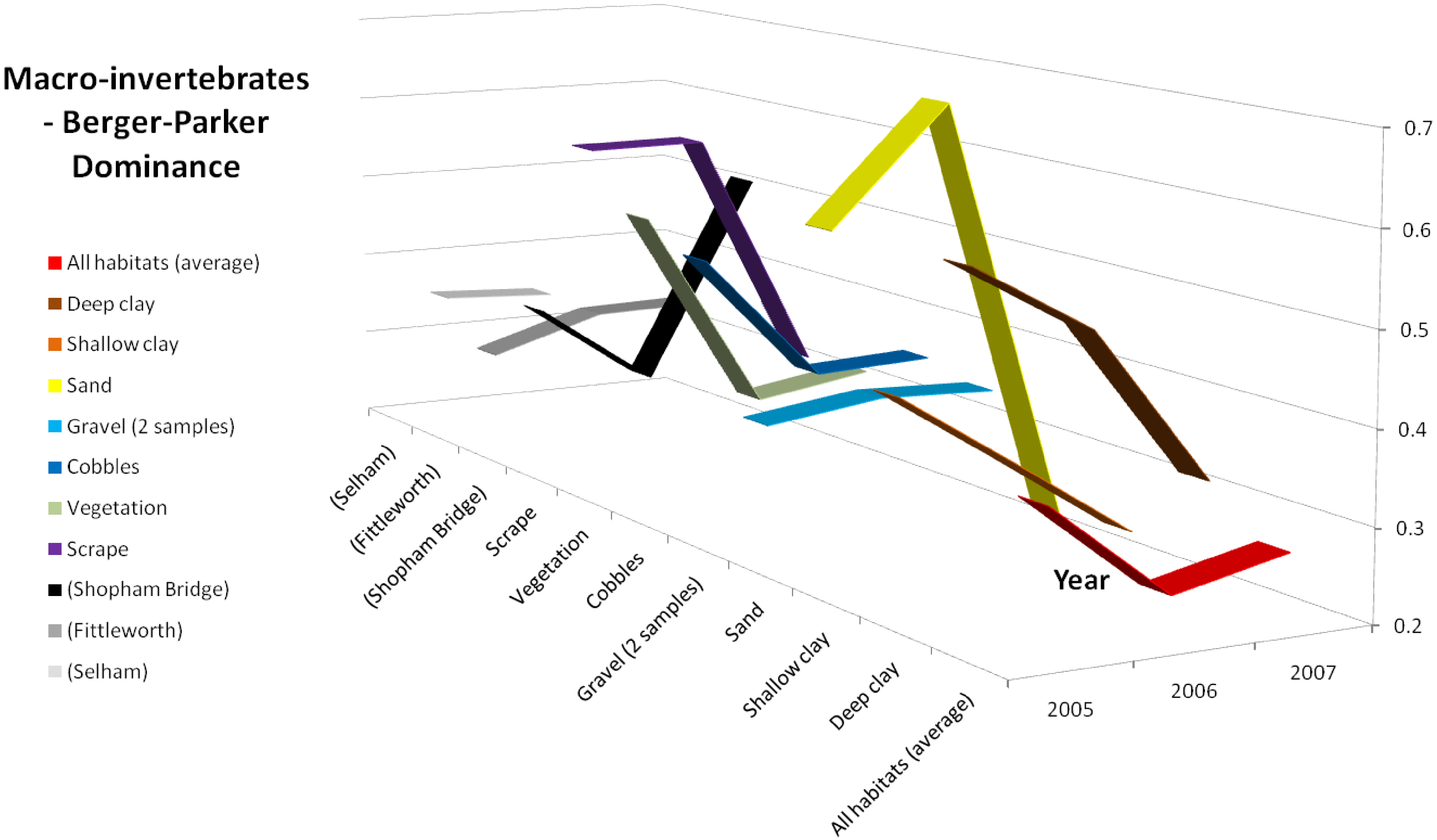

Figure 51: Berger-Parker Dominance Indices for kick-samples between 2005 and 2007. Sampling effort is 3 minutes except where aggregated (All habitats - 19x 1 min) and for Gravel (2x 1min), and note that outside the loop (Selham, Fittleworth and Shopham Bridge) these are 1x 3 min samples each.

Note that these complex datasets require extensive quality control, analysis and interpretation, all of which increases the probability of erroneous conclusions being made.

However, the following conclusions can be drawn from these results with a ***high*** degree of confidence:

- There were significant differences in the macro-invertebrate community within the loop and further up- and downstream between years.
- Diversity (Simpson's 1-D) varies greatly between mesohabitats, and is greatly influenced by a small number of especially populous species (e.g. *Gammarus* spp.).

The following conclusions can be drawn with a ***reasonable*** degree of confidence:

- BMWP, LIFE, biomass (number of individuals) and taxonomic richness (no. taxa) in the loop appear to have reflected the same general trends as the downstream sites between 2005 and 2007, all except LIFE peaking in 2006 and declining fairly significantly in 2007. The opposite trend in LIFE scores is likely to represent reduced flows in this year of relatively low rainfall.
- Macro-invertebrate biomass and species richness in the loop appears to have increased significantly since the restoration project was carried out.
- Water quality, as indicated by BMWP and ASPT scores, appears to have improved as compared to the 2002 pre-project baseline.
- Average water velocities, as measured by LIFE scores, have increased steadily over the course of monitoring, with the greatest change between 2002 and 2005, during which time the restoration works were implemented.
- Average water velocities (LIFE) have been consistently higher at gravel and cobble sites, as would be expected.
- The scrape habitat has consistently supported a less species-rich and more 'pollution tolerant' (ASPT, BMWP) macro-invertebrate community.
- The vegetation and cobble habitats are particularly important in terms of biomass, species richness and supporting pollution-sensitive fauna.

The following conclusions may be made only ***tentatively***:

- The scrape habitat has been colonized by species increasingly typical of faster-flowing water (increase in 'pseudo-LIFE' 2005-2007), suggesting its effective ecological connectivity with the channel.
- The initial dominance of a few species post-works (high B-P Dominance in 2005) and subsequent decline may indicate active colonization and the establishment of an increasingly 'balanced' ecosystem.

2.4 Landscape ecology

2.4.1 Fixed-point photography

Sample results are presented in Section 2.3.1.

2.5 Drivers of changes

As discussed in Section 3.6, the examination of linkages between datasets has not been carried out owing to the disproportionately large potential for error upon adding a further layer of analysis. As such, very few conclusions drawn from the evidence collected could be made with any significant level of confidence.

However, as already stated in Section 2.1.1, anecdotal evidence (the water level recorders were not installed sufficiently early to substantiate this), it can be concluded with a ***reasonable*** level of confidence that:

- The increases in cross-section complexity which occurred very quickly after the re-connection of the loop were likely due to high flows.

Furthermore, minor supplemental investigations were carried out into the changes in the depth data when aggregated (rather than looked at in terms of cross-sections); and the changes in depth-averaged velocity and boundary shear stress profiles of the 5 best-matching sections. The intention here was to examine the available hydromorphological and hydraulic variables most significant to physical habitat generation by more statistical methods. Appendices A and B present the rationale, methods, results and discussion of these investigations, respectively.

3. Evaluation and discussion

For the whole programme and then each dataset, this section details the analyses performed on the supplied information, limitations and further possibilities for the types of data collected.

Lessons learnt from practical implementation of the monitoring and the extent to which monitoring and project objectives were met are discussed.

3.1 General

3.1.1 Summary of key lessons learnt

The key observations are briefly stated here and further discussed below.

- The restoration project lacked clear **objectives**, which prevented measurable monitoring objectives from being set. Consequently, the data were not collected for explicit, defined analyses, which necessitated significant extra time and resources in order to determine what was possible to determine from the data.
- The monitoring programme lacked **central coordination** and a formal protocol, introducing many inconsistencies in data collection by different members of EA staff and others working on the project, often preventing true comparisons between different years' data and strongly limiting the types of analysis possible. This significantly increased the burden of quality control required to adjust values and identify those data which had to be excluded from analysis.
- Pre-project planning (i.e. protocol development etc.) was not sufficiently detailed nor performed early enough, leading to a weak **experimental design**, primarily in the form of little or no control data.

3.1.2 'SMART' objectives

It is very common that river restoration and enhancement projects proceed without very clearly defined objectives, and this is in part down to the difficulty involved with predicting the outcomes of intervening in such environmental systems (itself somewhat due to little monitoring and the resulting evidence base). If the aim of monitoring is to determine whether or not the project has been successful however, definite measures or indicators of success need to be decided upon. Monitoring objectives can then be crystallized in order to do the 'measuring' effectively.

A useful acronym for the development of effective objectives is 'SMART', meaning that they should be Specific, Measurable, Achievable, Realistic and Time-framed. Detailed guidance on objective-setting and monitoring is provided in the RRC's PRAGMO monitoring manual {{515 Hammond,D.M. 2011}}. From a scientific point of view, these monitoring objectives can be considered as testable hypotheses which, if true, lead to the conclusion that the project has been successful. Alternatively, one could consider the process to be testing that null hypotheses (i.e. that there has been no change or negative change). In any case, to draw conclusions, these need to be explicitly defined in advance of data collection.

The programme objectives (Section 1.2.2) did provide a good framework for the development of more specific, testable hypotheses, but with data collection not tailored to these directly, this process required repeated in-depth inspection of the data, consuming a vast amount of time. For monitoring to be wholly successful, the methods and types of data collection should be inextricably linked to the objectives and their development.

3.1.3 Project management and delivery

A comprehensive project such as this necessarily involves many people and several different types of data collection. It should be noted that the Shopham programme was intended to be experimental, and one or two people involved wished to take the opportunity to test different methods (notably, the 1-minute kick-sampling), however, without defined, written methodology, once others took over the sampling, they proceeded in different ways. Most of these differences were very slight, but any deviation at all from previously applied methods limits conclusions from being made confidently, or in some cases completely precludes any comparisons and determination of change.

3.1.4 Experimental design / Framework for data collection

River restoration monitoring lends itself well to a 'Before-After-Control-Impact' (BACI) design, and this would be one of the most effective ways of detecting the changes due to intervention in such complex and already very variable systems (see Table 9)

	Control	Impact
Before	All planned monitoring of the project should also be carried out in up- and/or downstream reaches for sufficient time to represent main natural trends.	All planned project monitoring should be carried out at the project site for sufficient time before the works to capture natural variation and trends.
After	After the works, control site monitoring must be continued in an exactly equivalent way to that at the project site.	This is the post-works monitoring which can be tested against any changes detected in the control site(s), in order to determine whether or not it is due to the intervention.

Table 9: Application of BACI design to river restoration monitoring

Importantly, the exact same sampling effort should ideally be applied to all four cases, though this rarely happens. In practice, it is normally only the 'Impact, After' case which receives significant attention. In this particular case, there was a general lack of explicit control data collection (requiring data collected for other purposes to be used where it was available), and 'before' data collection was insufficient to pick up any natural trends which may have been superimposed on the monitoring data.

To guarantee the success of a monitoring investigation, or any other experiment, it is necessary to consider the type of data that the methods will generate *and* the statistical analyses to be performed upon them early in the planning stages. This will help determine whether or not the methods selected will allow one to draw confident conclusions, often relating to whether the objectives have been met in the case of river restoration or, more generally, whether hypotheses can be accepted or rejected. Furthermore, this will also indicate the necessary sampling effort (i.e., amount of replicates etc.) required. In any case, replication should be sought to be maximised to avoid erroneous conclusions, though this is always a compromise with limited resources.

3.1.5 Summary of confidence in conclusions and project success

It has been possible to draw a great many conclusions from the Shopham Loop monitoring data, but owing to the issues discussed in this section, which arise from often only apparently minor initial oversights or unforeseen problems, most can only be asserted with limited confidence (Figure 52). It should be the aim of monitoring programmes – and it is possible with careful experimental design – to provide evidence for unequivocal conclusions to be made about the success, or otherwise, of a project.

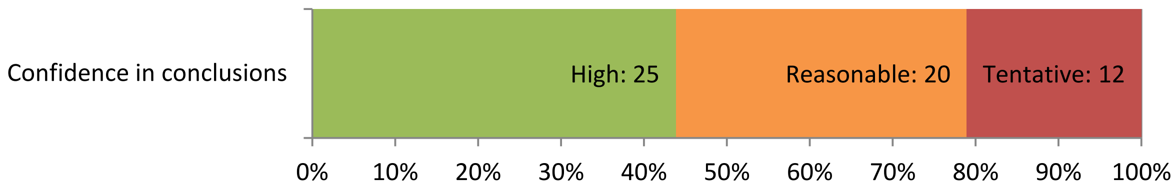

Figure 52: Summary of confidence in conclusions of study, and number of conclusions.

Depending on the particular definition of project and monitoring objectives, it may be the case that there is simply only one conclusion to be drawn (with confidence): that the project has or has not been a success. In this case, the project objectives were not defined in sufficient detail to relate the conclusions of monitoring to overall success. However, returning to these…

- Restore 1 km of degraded watercourse and its associated floodplains.
  Considering expert judgement and the data collected, there is ***some*** *evidence of this having been achieved.*
- Restore natural river processes to provide additional habitat diversity to benefit the ecology of the river.
  Considering expert judgement and the data collected, there is ***significant*** *evidence of this having been achieved.*
- Enhance and diversify the fishery of the lower river Rother catchment.
  Objectively, there is ***significant*** *evidence of this having been achieved.*

3.2 Geomorphology

3.2.1 Topographic survey

Practicalities

Accurately surveying river channels is inevitably challenging and potentially hazardous (Figure 53). The Shopham Loop surveys have been ambitious in scale, probably with the initial aim of revisiting the designed and modelled sections, of which there are necessarily many (over 40 in the loop). Apart from the difficulties of working in and on the water, there may be numerous obstructions to accessing the channel, particularly when flow conditions may be most amenable but vegetation well developed, in the summer.

Figure 53: 'As-built' survey in progress (cross-section 3) during high flows in late 2004. (Photo: Halcrow Geomatics)

These types of issues, as well as calibration problems (as seems to be the case with the 2009 survey) and presumed difficulties in finding the benchmarks visible in Figure 53 once vegetation had established, resulted in frequent mis-matching of sections (Figure 54), sometimes by more than 10 m. Though arguably access may have been easier and benchmarks more visible during the earlier surveys, this demonstrates the importance of quality control measures employed by these professional contractors. It was most unfortunate that the latest (2009) topographic survey could only be used for small-scale, relative comparisons of coincident features, as this may have shown the greatest degree of medium-term channel adjustment (as opposed to immediate adjustment following reconnection).

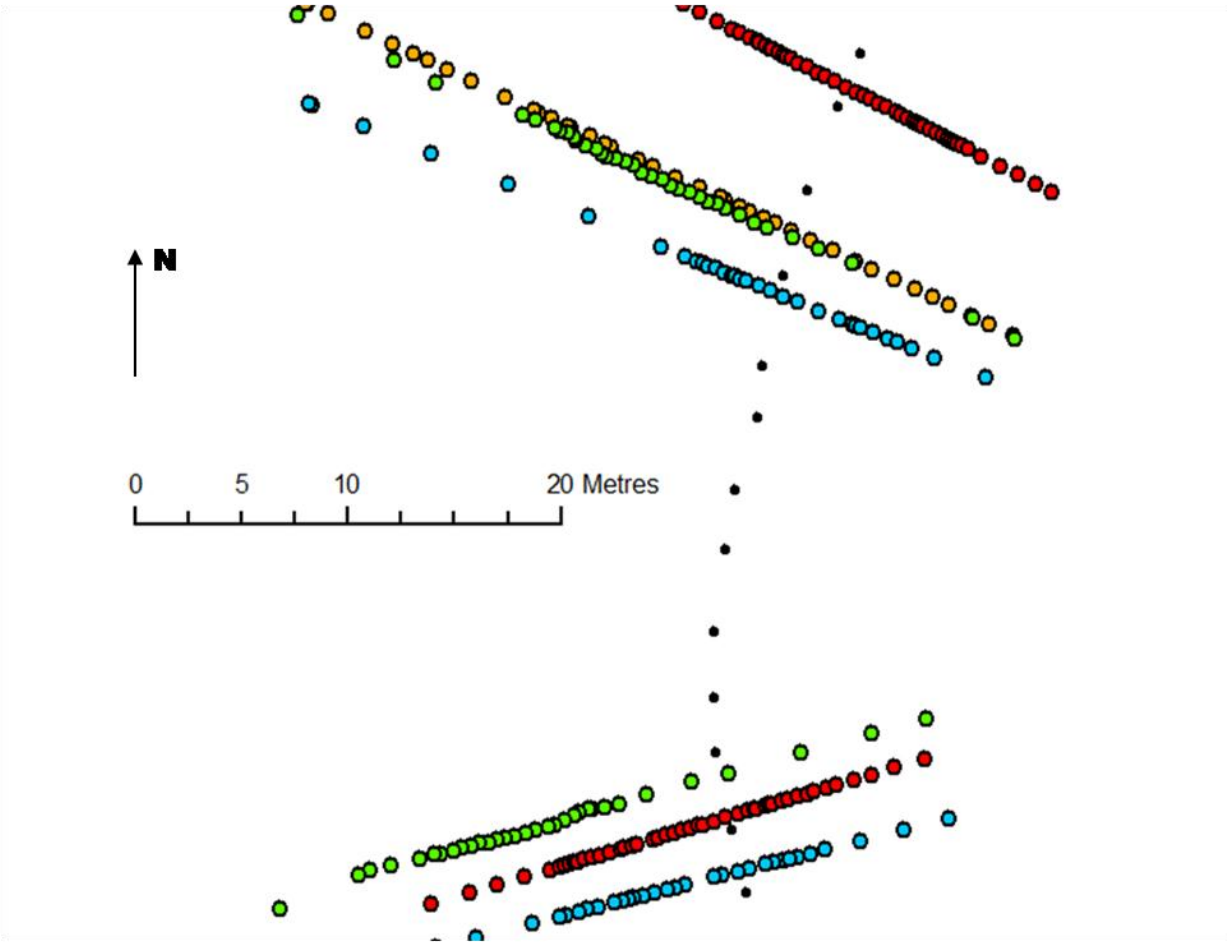

Figure 54: An example of poor matching of sections between years (cross-sections 4A and 5).
Orange: 'As-built'; Red: 2005; Blue: 2006; Green: 2009.
Note the west-shifted channel position (area of highest point density) in the 2009 (green) data.
Other evidence suggests that the channel has not actually migrated to this extent.

Section overlays

Drawings only, not raw data, were available for the 2002 (pre-project) Halcrow survey, and this has prevented the easy use of this dataset in section overlays. Given time, it would be possible to extract the levels from these drawings or simply overlay them graphically on the rest of the plotted sections, but this does serve to show the value of holding the raw data.

This mis-matching of sections as described above has significantly reduced the number of usable sections represented by all years' surveying, leaving only cross-section 4 and sections A and B on the original course of the Rother, downstream of the loop.

The assumed calibration issues with the latest dataset, and the lack of x,y data for the design sections (taken from a 1-dimensional model), have meant that sections from these years have had to be aligned by eye. Consequently, these section overlays are able to capture changes in the channel shape and elevation, but not any possible lateral channel migration outside of the 2004-2006 period.

Thalweg data

The data for analysis here were presented with reference to channel chainage back-calculated from x,y coordinates of depth sampling points, rather than any pre-defined reference chainage. This presents problems when trying to align and overlay surveys of the channel's longitudinal bed profile, as the chainage is strongly dependent on the sampling density (Figure 55). As can be seen in Figure 19, particularly at the beginning and end of the loop, the sampling density is very much lower in 2005 than

2006 (91 points, vs. 307). Consequently, even when starting from a common point, by the end of the loop, samples of apparently matching chainage are found to be tens of metres apart.

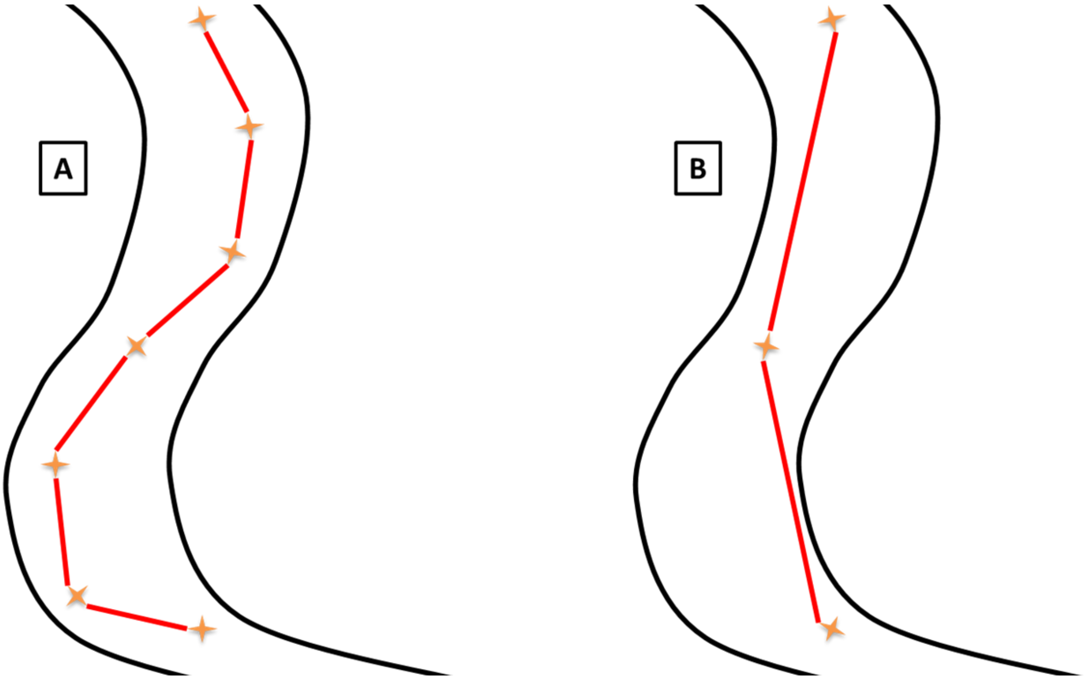

Figure 55: Effect of sampling density on back-calculated chainage. A: High density, long chainage; B: Lower density, shorter chainage.

Fortunately, as the full x,y data are available for these thalweg points, it will be possible to realign the longitudinal profiles to produce an overlay. This is, however, particularly labour-intensive and furthermore, the disparity of sampling densities between years limits the value of this exercise, as the depth data will not be legitimately comparable.

Section perimeters

This descriptor is not an ideal measure of structural complexity, as it is so strongly influenced by the resolution of the survey data (i.e. fewer measurements will not be able to capture higher complexity). As the sampling density between years and cross-sections differed in this case, comparisons do not permit conclusions to be drawn with a high degree of confidence (a 1-tailed paired t-test between the 2005 and 2009 data gave a P value of 0.44, i.e., not statistically significant).

A more statistical approach

Alternatively, depth data, either for the entire reach or key areas where change is expected or important, could be collected either in an evenly distributed (gridded) or in a properly randomized manner. This would allow more powerful statistical and modelling analyses and importantly, reliable interpolation (kriging) between the measured points, building a 3D surface model of the channel and eliminating many of the problems associated with matching up sections. Indeed, approximate cross-sections can be extracted at any desired point from this surface. An example of such an interpolated surface is given in Figure 56, below, though robust change analysis would require more evenly-distributed survey points (the example given is for a much larger river than most restored channels in the UK).

Even in the sparsely distributed, large-scale example illustrated, it's clear that this approach aids identification of morphological features such as pools and meander bars, and it will facilitate the application of habitat suitability models and examination of wider trends and effects than can be covered by a section survey. Interpolation was attempted with the Shopham data, but it was found to be not sufficiently extensively distributed. Some basic statistics of the aggregated data are broadly informative, however, and are presented and discussed in Appendix X.

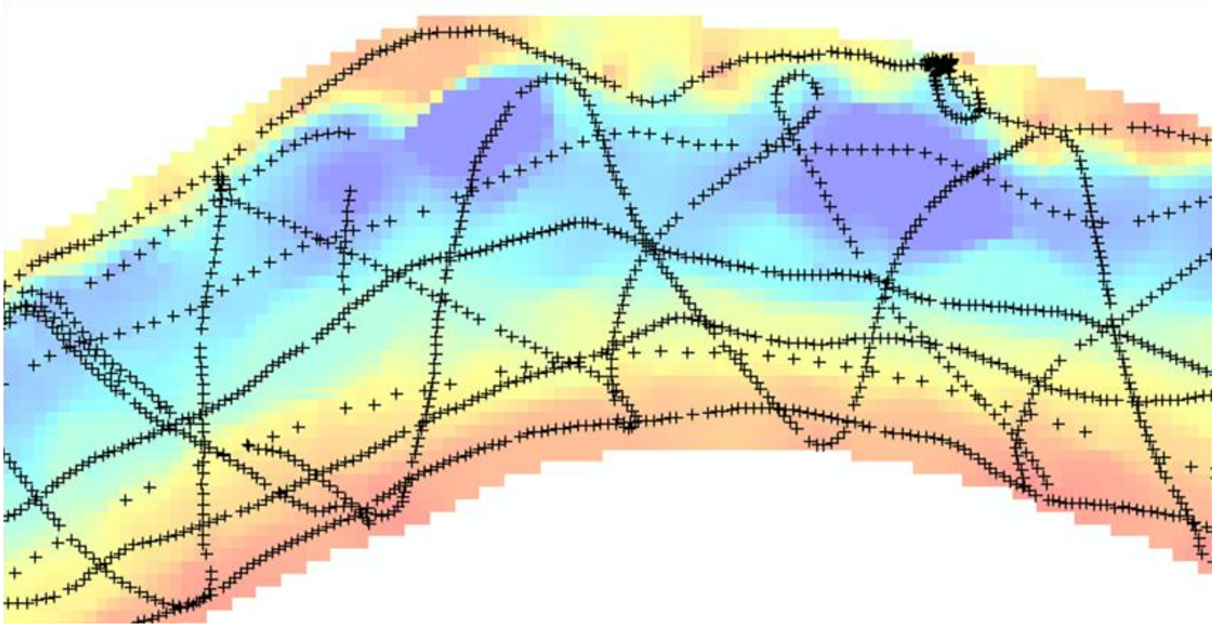

Figure 56: An example of an interpolated bathymetry dataset (increasing in depth from red to blue) from survey points (crosses). Data and image: University of Texas

3.2.2 Fixed-point photography

Practicalities

In a similar way to the undertaking of repeat cross-section surveys, it is difficult to return to an exact point on a site, year upon year, over time-periods suitable for detecting change due to a river restoration project such as this. An obvious way of avoiding this problem would be to have cameras permanently installed, and this is becoming a more attractive possibility as technology develops. Durable set-ups similar to wildlife camera traps may be justifiably employed to record exactly equivalent images at regular intervals in the future. This would of course allow the production of time-lapse imagery of the project evolving.

Typically, however, the most convenient way to locate the fixed points from which repeat site images are taken is to compare what is visible through the camera viewfinder with previous years' images. However, the advent of digital photography and image analysis permits ever more sensitive detection of changes in such image sets, and the tolerances of such 'by eye' matching may be so large as to prohibit the effective use of these techniques (discussed below).

Given the inevitable but unpredictable difficulties in collecting these images, it would be prudent to begin by attempting to cover as many fixed points as possible, to minimize the impact of having to abandon a proportion of them over the course of the monitoring. The most actively evolving parts of the channel in this case (from visiting the site in person) appear to be closely downstream of the engineered structures (bed checks). Unfortunately the more significant of these areas of bank erosion and slumping (at the downstream confluence of the loop and old canal cut) is not sufficiently covered by the main monitoring points. This is a predictable area of change which should have been foreseen at the initiation of the programme.

The use of slide film here also made the process of collating the images very labour-intensive, with their having to be mounted, identified, scanned and digitally processed. This is why the current analysis, of change over the course of the monitoring period, was limited to the main 25 points which had the best coverage. This type of monitoring will obviously benefit from digital image capture.

Quantitative analysis potential

Cropping to the same field of view and simply comparing images side-by-side or flipping between them in the same frame is the simplest and perhaps clearest method of analysing fixed-point images.

However, with regard to channel morphology, freely available image processing software may allow such datasets to be used as vastly cheaper surrogates to topographic survey. These types of analyses were not possible with the scanned slides, owing to a lack of lens information, normally recorded automatically as file metadata with digital cameras.

The open-source (free) ‘Hugin’ package, for example (http://hugin.sourceforge.net), though aimed at activities such as stitching photos into panoramas, provides a simple-to-use interface with innovative underlying code, under constant development, which has applications for standardizing digital images by accounting for different lenses, exposures, etc., and also accurately overlaying them and automatically detecting differences.

Where images are taken within a few seconds or minutes of each other and from similar positions, the software is able to find shared ‘control points’ between images automatically. Changes in factors such as vegetation which occur over longer periods, however, are likely to require human input to identify these shared reference points. The idea would be match up photos by identifying points which will not change over time (e.g. telegraph poles, features on the horizon, or survey benchmarks – see Figure 57). With a suitable number of these fixed, differences in the projection of the image due to different lenses can be corrected for by ‘warping’ the images.

With these standardized images, changes may be detected by placing them in sequence as a time-lapse video, or by overlaying them and looking for changes in the position of hypothetically mobile reference points (most likely on the river banks). Though more complicated to interpret, the software is also able to produce a false-colour image which highlights the differences between photos.

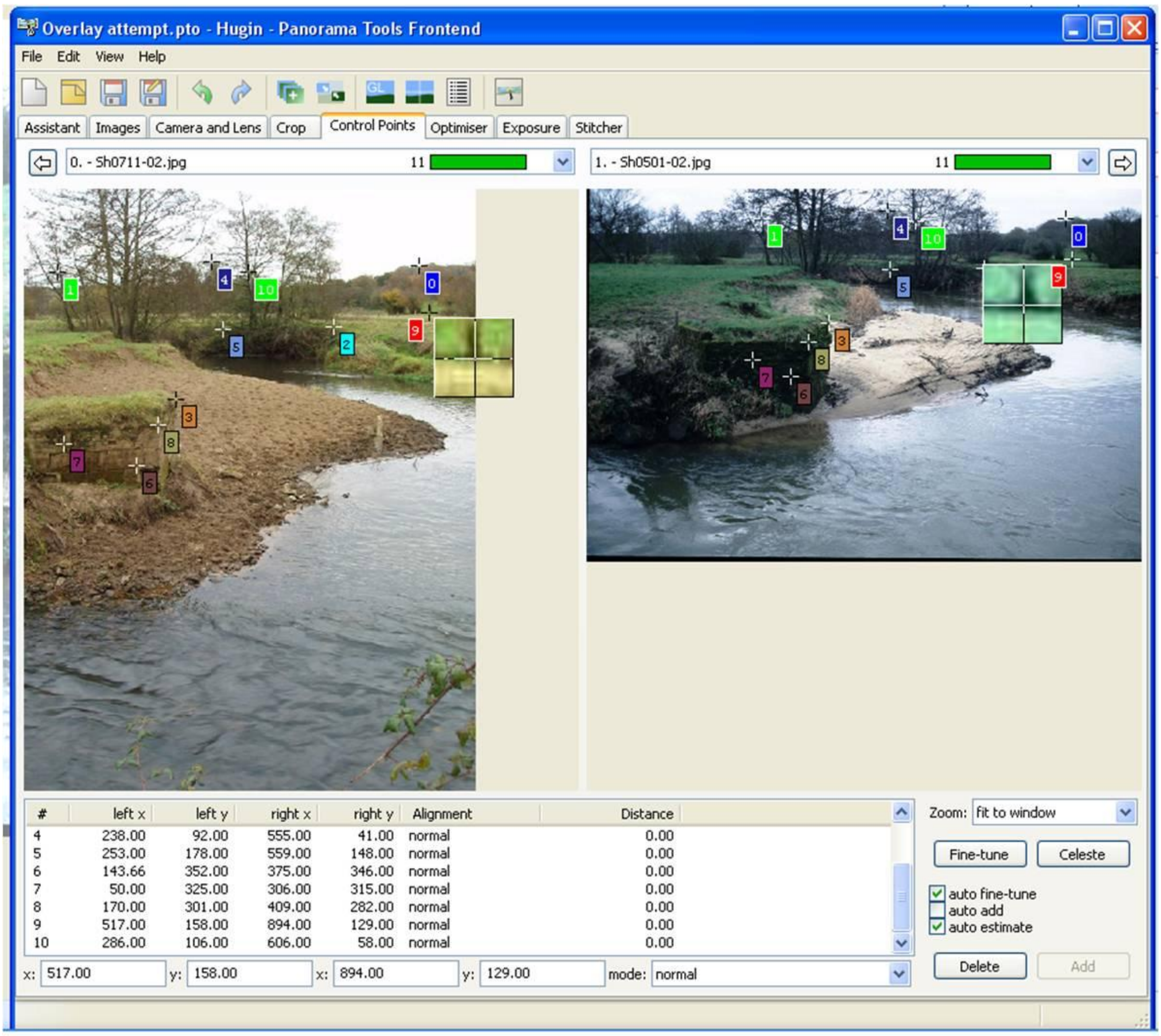

Figure 57: Identifying fixed common control points between images in 'Hugin'

A dataset for ecological monitoring?

The photographs collected at Shopham have been considered here under the heading of 'ecology', as small inconsistencies in the viewpoints limited the power to draw conclusions about geomorphological changes, but this classification is fairly arbitrary. The principal value of this type of information is in the ability to detect broad changes in the vegetation of the banks and floodplain. Though higher-resolution images may enable an expert to estimate some of the species present, the main detectable variables will relate to more structural characteristics. Importantly, however, photographs must be taken at the same time of year to account for seasonal changes.

3.2.3 Floodplain sediment monitoring

As excess fine sediment deposition was a key issue at the Shopham site, it was intended that the modifications to 'reconnect the floodplain' would promote the sediment sink function of the floodplain. However, this is not currently assessed in the monitoring. A number of potential methods are available, but the use of mats, of similar roughness to the floodplain, which are pinned to the ground at the site and weighed at regular intervals. Such information of course needs to be considered in the context of pre-project 'before' data and 'control' data from other sites.

3.3 Hydrology and hydraulics

3.3.1 15-minutely water levels

Practicalities

It's probably perceived that the advantage of logging pressure transducers is that they can simply be left to collect data, without any requirement for visiting the site. Indeed, this is potentially the case, but initial installation and unforeseen disturbance must be carefully considered.

There are three main practical obstacles to the confident use of the water level data to determine flooding at Shopham.

Firstly, the devices installed in Shopham loop, as far as is known to the current author, were housed in plastic tubes of fairly small (a few cm) diameter, with ends exposed to water in the channel. The drift evident in the time series, and particularly the estimated bank top levels, may be inherent to the sensors themselves, but also suggests that some of these physical installations may not have been sufficiently robust, with the angle of the tube or the position of the sensor within it changing. Indeed, it is known that at least two of the set-ups were vandalized, and it seems likely that attaching the first sensor, in the loop, to an overhanging tree is unlikely to have been sufficiently secure to maintain the transducer at a fixed level. The buried pipe design, as is known to have been in place at the bridge, is more suitable. This vertical drift limits the confidence with which bank top can be inferred from the method of inspecting the gradient of the rising limbs of the hydrographs employed in the current analysis, as it is not consistent over the monitoring period, particularly for loggers 2 and 3. As such, it was not possible to estimate flooding statistics for these positions.

Secondly, the sensors were not 'surveyed-in' to ordnance datum at the time of installation, and high flows on many occasions prohibited doing this retrospectively. Had this been the case, determination of out-of bank flows would have been extremely straightforward, as a threshold could have been taken from the topographic surveys.

Finally and inevitably, there were equipment malfunctions and failures, resulting in periods of no data; the necessity for a member of staff to correct the readings manually; and mis-matching of data in terms of time. Information recorded automatically by the loggers eases filtering of the data, but these may not always be recorded. This was the case for the temporal drift of logger #2, nearest the pump, which resulted in peak flow events creeping forward in time with respect to the other two loggers (see Figure 58, below).

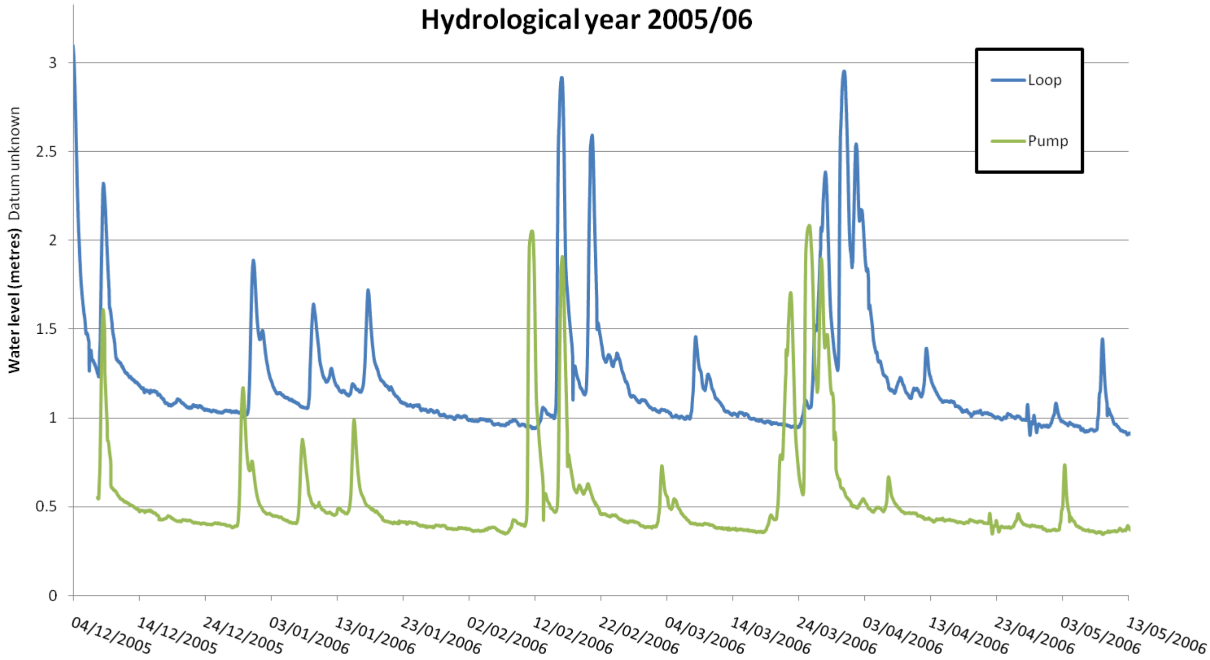

Figure 58: Temporal drift (not picked up in quality flags) in the data for logger 2 (nearest the pump).

Two other practical considerations for the installation of such temporary stage recorders relate to hydraulic artefacts which may be encountered. As with stilling wells, the tube orifice should not be exposed to water flowing with any significant velocity, which would cause a draw-down of water within the tube related to that velocity. This is accounted for in, e.g., gauging stations, by ensuring that the opening to the well is completely flush with the flume wall. The other consideration is the 'throttling' effect that the constrictions of the bridge arches have on water levels, which will produce a rather different stage-discharge relationship to that of the other two installations. Though a convenient location, it may be at the sacrifice of comparability with the open-channel recorders.

As noted in the recommendations (Section 4.3.1), the data do contain a wealth of useful information in spite of the problems encountered which, it should be said, are common in most forms of hydro-meteorological data collection. However, to extract this information, small time periods where data quality can be assured must be analysed specially, which requires significant time and/or specialist software. Indeed, given sufficient time, there is certainly capacity within the EA to perform this analysis.

Experimental design

Given that the principal objective of the project was to change the channel and floodplain hydrology, these were key datasets for the detection of this change. The lack of pre-project data for comparison, however, prohibited any analysis of the effect of the project on flood event water levels – only comparisons with the other two simultaneously logging sample points up- and downstream can be made.

If floodplain inundation (as opposed to in-channel levels) is the only concern of monitoring, it may be more effective to place logging sensors at key points of interest on the floodplain. The extent of the array of sensors required will depend on the extent of the knowledge of floodplain topography. For example, if a detailed survey is available, it may only be necessary to know the depth of water at just one point on the floodplain surface to be able to establish the areal extent of flooding from contours (though it would be prudent to gather duplicate of triplicate data). Should this information not be available in sufficient detail, or at all, it will be more effective to place sensors in a distributed array, and/or at key points on the floodplain surface (e.g. approaching 'at risk' infrastructure). Simpler sensors which do not detect water depth may be used in such a network. In either case, having sensors on the floodplain itself eliminates some of the issues associated with fast-moving discussed earlier.

3.4 Channel ecology

3.4.1 Macrophyte survey

The raw survey data demonstrate that really, a great deal of information on the loop flora were collected through some thorough work, however, their analytical value was limited by a lack of standardization. The analysis was limited to listing the species recorded and how they changed. Given further time and resources, the species data could be stratified by 100 m sub-reach.

Particular standardization issues were that the level to which species were identified (i.e. genus, family etc.) was not fixed; cover estimates were not made each year, nor were they always stratified by sub-reach; and the opinion of which species constituted riverine (cf. bank or floodplain, etc.) vegetation differed between surveyors. Furthermore, site visits and expert consultation have spotted discrepancies in the identification of some species.

A mapping approach is likely to be the most effective method for detecting changes due to the work in this context, however, where particular attention is directed to mesohabitats. Specific recommendations are presented in Section 4.4.1.

3.4.2 Fisheries surveys

Electro-fishing.
This dataset benefited from the well defined standard methodology used for collection, and the existence of control data, allowing some robust conclusions to be drawn.

Estimated catch efficiency was only reported for 2005 (at 30-40%). Considering this, and that the these two external stations are fished more thoroughly by a three-sweep depletion netting method, the loop data are likely to represent low-end estimates of populations. Without size or weight measurements, however, little more can be deduced about enhancement of the fishery of the lower Rother (an explicit project objective (Section 1.2.1), taken to mean an increase in total biomass and/or average fish size).

Continuing to assume a similar catch efficiency for all years, there may be significant under-representation of the community diversity, as species represented by fewer individuals may have been missed altogether. This depends on the particular species depletion rate for the site and season (unknown). The impact of the decreasing dominance of Minnow and 3-Spined Stickleback (in the loop and scrape, respectively) is clear in the concomitant increases in diversity indices.

Determining inter-annual trends is problematic with only 4 surveys and 3 control datasets which are less well-spread in time, and this is why conclusions as to the dynamics of particular species are not robust. Conclusions about the status of Lamprey, Perch and Carp in the loop are difficult to draw owing to the fact that they were caught so infrequently, or in such low numbers.

Project objective 2 (Section 1.2.1) refers to habitat diversity, to which β-diversity indices are more sensitive. The stratification of the loop survey into 100 m reaches may not necessarily represent habitat stratification, and indeed the power of such an analysis may be reduced when examining the rather mobile communities represented by fish. This measure has been used here, however, as it may provide some insight to the achievement of this objective. Note that, in order better to meet the assumption of equal sampling effort between samples, results from the shorter bed-check sections A and B were combined.

Scrape surveys
Catches in the scrape surveys were classified as either < 10 cm, 10-20 cm or > 20 cm, giving greater insight into population dynamics. The basic analyses performed here assumed all individuals to have

lengths of the mid-point in each class (5, 15 or 25 cm), which of course may represent a significant oversimplification for the larger fish. Length was taken to be directly proportional to biomass.

In spite of these assumptions and the loosely defined project objectives, however, this methodology is probably fit for purpose.

3.4.3 Macro-invertebrate kick samples

This type of sampling yields a vast amount of potentially powerful data. As an indicator of restoration success, however, the vast majority of published studies find that measuring invertebrate community changes is not entirely suitable. The reasons for this are not simple, but what is certain is that such data collection requires very rigorous experimental design, and this is what may be lacking from many restoration monitoring programmes. The data so diligently collected as part of the Shopham programme illustrate well some of the pertinent issues.

Consistency

By far the greatest limitation on the value of these kick sample data is the fact that sampling was not performed in exactly the same way each year and comparisons are therefore not valid. It seems that the main reason behind this was confusion resulting from a lack of formal planning and communication.

Unfortunately the 1 minute (2005-07) and 3 minute (2002 and 2009) samples cannot be adjusted to be made comparable as the number of species sampled is not linearly related to the sampling effort (see Figure 59). This well-documented relationship is intuitive when one considers, for example, that unless there are infinite species, with each new round of collection one will find fewer and fewer new species, up to the eventual point of having sampled them all. The specific parameters of this relationship depend on many factors and are site-specific, so no generic scaling can be applied. Sampling effort also differed between years in terms of the number of replicates available, eliminating certain sample types from parts of the analysis. Analyses in section x, where comparing between years, have been normalized to the lowest sampling effort by taking an average of all possible combinations of totals of these reduced 'bottleneck' sample sizes – a rather labour-intensive process.

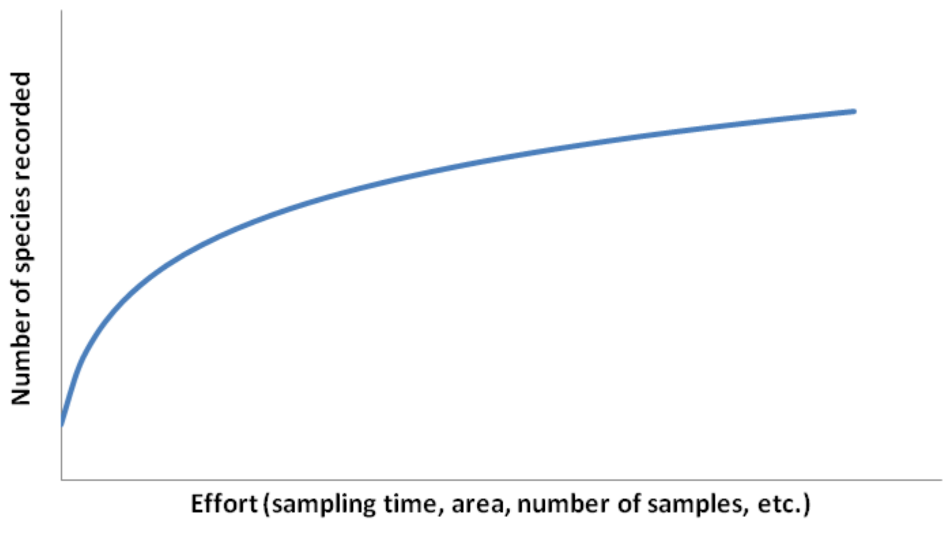

Figure 59: The generic relationship between species and sampling effort.

Another area of inconsistency in this case is the definition of the different mesohabitats. It is clear from the data that the invertebrate communities differ significantly between them, but without a clear definition for each, different members of staff visiting the site will have sampled in somewhat different habitats and so this may lead to false conclusions from comparisons. This will particularly be the case for the 'vegetation' habitat, as there will be many species and types (e.g., emergent vs. submerged, marginal vs. in-channel) are known to be tightly associated with particular invertebrates. Indeed, many studies find that the person collecting the data is the most statistically significant influence on the recorded information. With a standard definition decided upon (perhaps further development of those in the River Habitat Survey method), mapping of these habitats may provide a more direct method of monitoring success relating to the objective of increasing habitat diversity

The measure of the number of taxonomic groups present in a sample is dependent on the level (taxon) to which organisms can be differentiated and identified, and this was also different for some samples. In several cases, presumably difficulties with identification led to the recording of counts of members of a family, such as the Gerridae, which resulted in artificially low 'numbers of taxa' as compared to a sample in which the organisms were able to be separated further into genera or species. The analyses presented in Section 2.3.4 do not account for this error, and assume that each record within a sample represents a separate species. The effect of this, of course, is to reduce dramatically the analytical power of the 'number of taxa' statistic, as well as diversity measures and the confidence which can be put in any conclusions.

Which measure?

The sheer volume of data collected via these methods may be rather daunting and difficult to comprehend, hence the development of various indices to aid interpretation. The BIOSYS indices calculated as standard for EA monitoring and used here are powerful in this respect, but were all developed for particular purposes, and may not be appropriate for the monitoring of such a river restoration project. BMWP and ASPT were designed to provide integrated indicators of water quality, CCI of conservation value, and LIFE of flow conditions – that is, they are all in some way subjective.

Ultimately, the metric(s) used must relate to project and monitoring objectives, which are inherently subjective. In practice, the objectives may need to be defined in terms of what is possible to monitor, and what data are already in existence, if planning to use them to control for external trends. Here, the project objectives were simply to 'benefit the ecology of the river', for which measures of conservation value (e.g. CCI, or presence or numbers of particular species), diversity (e.g. number of taxa, or α- and β-diversity indices), or biomass (e.g. sample mass or numbers of individuals) are probably appropriate. As the monitoring objectives were simply to 'document the response' of the fauna, any number of indicators of change could be analysed.

Timescales

A likely explanation for the failure to find measurable 'improvements' in invertebrate communities – and indeed many other factors influenced by river restoration attempts – is that monitoring does not continue for sufficient time. Recolonisation and dispersal are controlled by many factors and very much determined by chance. In such situations as habitats are disturbed and created, it is these mechanisms which will initially dominate the ecology, often for many, many years. Comparison with the pre-existing ecosystem, which has usually had far longer than the period of monitoring for colonisation and more stable intra- and inter-species interactions to develop, may not be a true representation of 'success'.

The mesohabitat signal

The stratification of the data collection by habitat was a particularly novel approach adopted by the programme. Though an understanding of the degree of influence of habitat was hampered by the inconsistencies in definition and sampling as described above, as well as a lack of habitat stratification in control sampling sites, and the mis-matching of surveyed sections and transect samples, much more could be gleaned with further analysis.

Unfortunately the significant time required for data quality control and preparation for the purposes of this report did not leave sufficient resources for their application, but cluster analysis, and a basic analysis of variance (ANOVA) could be applied. In the first instance, cluster analysis may provide an indication of the strength of the habitat signal, and whether particular habitats more strongly determine the kick sample results. ANOVA will provide a quantitative statistical measure of the degree of influence relative to that of the sample year, however, its application to kick sample data, comprising many different species, may be limited either to particular species or overall metrics (BMWP, CCI, etc.). In the latter case, many more samples may have had to have been collected to identify statistically significant influence.

3.5 Landscape ecology

3.5.1 Fixed-point photography

(See earlier notes, Section 3.2.2)

3.5.2 Further data

An explicit monitoring objective (see Section 1.2.2) was to detect the ecological response of the surrounding landscape, and this has not been covered in much detail. Three fairly straightforward approaches to addressing this are briefly discussed below.

Quadrat-based floodplain plant survey

A widely used method for establishing changes in plant community composition looks at a number of samples of an area of the ground defined by a quadrat (frame). This is randomly placed within the study site and usually the species present within the frame and their approximate coverage (% of quadrat area) recorded. For the purposes of floodplain flora, a 1 m^2 frame is probably most suitable. In the case of this particular project, one would require about 5 replicates, perhaps surveyed each year in the spring, ideally with more than one years' worth of pre-project sampling and a comparative control site. This would generate robust quantitative data for analysis.

Pit-fall traps

The invertebrate community is likely to be another ecological element particularly responsive to changes in the floodplain hydrology and riparian habitat. A simple methodology for assessing this change would be to set pit-fall traps throughout the study area. These simple devices are containers (e.g. ice cream tubs) set into the ground with the rim at or slightly below the level of the soil surface. A lid (to exclude rain) is placed over the container raised a centimetre or two on, e.g., small stones or sticks, and usually weighted to stop it blowing away. Any insects and similar small animals encountering the apparatus pass through the gap beneath the lid and fall into the container, unable to crawl out owing to the steep, smooth sides.

The types (species, or more practically, families) and abundance of invertebrates sampled in this way would represent a quantitative dataset, again, for comparison with one or two years' pre-project data and perhaps a comparable 'control' or 'reference' site. Practical considerations include:

- Avoiding flooding of the traps (summer is more convenient from this point of view and given that crawling invertebrates will be more abundant).
- Two site visits will be required (one to set up, and another to collect samples a few days later).
- Traps should be identical between years in terms of design, placement, number, time of year (equivalent weeks, as mass emergence of larvae may skew results), and sampling period (trapping time).

An alternative or supplement may be to perform sweep-net surveys on floodplain vegetation to sample flying (and perching) insects.

Bird surveys

The Sussex Ornithological Society is a well-established group of enthusiasts who both collect and collate data and conduct focused surveys. The society regularly performs Waterways Breeding Birds Surveys (a standard protocol) along the Rother, and pre-project data (April and May 1999, 2000 and 2002) for the loop site are certainly available. The current author enquired as to whether later surveys had been performed, but no data were readily available at the time. Such surveys by voluntary groups represent good value for money in the detection of wider ecological changes due to river restoration, and should be explicitly included in any future monitoring where possible.

It must be noted that the fact that birds are very mobile in the landscape may require monitoring to be undertaken and analysed over a significant period of time (accounted for to a certain extent by the standard practice of visiting the survey site twice), and may limit the value of such data for fairly small-scale schemes such as Shopham. However, as data are already available, it is certainly worth pursuing in this case.

3.6 Drivers of change

The multifaceted nature of the sampling at Shopham Loop was designed to open up the possibility of identifying linkages between the various elements monitored. As described above, however, most of the datasets ran into significant problems, significantly limiting the confidence with which authoritative conclusions could be drawn. Furthermore, the difficulty of co-locating the different sampling points accurately enough within and between monitored elements in such a complex physical environment, in combination with limited replication, led to a situation in which these datasets could not be validly compared. Thus it was considered that applying a second level of analysis, or meta-analysis, would not have added value.

However, Appendices A and B have looked at the larger (i.e. more statistically robust) datasets generated from the topographic surveys in order to examine potential linkages between the morphology and hydraulics, acknowledging their strong potential for being drivers of physical and hydraulic habitat changes.

The co-location of cross-section and ‘transect’ macro-invertebrate sampling points was a particularly good idea for investigating the influence some of these variables may have on the organisms which inhabit the channel, but inconsistent sampling and mis-matching of sections precluded the unequivocal detection of change.

4. Recommendations

The bulk of this section presents recommendations, in light of lessons learnt, for the types of data collection performed within this project. Those recommendations which may still be enacted within a continuation of the monitoring actually conducted at Shopham are *in italics*, below, though virtually all may be applied to river restoration projects elsewhere.

Initially, however, there are some more general points to consider about monitoring design and delivery.

4.1 General recommendations for any monitoring project

- Set very Specific, Measurable, Achievable, Realistic and Time-framed objectives for both the project and its monitoring, to define 'success' and how it will be determined.
- Plan the monitoring programme well before the start of works, so that sufficient control data can be collected.
- Fully consider the type of data the selected methods will generate, and select the analyses to be undertaken at this stage – before any actual data are collected. Will these answer the question of whether you have met your objectives?
- *Have the monitoring methods defined in as much detail as possible* in a format which will provide a convenient reference for those collecting the data.
- Wherever appropriate, use standard sampling methods for ease and quality of data collection and comparison with any surveillance monitoring data already available. If possible, arrange for surveillance data used as a control to be collected at the same time as project monitoring data, or vice versa.
- *Make use of project management software or electronic calendars* wherever possible to facilitate delegation and advance planning of data collection, ensuring sampling occurs at the planned time.
- If investigating some of the drivers of changes detected, co-locate as many datasets as possible.
- For all datasets, maximize replication as far as possible and ensure equal replicates per sample – particularly if taking stratified samples.
- *Ensure sampling is performed at the same time of year each year* (particularly important for ecological data collection and fixed-point photography).
- *Extend all sampling to the newly created backwater*, as this represents new habitat which is currently under-valued.
- Baseline sampling should aim to have as wide a coverage as possible. This will safeguard against compromises which will almost inevitably emerge over time (if, for example, resources or access issues dictate abandonment of some sampling points). If the scope of monitoring is expanded over time (e.g., as opportunities or new resources arise), this will produce data of limited analytical value as they lack baseline data for comparison.
- *Refer to river restoration monitoring literature* when planning a monitoring programme, such as Roni (2005), or RRC (in draft 2011).

4.2 Geomorphology

4.2.1 Topographic survey

- *Set up robust and highly visible benchmarks throughout the site.* These must be easy to find perhaps more than 10 years later and within thick vegetation which may have established. It should be obvious to any other visitors to the site that these must not be moved or removed.
- Though it is important to collect and archive full x,y,z data, long-section surveys will produce more readily usable results if taken with reference to a pre-defined standard channel chainage. If cross sections are taken at a high enough number of well distributed points along the channel, the standard chainage of each of these may be used as a datum for long-section measurements. Note that, to a greater or lesser extent dependent on the spacing of the cross-sections, this still represents a compromise on accuracy, though it will prevent the cumulative drift which was a problem at Shopham.
- Conduct 'as-built' survey as soon as possible after completion to avoid recording the effect of extreme events.
- Sample depth extensively and randomly or evenly distributed both along and across the channel at key points where change is expected or important, to allow modelling of the bed surface and further spatial statistical analyses.

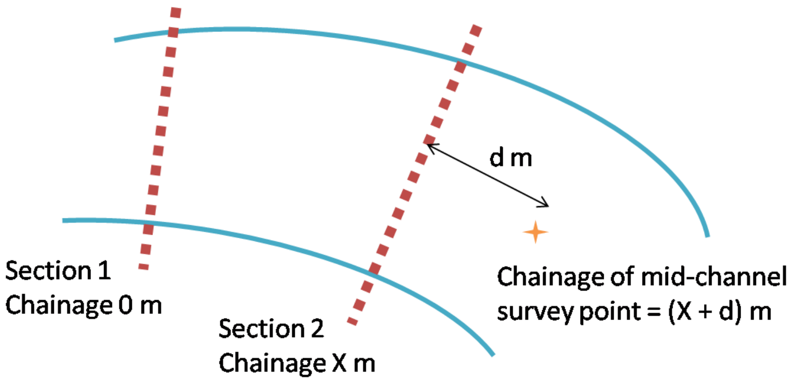

Figure 60: Using cross sections to 'anchor' chainage measurements

4.2.2 Fixed-point photography

- Begin by attempting to cover as many points and fields of view as possible.
- If resources permit, install physically fixed camera trap-style devices set to capture images at regular intervals.
- *Use a digital camera of the highest quality available* – the same device each time if possible – ensuring that lens data are recorded either automatically or manually.
- *Mark survey points with fixed physical benchmarks* as described for the topographic survey. Tall stakes may be suitable, as the camera may be physically rested upon them when taking photos. Note that the points must be defined in 3 dimensions.
- *Use professional judgement* to cover sufficiently points where significant change is expected.
- *If possible, place visible markers within the field of view* on points (e.g., bank top) where significant change is expected. This will increase the sensitivity of the morphological change detection.
- Continue to monitor the new point a17 closely.

4.2.3 Floodplain sediment monitoring

- *Initiate monitoring of sediment-trapping mats* pinned to the floodplain and in comparable sites with different levels of floodplain connectivity. Ideally, there should be several years' pre-project control data.

4.3 Hydrology and hydraulics

4.3.1 15-minutely water levels

- Any equipment on site should be briefly inspected every time anyone visits the site, and more thoroughly inspected by a technical specialist at regular intervals.
- *Further analyze water level data*, should time and resources become available. There is still much the data may be able to tell us, even if only for short periods where all loop and control data are of sufficient quality for comparison.

4.4 Channel ecology

4.4.1 Macrophyte survey

- *Limit species to be recorded to a pre-prepared list* of agreed riverine species or genera (e.g. those specified in the UK Water Framework Directive Technical Advisory Group LEAFPACS protocol).
- If identifying to species level, staff should be sufficiently competent to do this in the field, or collect samples for later identification.
- Species / genus presence should be mapped on an area coverage (cf. point) basis, to facilitate digitization to a raster (gridded) dataset, and the further analysis this will permit. It is suggested that a minimum density be set for mapping as a continuous area. Areas of mixed and single species may be determined by the overlap (or lack of it) of mapped areas (see Figure 61). Alternatively, percentage cover could be estimated and mapped for the different stands of plants.

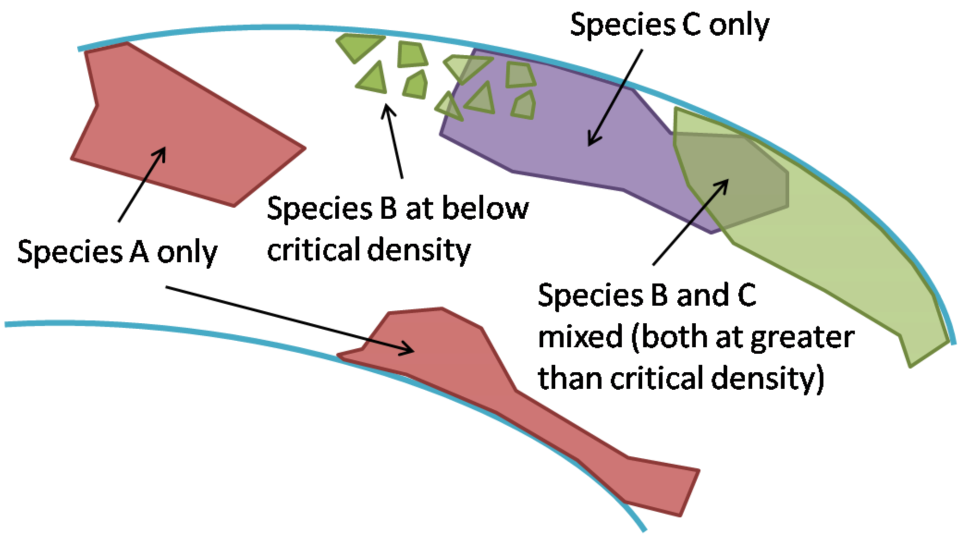

Figure 61: Schematic of suggestions for mapping macrophyte areal coverage

4.4.2 Fisheries surveys

- *Extend follow-up surveys to cover the backwater of the canal cut remnant.* The ecological benefit of this entirely novel habitat on this part of the Rother is currently un-assessed.
- Conduct surveys using the same methods as, and as close in time as possible to, wider surveillance monitoring.
- *Collect size/weight data as routine* during all surveys, to evaluate the effectiveness of the restored reach at improving recruitment to the populations, particularly of highly valued species.
- *Follow up the 2005 larval survey*, to elucidate recruitment dynamics.

4.4.3 Macro-invertebrate kick samples

- Adopt an extensive, randomized sampling strategy, to account for natural variation and difficulties in defining mesohabitats in stratified sampling. This must also apply to control data beyond the monitored reach.
- If stratifying samples by mesohabitat, compose standard, unambiguous definitions of these for the reference of the sampler.
- Work to family, not species level in the analysis of samples, to allow for problems with identification and achieve faster through-put.
- Sift data for quality and suitability for cluster analysis and ANOVA and apply these where possible to identify strength of influence of mesohabitat.

4.5 Landscape ecology

4.5.1 Bird survey

- *Consult Sussex Ornithological Society* regarding availability of later Waterways Breeding Birds Survey data, and arrange or request follow-up surveys if necessary.

4.5.2 Invertebrate surveys

- Set up a network of invertebrate pit-fall traps on the floodplain and monitor each summer.
- *Conduct sweep-netting survey* of floodplain and riparian vegetation each summer, using a standard protocol, to monitor flying insect community.

4.5.3 Floodplain plant survey

- *Conduct a quadrat-based survey of the floodplain flora* every (late) spring to monitor plant recruitment and community dynamics.

5. References

Darby, S. (2007) *Shopham Loop Geomorphology: Update on Shopham Loop Monitoring*. Report to EA.

Roni, P. (Ed) (2005) *Monitoring Stream and Watershed Restoration*. American Fisheries Society, Bethesda, Maryland.

RRC (in draft, 2011) *Practical River Restoration Guidance for Monitoring Options (PRAGMO)*. The River Restoration Centre, Cranfield, Bedfordshire.

Appendix A
Aggregated depth data statistics

Rationale and Method

Some general descriptive statistics generated from the complete aggregated within-bank elevation datasets (graphed in Figure 62) can be informative, and are presented in Table 10, below. Though likely to be of fairly low impact, it should be noted that, from the point of view of plan geography, these data were neither collected randomly throughout the reach nor the sections, but in such a way as to capture the shape of the channel (i.e. there may be more intensive sampling on steeper banks, and under-representation of lower (bed) elevations).

Results

Statistic	2005	2006	2009
Sample size	440	423	**451**
Maximum	7.38	**7.80**	7.45
Minimum	3.60	3.56	**3.61**
Mean	**5.50**	5.46	5.09
Median	**5.35**	5.27	4.81
Variance	0.79	0.87	**0.88**
St^{d} deviation	0.89	0.93	**0.94**
Skewness	0.23	0.30	**0.54**
Kurtosis	-1.07	-0.95	**-0.86**

Table 10: Descriptive statistics for channel elevations (m above ordnance datum). Highest values are in heaviest type.

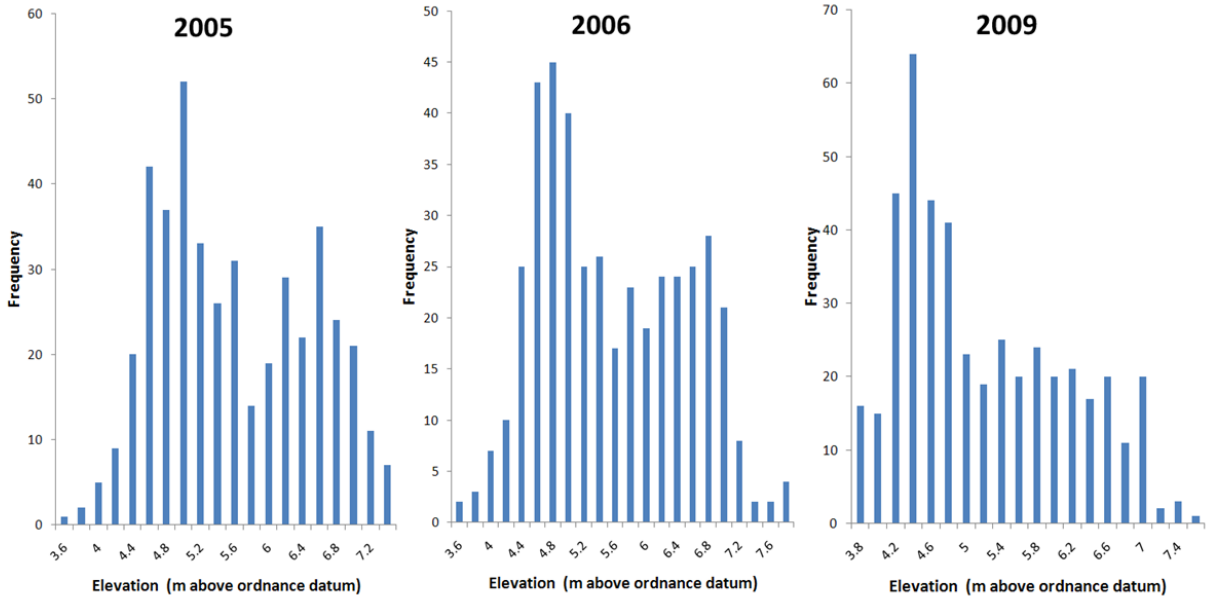

Figure 62: Frequency distributions of channel elevation data.

Discussion

It can be seen that these combined annual datasets are now of comparable size. The maximum and minimum elevation statistics are of limited analytical power owing to the fact that they are only point values, highly sensitive to sampling resolution. This is particularly true in the case of maxima, recorded near the top of the banks which can be quite steep.

There do seem to be distinct trends of decreasing mean and median elevations, perhaps reflecting the evolution of the excavated flat bed to a more concave form, via downward erosion. It is also clear that the variance and standard deviation of bed elevation data have been increasing, reflecting a greater diversity of channel depths, and therefore habitat.

Interestingly, the distributions show an increase in skewness towards deeper measurements, and decreasing platykurtosis, tending towards a more strongly peaked Gaussian distribution (albeit asymmetrical when untransformed), which is more typical of a natural channel. The skew towards deeper channel measurements may reflect the development of a narrower low-flow channel.

In general, the large differences between the 2006 and 2009 datasets demonstrate that, despite the fact that the most dramatic changes in channel morphology occurred within the first year, significant changes are still likely to be taking place.

Appendix B
Velocity and shear profiling

Rationale

Where cross-sections are comparable between years, the effects of their changing shape on the distributions of average velocity and boundary shear stress across the channel can be modeled for different flows. These variables are strong determinants of habitat niche space for plants, invertebrates and fish, and so the second objective of the works – to provide additional habitat diversity – could be interpreted as seeking to increase the range and variance, and perhaps decrease the kurtosis (or at least increase in number of peaks) of these distributions. Such factors are also drivers of morphological change in high flows, and so their approximate range is indicative of the state of such processes.

Methods

Wallingford Software's Conveyance Estimation System (CES) was used to generate these distributions from the five usable sections, together with an approximate roughness distribution (to model the effects of marginal vegetation) (Figure 63). A valuable function of this modeling tool is the ability to visualize the depth-averaged velocity and boundary shear distribution across the channel (Figure 64). For statistical analysis however, probability distributions from the CES outputs (for which data are evenly spaced across the channel) were analyzed for 3 approximate key discharges (adopted from data for the Hardham gauging station (NGR TQ0344017940, approximately 8 km downstream)): the median flow (Q50: 2.32 m s-1); the 95 % exceedance flow, important with respect to habitat provision throughout the year; and the 10 % exceedance flow, more important for hydrogeomorphic processes. Some key outputs are presented below (Figure 65, Figure 66, Table 11, Table 12, Table 13 and Table 14).

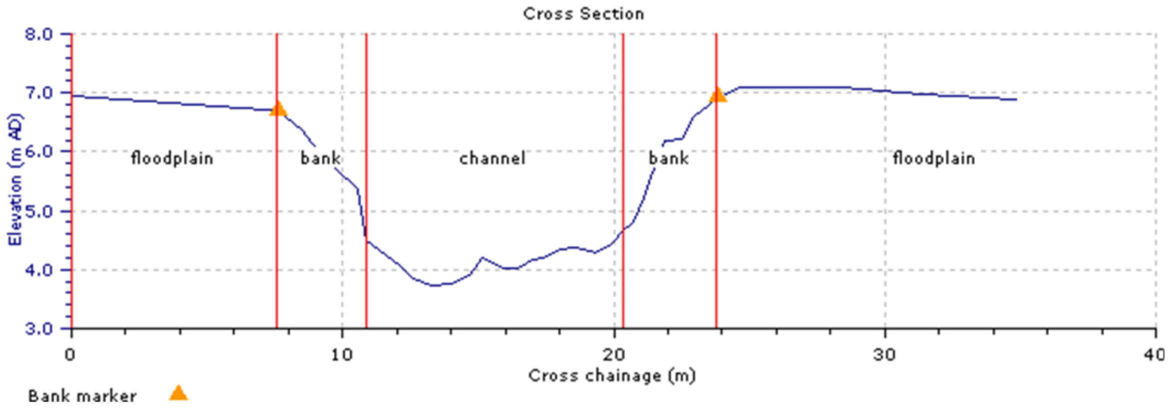

Figure 63: Typical distribution of roughness zones on cross-sections within the CES model.

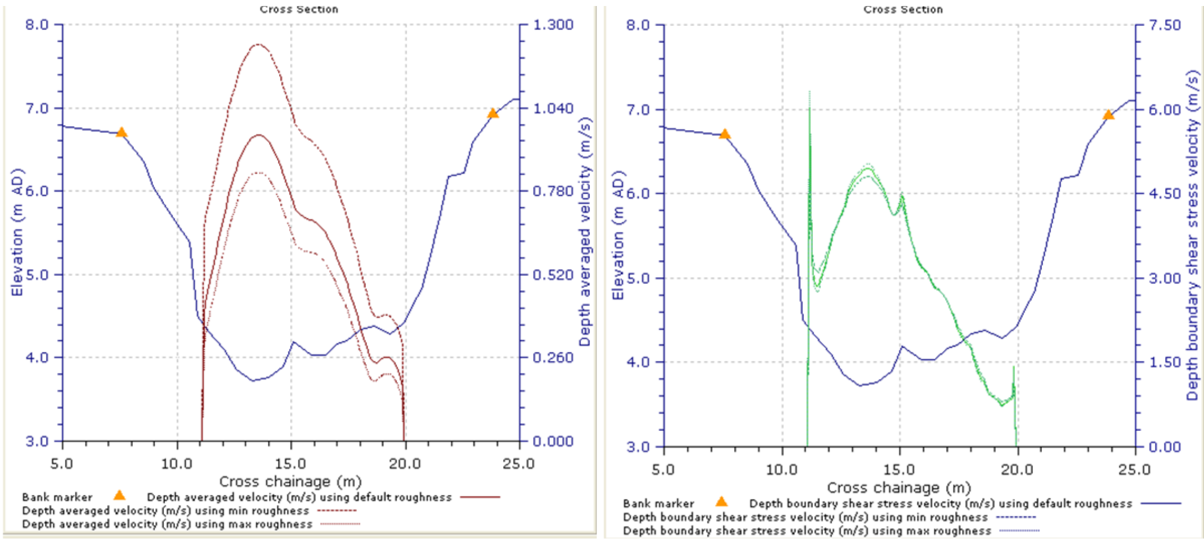

Figure 64: Example CES distribution plots for depth-averaged velocity and boundary shear stress velocity.

Results

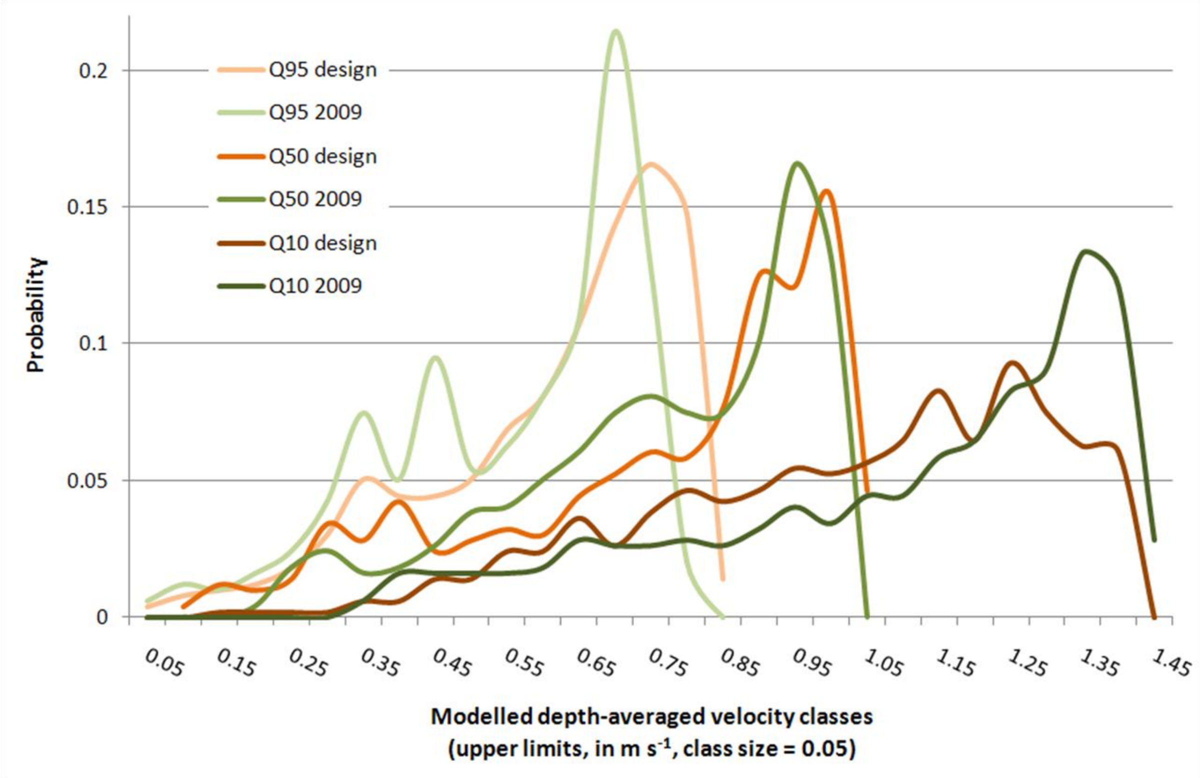

Figure 65: Probability distribution functions for modeled average velocity at 3 important discharges, comparing 5 designed sections to the same 5 in 2009.

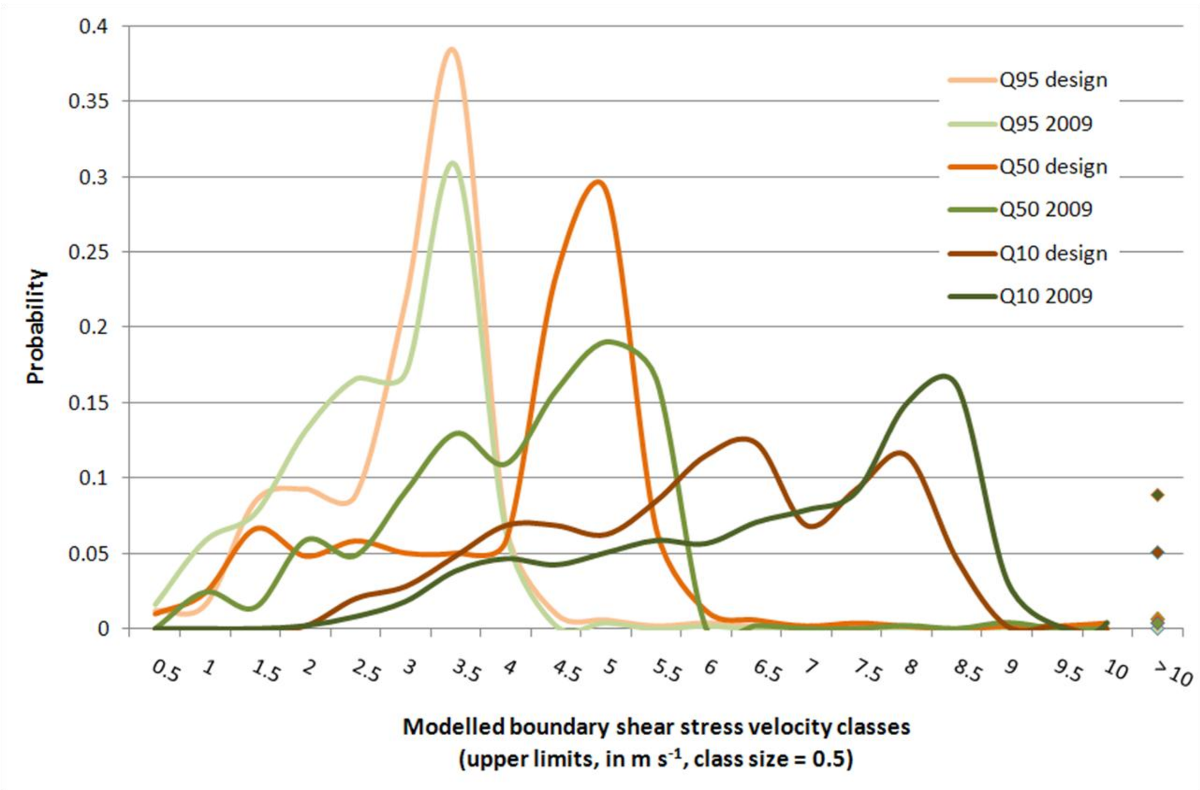

Figure 66: Probability distribution functions for modeled boundary shear stress at 3 important discharges, comparing 5 designed sections to the same 5 in 2009.

Statistic	Design sections		2005		2006		2009	
	Velocity	Shear	Velocity	Shear	Velocity	Shear	Velocity	Shear
Sample size	1485	1485	1485	1485	1485	1485	1485	1485
Maximum	1.37	**79.1**	1.38	50.7	1.37	52.1	**1.41**	51.5
Minimum	0.02	0.09	**0.08**	**0.60**	0.01	0.03	0.02	0.06
Range	1.35	**79.0**	1.30	50.1	1.36	52.1	**1.39**	51.4
Mean	0.77	4.44	**0.79**	4.73	0.78	**4.85**	0.78	4.70
Median	**0.76**	**4.00**	0.74	3.80	0.75	3.84	0.73	3.76
Variance	0.083	13.3	0.087	13.2	0.090	**16.1**	**0.101**	14.9
St[d] deviation	0.29	3.64	0.30	3.63	0.30	**4.01**	**0.32**	3.85
Skewness	0.01	**9.53**	**0.36**	5.02	0.19	4.73	0.24	5.07
Kurtosis	**-0.43**	**156**	-0.73	41.4	-0.59	36.5	-0.66	40.6

Table 11: Summary statistics for aggregated modelled depth-averaged velocity and boundary shear stress data (both m s-1) for Q95, Q50 and Q10 flows. Highest values in heaviest type.

Statistic	Design sections		2005		2006		2009	
	Velocity	Shear	Velocity	Shear	Velocity	Shear	Velocity	Shear
Sample size	495	495	495	495	495	495	495	495
Maximum	**0.80**	**14.7**	0.77	7.60	0.79	10.3	0.75	7.00
Minimum	0.02	0.09	**0.12**	**0.88**	0.01	0.03	0.02	0.06
Range	**0.78**	**14.7**	0.64	6.71	**0.78**	10.2	0.74	6.93
Mean	**0.59**	**2.82**	0.57	2.70	0.56	2.69	0.53	2.51
Median	**0.64**	**2.98**	0.58	2.70	0.60	2.86	0.58	2.66
Variance	0.030	**1.47**	0.020	0.57	**0.033**	1.09	0.030	0.83
St[d] deviation	0.17	**1.21**	0.14	0.76	**0.18**	1.04	0.17	0.91
Skewness	**-0.97**	**3.72**	-0.44	0.80	-0.83	1.20	-0.73	-0.20
Kurtosis	**0.19**	**31.3**	-0.64	3.79	-0.09	10.9	-0.33	0.78

Table 12: Summary statistics for modelled depth-averaged velocity and boundary shear stress (both m s-1) for Q95 flows. Highest values in heaviest type.

Statistic	Design sections		2005		2006		2009	
	Velocity	Shear	Velocity	Shear	Velocity	Shear	Velocity	Shear
Sample size	495	495	495	495	495	495	495	495
Maximum	1.01	20.3	**1.02**	13.7	1.01	**21.6**	0.99	17.8
Minimum	0.07	0.27	0.08	0.60	**0.25**	**1.26**	0.17	0.75
Range	**0.95**	20.1	0.94	14.1	0.76	**20.3**	0.81	17.0
Mean	0.74	3.90	0.74	3.94	**0.75**	**4.03**	0.74	3.90
Median	**0.82**	**4.30**	0.79	4.03	0.80	4.21	0.78	4.12
Variance	**0.058**	3.11	0.038	1.72	0.040	**3.12**	0.041	2.09
St^{d} deviation	**0.24**	1.76	0.20	1.31	0.20	**1.77**	0.20	1.45
Skewness	**-0.85**	2.54	-0.71	1.22	-0.52	**3.85**	-0.82	2.29
Kurtosis	-0.37	21.6	**-0.17**	11.1	-0.90	**31.2**	-0.22	21.8

Table 13: Summary statistics for modelled depth-averaged velocity and boundary shear stress (both m s-1) for Q50 flows. Highest values in heaviest type.

Statistic	Design sections		2005		2006		2009	
	Velocity	Shear	Velocity	Shear	Velocity	Shear	Velocity	Shear
Sample size	495	495	495	495	495	495	495	495
Maximum	1.37	79.1	1.38	50.7	1.37	52.1	**1.41**	51.5
Minimum	0.14	1.85	0.20	1.15	0.15	**2.30**	**0.30**	1.85
Range	**1.23**	**77.2**	1.18	49.6	1.22	49.8	1.11	49.6
Mean	1.00	6.60	1.05	7.56	1.02	**7.83**	**1.08**	7.70
Median	1.05	6.02	1.15	7.01	1.11	6.83	**1.17**	**7.19**
Variance	0.072	27.7	0.084	24.6	**0.090**	**29.9**	0.083	27.2
St^{d} deviation	0.27	5.26	0.29	4.96	**0.30**	**5.47**	0.28	5.22
Skewness	-0.63	**8.19**	**-0.90**	4.16	-0.75	3.85	-0.86	4.34
Kurtosis	-0.37	**92.7**	**-0.24**	24.0	-0.54	21.0	-0.31	24.0

Table 14: Summary statistics for modelled depth-averaged velocity and boundary shear stress (both m s-1) for Q10 flows. Highest values in heaviest type.

Discussion

Examination of the aggregated data (it could be argued that these should be weighted on compilation according to the probability of exceedance, but time did not allow for this) reveals no clear trends in velocity and shear stress minima, maxima, ranges and averages, with the exception of:

- a drop in the peak shear stress from the designed sections, and consequently, a drop in the range of shear stress values,
- a tentative increase in mean shear stresses but…
- a tentative decrease in their median values.

Both points 2 and 3 above would imply the increasing dominance of extreme values (which may or may not be model artefacts), though, interestingly, this is not evident as an increasingly positive kurtosis or skewness as might be expected, suggesting that these peak shear conditions are infrequent.

What is encouraging is that the variances (including the standard deviation) of both shear and velocity distributions appear to have increased, while the kurtosis has become more negative, suggesting a wider, more even spread of hydraulic habitats. An increase in the skewness of the velocity distributions without a concurrent increase in averages hints at greater occurrence of higher velocity flows with an increasingly complex channel section.

When the velocity data for the 3 different exceedance flows are looked at separately, a slight increase in the incidence of relatively higher velocities at lower (Q_{95} and Q_{50}) flows, and a rather distinct increase at the higher, more channel-forming discharge (Q_{10}), is apparent, and reflected by a more negative skewness in the latter. Furthermore, there are new peaks in the frequency of mid-distribution velocities at these lower flows, implying their increasing dominance.

Conversely, the boundary shear stress outputs show a reduced dominance of the most frequent values at low flows, while showing an increase at the Q_{10} discharge. These outputs may suggest a more even distribution of physical habitats at these important, more dominant lower flows, but also a strong capability for erosion at the greater, but more infrequent, Q_{10} flow.

Appendix C
Fixed-point photographs

The full set of scanned slides used in the analysis are supplied on a separate CD in jpeg format.