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Ecological benefits of creating messy rivers

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This study explores the ecological effects of a woody bank revetment in an upper reach of the River Manifold, Staffordshire, UK. Significantly higher abundances of macroinvertebrates were recorded immediately downstream of the deciduous bank revetment compared with a reference site, in 3 out of 4 months surveyed. The watercourse at the revetment also had significantly higher species richness of aquatic fauna than the reference site in some months. While there was no evidence of spatial or temporal variation in aquatic species richness within the reference site during the study period, the species biodiversity of the sub-sample collected from the deciduous revetment zone was more varied: there was significantly higher Ephemeroptera/Plecoptera/Trichoptera (EPT) richness close to the woody bank. Additionally, three relatively rare mayfly species were exclusively associated with the woody revetment (Baetis niger, Ameletus inopinatus and Siphlonorus alternatus). Water temperatures were also found to be lower in close proximity to the revetment. These micro-scale effects suggest that revetments could deliver a range of conservation benefits, not least habitat creation and mitigation of rising river temperatures under climate change.

Key words: *river restoration, macroinvertebrate, species richness, water temperature, River Manifold*

Introduction

Over the past 20 years there has been a changing ethos behind river restoration work, with a shift in emphasis from hard to soft engineering solutions for improving degraded watercourses (Brookes 1996; Holmes 1998; Malakoff 2004; Mainstone and Holmes 2010). The majority of watercourse restoration work has taken place in lowland river systems in order to reinstate flow-habitats lost as a result of river modification schemes during the twentieth century (McCarthy 1985; Brookes 1988; Henry *et al*. 2002; Ormerod 2003).

Given the scale of watercourse restoration work during the past 20 years, few studies have measured the impact of different river rehabilitation techniques on the receiving watercourse ecology (Brookes 1996; Friberg *et al*. 1998; Harrison 2000; Hansen 2001; Mainstone and Holmes 2010). Where ecological investigations of river restoration work have taken place, these studies had largely concentrated on the impacts of artificial riffles or flow deflectors (Pretty *et al*. 2003; Harrison *et al*. 2004; Muotka and Syrjänen 2007). Very few studies have examined the impacts of river works on higher order, higher gradient and more erosive river systems (Harrison *et al*. 2004; Mainstone and Holmes 2010).

Our study examined the micro-scale effects of a bank revetment in the upper reach of the River Manifold, Staffordshire, UK (Plate 1). The revetment comprises soft woody brush cut locally, and pinned by wooden stake and wire to the bank. The River Manifold is a tributary of the River Dove and, like other rivers in this catchment, has a long history of intensive agricultural pressures from cattle and dairy farming (Environment Agency 1999; Everall 2010). However, this study area is outside the documented hot-spots for environmental stress associated with organic enrichment and siltation (Environment Agency 1999; Everall 2010).

The overall objective of the survey was to increase understanding of the extent to which variations in species abundance and richness linked to local modifications in

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Plate 1 The test site (looking up stream) showing a bank side woody revetment in the River Manifold at Ludburn Farm in Staffordshire, UK

Plate 2 The reference site (looking up stream)

channel habitat could contribute to river conservation management at the catchment scale.

Materials and methods

Two field survey sites were chosen in the River Manifold near Ludburn Farm in Staffordshire for the river restoration work study in 2010. The reference site (Plate 1) at 53°9′23.6″N, 1°51′27.58″W (national grid reference SK09517 62200) was approximately 600–700 m upstream of the test site (Plate 2) at 53°9′48.10″N, 1°51′30.40″W (SK09463 62957). Both the reference site and the test site incorporated sections of river corridor where cattle fencing had been in place for at least 1 year prior to the commencement of the field trial. The presence of cattle fencing at both the reference and the test site prevented cattle 'encroachment' impacts during the survey period. The lower 300 m of the study river between the two survey sites has a deciduous woody bank revetment that was installed in the right bank riparian zone in March 2009. The deciduous bank revetment had therefore been in place for 15 months prior to the commencement of our field surveys.

The reference river site contained a moderate amount of natural woody structure in the form of tree roots and was considered hydraulically independent of the test section of watercourse given the distance between the two survey areas. The reference site was chosen to represent the channel form that existed in the rehabilitated section of watercourse before the installation of deciduous bank revetment.

Macroinvertebrates were sampled monthly at the revetment and reference sites from spring to autumn 2010 on 12 May, 22 June, 25 August and 17 September. Watercourse sampling was only carried out when the river bed visibility was good and water turbidity was low. Flow-habitat for macroinvertebrate sampling was limited to riffle-tree roots at the reference site and riffle-deciduous bank revetment at the test site due to the absence of any other in-stream or marginal habitat at the study sites such as macrophytes.

On each sampling visit, ten 0.1 m^2 Surber net samples were taken, with eight from riffles and two from either immersed tree roots at the reference site or two from within the right bank woody revetment and eight from riffle areas at the test site. The sampling regime was stratified by the percentage of surface habitat cover with approximately 20 per cent of the river marginal zone comprising immersed tree root at the reference site or bank revetment at the test site. Sampling was carried out using a short-handled Surber net fitted with a 0.5 mm mesh. The 10 Surber net samples taken on each sampling occasion at each site were pooled to provide five composite 0.2 m^2 macroinvertebrate samples from both the reference and the test site per monthly visit.

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All macroinvertebrate samples were preserved in the field in 70 per cent industrial denatured alcohol followed by macroinvertebrate sorting and identification in the laboratory, generally to species level. The order of macroinvertebrate sample sorting and identification was altered between all of the composite 0.2 m^2 samples to reduce observer drift. Some taxa were identified to order (e.g. Hydracarina), family (e.g. Oligochaetes), sub-family (e.g. Orthocladiinae) or genus (e.g. *Simulium* and *Hydroptila*). In-stream temperature recordings were taken at 30-minute intervals at the test site on 30 August 2010 using a portable waterproof meter (HANNA H19146).

Paired t-tests were then used to examine the statistical significances of differences in Ephemeroptera/Plecoptera/Trichoptera (EPT) richness (Kiffney and Clements 1996; Brown *et al*. 2009) and overall animal abundance and average score per taxon (ASPT) (Hellawell 1986) between/within the revetment and reference sites.

Results

The biometric measurements for the macroinvertebrate data collected from the River Manifold in 2010 are summarised in Tables 1 and 2.

It is evident from Table 2 and Figure 1 that there was a significantly ($P \leq 0.05$) higher abundance of macroinvertebrates in the River Manifold downstream of the deciduous bank revetment when compared with the reference site, in 3 out of 4 months surveyed.

In May and September 2010, macroinvertebrate surveys in the receiving watercourse at the test site produced a significantly ($P < 0.05$) higher species richness of aquatic fauna than the reference site, as shown in Table 2 and Figure 2.

There was no significant difference between the reference and test site species richness in June and August 2010. Macroinvertebrate sub-sample data for species richness are plotted as a cross-sectioned representation of the flow-habitats in the river channel at the reference and test sites in Figures 3 and 4 respectively. Site 1E sub-sample was bank-side in the stream bed below the woody revetment and 1D, 1C, 1B and 1A were the remaining mid-channel transect.

There appeared to be no marked spatial or temporal differences in species richness at the reference site over the 5-month study period in 2010, as shown in Figure 3. However, macroinvertebrate species richness was greatest close to the deciduous revetment zone at the test site at 2D and 2E during the sampling period (Figure 4).

Table 1 Summary of macroinvertebrate biometric data for the reference site in the River Manifold in 2010

River Manifold reference site: SK09517 62200							
	Site 1A	Site 1B	Site 1C	Site 1D	Site 1E		
Summary biometrics	Riffle	Riffle	Riffle	Riffle-glide	Riffle-glide-tree root	Mean	95% CL
12 May 2010							
No. animals 0.2 m^{-2}	162	177	164	175	227	181	32.96
ASPT	6.13	6.33	5.67	6.15	6.56	6.17	0.41
Species richness (R)	21	16	21	16	21	19	3.4
EPT richness	11	8	11	10	11	10.2	1.62
22 June 2010							
No. animals 0.2 m^{-2}	225	205	228	210	223	218.2	12.52
ASPT	6.06	6.82	6.5	7	6.71	6.62	0.45
Species richness (R)	22	16	26	14	24	20.4	6.43
EPT richness	11	9	13	10	11	10.8	1.84
25 August 2010							
No. animals 0.2 m^{-2}	304	271	294	381	246	299.2	63.21
ASPT	5.47	4.81	5.57	4.63	4.94	5.08	0.52
Species richness (R)	27	23	27	24	25	25.2	2.22
EPT richness	9	6	10	7	7	7.8	2.04
17 September 2010							
No. animals 0.2 m^{-2}	138	170	179	181	149	163.4	23.63
ASPT	4.92	5.64	4	4.64	4.77	4.79	0.73
Species richness (R)	17	17	22	17	16	17.8	2.96
EPT richness	7	8	4	6	5	6	1.96

Notes: ASPT: average score per taxon; CL: confidence limit; EPT: Ephemeroptera/Plecoptera/Trichoptera. Sites 1A to 1D are riffle areas, and Site 1E is the bank margin

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Table 2 Summary of macroinvertebrate biometric data for the revetment (test) site in the River Manifold in 2010

River Manifold test site: SK09463 62957							
	Site 2A	Site 2B	Site 2C	Site 2D	Site 2E		
Summary biometrics	Riffle	Riffle	Riffle	Riffle-glide	Riffle-glide-woody revetment	Mean	95% CL
12 May 2010							
No. animals 0.2 m^{-2}	369	294	403	445	369	376**	68.89
ASPT	6	6.29	6.39	6.12	5.94	6.15	0.24
Species richness (R)	22	23	26	25	25	24.2*	2.04
EPT richness	11	14	15	14	13	13.4*	1.88
22 June 2010							
No. animals 0.2 m^{-2}	359	412	483	423	478	431***	63.68
ASPT	6.6	6.56	7.18	6.85	6.87	6.81	0.31
Species richness (R)	20	22	24	30	21	23.4	4.94
EPT richness	12	12	14	15	12	13*	1.76
25 August 2010							
No. animals 0.2 m^{-2}	361	340	307	270	264	308.4	52.73
ASPT	5.93	6.07	6.59	5.65	5.94	6.04***	0.43
Species richness (R)	23	19	24	29	23	23.6	4.44
EPT richness	10	8	11	10	11	10*	1.52
17 September 2010							
No. animals 0.2 m^{-2}	257	192	225	216	242	226.4*	30.87
ASPT	6.29	5.73	5.67	5.91	6.35	5.99*	0.39
Species richness (R)	24	23	23	35	28	26.6*	6.37
EPT richness	10	10	8	17	14	11.8*	4.51

Notes: ASPT: average score per taxon; CL: confidence limit; EPT: Ephemeroptera/Plecoptera/Trichoptera. Sites 2A to 2D are riffle areas, and Site 2E is the bank margin. Asterisks indicate a statistically significant difference between treatments (i.e. the reference and the test site) based on a two sample t-test where * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$

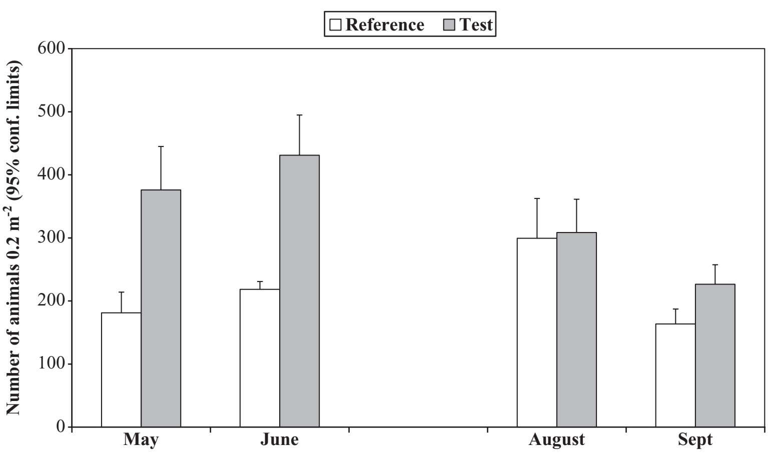

Figure 1 Macroinvertebrate abundance at the reference and test woody revetment sites in the River Manifold in 2010. The columns show the mean and the bars the 95% confidence limits

The EPT richness of aquatic macroinvertebrate communities is another useful biometric for measuring the ecological quality of upland watercourses (Kiffney and Clements 1996; Brown *et al*. 2009). It is also a biometric that has a strong association with the sentinel pollution monitoring regime employed by the National Riverfly Partnership Recording Scheme (see http://www.riverflies.org/index/riverfly-surveys.html). As shown in

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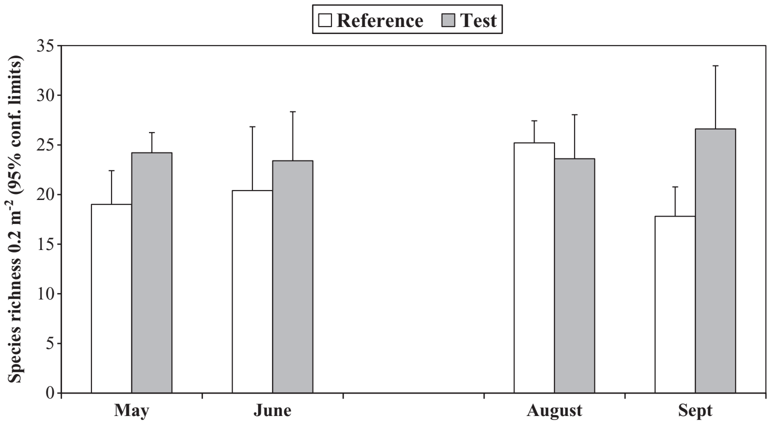

Figure 2 Species richness (R) at the reference and test woody revetment sites in the River Manifold in 2010. The columns show the mean and the bars the 95% confidence limits

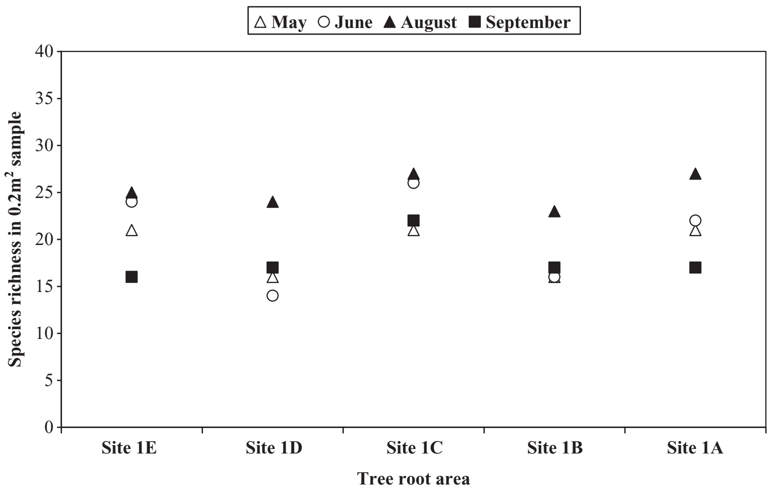

Figure 3 Macroinvertebrate species richness in the River Manifold at the reference site upstream of the woody revetment in 2010. Species richness across the river channel at the reference site from Site 1A to 1E

Figure 5, there was significantly ($P < 0.05$) higher EPT richness in the presence of woody bank revetment when compared with the reference site in all survey months in 2010. The higher EPT richness was due to greater numbers of mayfly, stonefly and caddis fly species in sub-samples collected from the test bank revetment zone.

Three notable species of mayfly were recorded within the 10 macroinvertebrate samples associated with woody revetment from the test site during the 2010 survey work that were not found in a total of 40 reference site samples. The three mayfly species were *Baetis niger*, *Ameletus inopinatus* and *Siphlonorus alternatus*. Some of these montane species may be indicative of cooler, *in situ* water temperatures.

River water temperatures were taken at 30-minute intervals in the variable flow habitats of the test site from 0900 to 1900 hours on 30 August 2010 and the data are shown in Figure 6. During the 10-hour monitoring period cooler water temperatures were recorded within the deciduous revetment when compared with the temperature data from the adjacent main river channel. The average temperate difference between the water within the shaded woody revetment and the open mid-channel was approximately 1.0°C.

The ASPT is a simple pollution index that was calculated from the macroinvertebrate community data to provide some measure of environmental stress at the study sites. For example, a macroinvertebrate community under stress from pollutants will exhibit a lower ASPT value than faunal communities from a 'healthy' watercourse. The ASPT at the reference and test site were not significantly different in the May and June 2010 macroinvertebrate

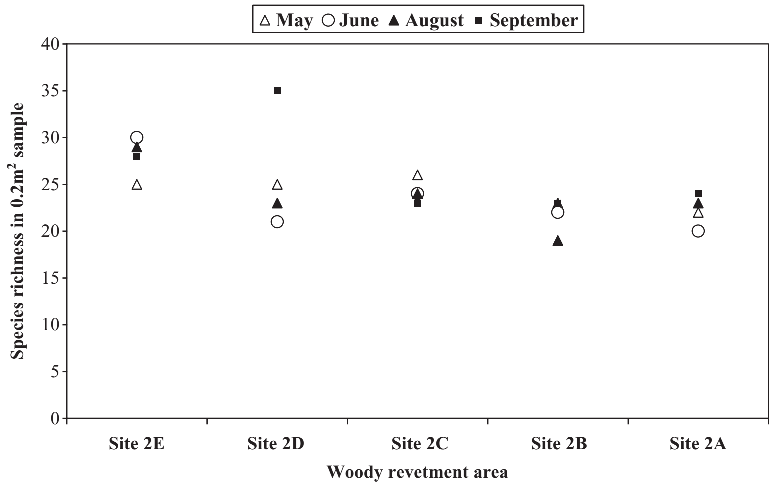

Figure 4 **Macroinvertebrate species richness in the River Manifold at the test woody revetment site in 2010. Species richness across the river channel at the test site from Site 2A to 2E**

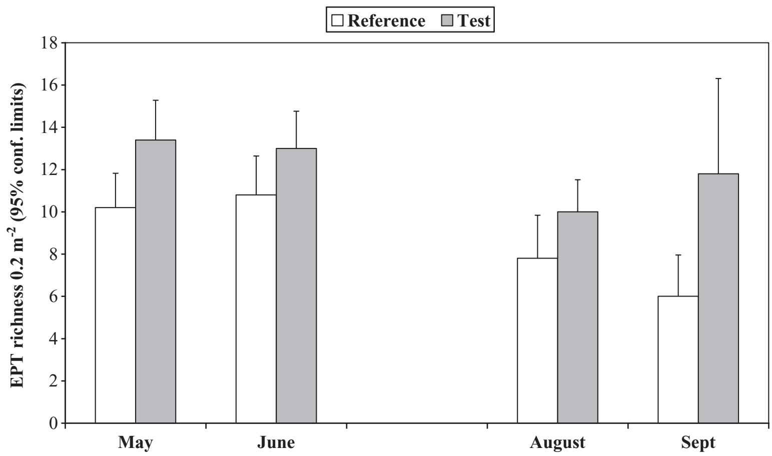

Figure 5 **EPT richness at the reference and test woody revetment sites in the River Manifold in 2010. The columns show the mean and the bars the 95% confidence limits**

surveys (Figure 7). However, both the reference and test site values were depressed in August and September. During these months the downstream test site ASPT was significantly ($P \leq 0.05$) higher than the upstream reference site (Figure 7). This could indicate that conditions at the revetment site are ameliorating unspecified seasonal stressors, such as reduced depth of flow.

Discussion

Aquatic macroinvertebrates form a fundamental component of watercourse ecosystems such that increasing the macroinvertebrate abundance and diversity strengthens the ecological integrity of watercourses (Spänhoff and Arle 2007). Many workers in the field of river restoration have argued that such ecological end-points should be one of many restoration and conservation objectives for such rehabilitation work (Mainstone and Holmes 2010). Although based on limited data, our survey of a reach in the River Manifold suggests that deciduous revetments could contribute to these ecological objectives in upland watercourses. However, further work is clearly needed to establish whether the observed ecological benefits are evident in other reaches and persist over time and after exposure to more environmental conditions and stressors.

A significant increase in the macroinvertebrate biodiversity of the rehabilitated reach of the River Manifold was attributed to the presence of approximately 300 m of deciduous bank revetment. Marginal and riparian habitats have been documented to be rich in terrestrial and

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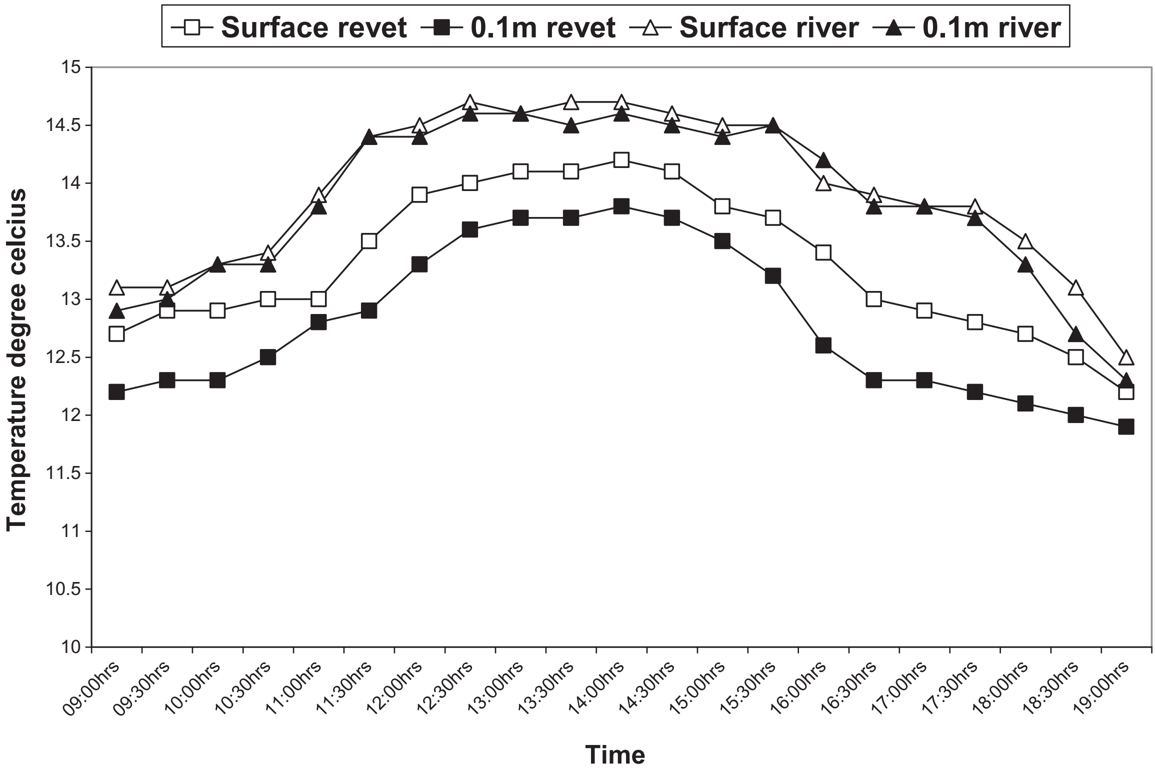

Figure 6 Water temperatures in the River Manifold on 30 August 2010 at the test woody revetment site. Temperature measurements within the bank woody revetment structure at the test site are marked 'revet' in the plots. 0.1m is depth from surface of the river

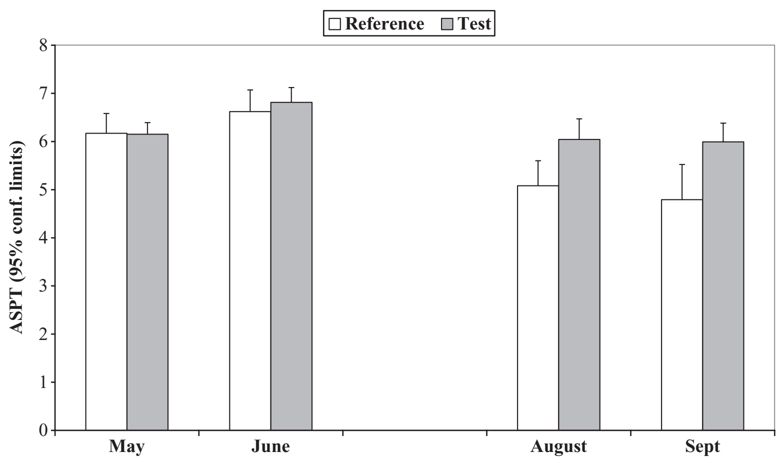

Figure 7 ASPT at the reference and test woody revetment sites in the River Manifold in 2010. The columns show the mean and the bars the 95% confidence limits

semi-aquatic species, to the extent that they have an important impact on the functional structure and diversity of watercourse ecosystems (Hynes 1970; Harrison *et al*. 2004). In a similar manner, the marginal woody revetment in the River Manifold appeared to act as a surrogate for marginal macrophytes, and exhibited ecological benefits in terms of macroinvertebrate biodiversity, otherwise reported in the presence of natural marginal habitat

(Harrison and Harris 2002; Harrison *et al*. 2004). Open structured woody revetment in the River Manifold appeared to behave in a similar way to logs when added to streams, which Johnson *et al*. (2003) reported were rapidly colonised by invertebrates, and that such habitat alteration was accompanied by changes in community composition and functional processes. While anecdotal, it is worth reporting that on all macroinvertebrate sampling occasions throughout the 2010 survey work in the River Manifold, bullhead (*Cottus gobio*), stoneloach (*Barbatula barbatula*), minnow (*Phoxinus phoxinus*) and brown trout (*Salmo trutta*) were inadvertently captured in the deciduous revetment. Only bullhead (*Cottus gobio*) were occasionally captured using the same surveying techniques in riffles near to the revetment structures during the 2010 survey work.

Although cattle fencing was present at both test sites in the Manifold study, such structures have been shown to protect and encourage riparian habitat (Harrison and Harris 2002) and the fencing may have provided an important secondary function in protecting surrogate macrophyte habitats in these upland watercourses. The primary role of cattle fencing in the rivers of the Upper Dove Catchment, like the River Manifold, is to prevent cattle encroachment and ameliorate anthropogenic sediment input to these watercourses (Everall 2010). Further research is needed to establish whether woody revetments yield the same ecological benefits at sites without cattle fencing.

Mayfly species have been shown to have very distinct habitat preferences (Elliott *et al*. 1988) and could therefore demonstrate how micro-habitat variables influence macroinvertebrate communities on a small scale. Mayfly, stonefly and caddis fly biodiversity appeared to benefit from the presence of woody revetment in the upper River Manifold as highlighted by raised EPT richness in these areas of the watercourse. Three relatively rare mayfly species were exclusively associated with woody revetment in the River Manifold study. Given the moderate level of sampling, it was probable that differences between the reference and revetment-treated stretch of watercourse were due to habitat variation rather than chance. However, the interaction of non-habitat factors requires further investigation, because the meta-population structure of these mayflies in the Dove catchment has not been thoroughly investigated (Everall 2010), and the dispersal mechanisms of many aquatic macroinvertebrates is still poorly understood (Wilcock *et al*. 2001; Berendonk and Bonsall 2002).

Given the evident ecological benefits afforded by the introduction of woody bank revetment into the River Manifold, there is an important question of whether or not these effects would prove self-sustaining, or require on-going management and repair. It is therefore important to continue these types of study to further our understanding of river habitat management outcomes. Despite similar pleas from other workers for the long-term assessment of river restoration outcomes (Zedler 2000; Hansen 2001), after 20 years there may be objective criteria for success (Palmer *et al*. 2005) but still no standardised protocols for doing so (National Research Council 1992; Jähnig *et al*. 2011).

As several workers have pointed out, the climate change agenda provides an important driver for river restoration in respect of mitigation and adaptation strategies (Battarbee *et al*. 2008, Mainstone and Holmes 2010; Wilby *et al*. 2010). Preliminary results from the River Manifold suggest that large-scale marginal woody revetment has the potential to mitigate rising river temperatures by increasing riparian shade and/or contact time with the cooler structure. The importance of riparian tree canopy in maintaining cool in-stream water temperature in lowland rivers has previously been documented (Broadmeadow *et al*. 2009; Wilby *et al*. 2010). The fact that deciduous woody revetment appeared to provide larger ecological benefits than tree-root habitat in the River Manifold, while still providing a water-cooling effect akin to riparian canopy, raises some interesting questions about the future management of marginal areas in upland watercourses and the sustainability debate over woody revetment. Despite evidence that deciduous bank revetments could provide climate space for some cooler water macroinvertebrate species (Mainstone and Holmes 2010), one needs to take a holistic view of river management objectives.

With a general lack of field evidence to support adaptive management of rivers under climate change (Wilby *et al*. 2010), as well as limited specific understanding of the ecological benefits of riparian revetment over time, it may be wise to employ a habitat mosaic approach to managing the marginal in-stream areas of upland watercourses. In other words, by creating messy rivers we may be creating an assemblage of habitats that is more resilient to climate change. However, further research is needed to provide quantitative evidence of the long-term success of these river restoration measures in upland watercourses. Furthermore, detailed macroinvertebrate monitoring of upland watercourses such as the upper Dove catchment could also provide important benchmark ecological data to assist Water Framework Directive assessments in areas where routine biological monitoring by regulatory bodies may be sparse (Everall 2010).

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