INTEGRATED BIO-GEOMORPHOLOGY INVESTIGATION
YEADING BROOK WEST IN HARROW

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SUMMARY

We sampled macroinvertebrates, physical (including vegetation structural) habitats and water quality at 8 sites along Yeading Brook West. Two sites were sampled within each of four reaches: Headstone Manor, Yeading Walk, Streamside, Roxbourne. The two sampling sites corresponded to locations that scored lowest (L) and highest (H) in River Condition Assessments of contiguous 100 m sections of the entire channel length within the reach.

Our survey data reveals a general increase in electrical conductivity and pH from upstream to downstream through the eight sites, whereas dissolved oxygen initially falls from Headstone Manor to Yeading Walk and then rises from that point downstream.

Despite the generally overdeep and narrow river channels that are present within the four reaches, we observed diverse hydraulic habitats and diverse patches of bed material of different size classes at each of the sampling sites. There were some superficial silt deposits across the bed at almost all sites and all sites showed some bed reinforcement in the form of boulder-sized pieces of washed out reinforcement materials (bricks, concrete blocks, etc.). In terms of physical habitats, most sampling sites displayed the number of pools and riffles that would be expected in a gravel-sand river. Despite the confined, deep channels, some marginal physical habitats (backwaters, side bars, berms and benches) were observed. The riparian vegetation structure across the bank faces was diverse and varied between sampling sites, with a good range of tree-related features indicating that the riparian vegetation was functioning naturally within the constraints of these overdeep channels. There were also variable extents of aquatic vegetation, mainly mosses and emergent linear-leaved plants, along the channel/water margins.

The macroinvertebrate samples yielded over 27000 individuals from 39 taxa (for full details see Table 4). When we computed rank correlations between both the number of individuals and the number of taxa and individual water quality and physical habitat variables, a range of statistically significant correlations were identified, indicating some dependence of macroinvertebrates on elements of their physical and water quality environment. These associations are detailed in Section 4.

Together, these results highlight the complex and multifaceted links between physical stream habitat and the abundance and diversity of stream macroinvertebrate communities. Despite the small sample size, water quality (electrical conductivity, dissolved oxygen) appears to be influencing macroinvertebrates at the sampling sites. Amongst the physical habitats, bed material size, superficial siltation, and pool-riffles all show notable associations with macroinvertebrates, and bank face vegetation, particularly unvegetated areas and areas under trees/saplings/shrubs and scrub, also appear to be influential.

Future monitoring that adopts the approach used here will increase the statistical power of the analyses and likely uncover further important links between these variables. Furthermore, future monitoring that incorporates additional biological groups (e.g. fish assemblages), or more detailed water quality assessments would be instructive for gaining a more holistic understanding of the ecological health of Yeading Brook West prior to restoration.

1. BACKGROUND

We report on the outcomes of a combined biological and physical habitat investigation of sites along the Yeading Brook West within Harrow. The following are key factors that influenced the work undertaken:

- The investigation was undertaken prior to any restoration interventions and at a time when precise restoration locations and measures yet to be finalised.
- The investigation builds on detailed physical habitat and River Condition Assessments conducted in 2023 (Gurnell et al., 2023).
- In terms of ‘biology’, we focused on the macroinvertebrate community occupying the bed of the Brook.
- Because water quality is known to influence macroinvertebrate communities as well as physical habitat, we measured three summary water quality indicators (electrical conductivity, pH and dissolved oxygen) at the sites where macroinvertebrates were sampled.
- Because flow disturbances are also important controls on macroinvertebrate communities, we sampled all sites for macroinvertebrates and water quality on the same day and during a period of low flow. We also recorded physical habitats within 24 hours of completing the macroinvertebrate and water quality sampling.

2. METHODS

2.1 Sampling sites

At the time field surveys for this investigation were carried out, precise locations for restoration interventions were unknown. Therefore, we based our sampling design on information concerning the range in stream physical condition identified from MoRPh surveys that had previously been recorded by Gurnell et al. (2023) along the four reaches of the Upper Yeading Brook being considered for restoration interventions (Figure 1).

The red lines shown on Figure 1, delimit the four reaches of Upper Yeading Brook West that were the focus of the present pre-restoration study. Throughout this report, we will refer to these red-line reaches as Headstone Manor, Yeading Walk, Streamside and Roxbourne. At Headstone Manor, the red line (Figure 1) extends northwards beyond the 2023 MoRPh surveys. During June 2024, we conducted additional MoRPh surveys in this upstream part of the reach (Figure 1) to give complete MoRPh survey coverage (a total of 120 MoRPh surveys) of the four reaches.

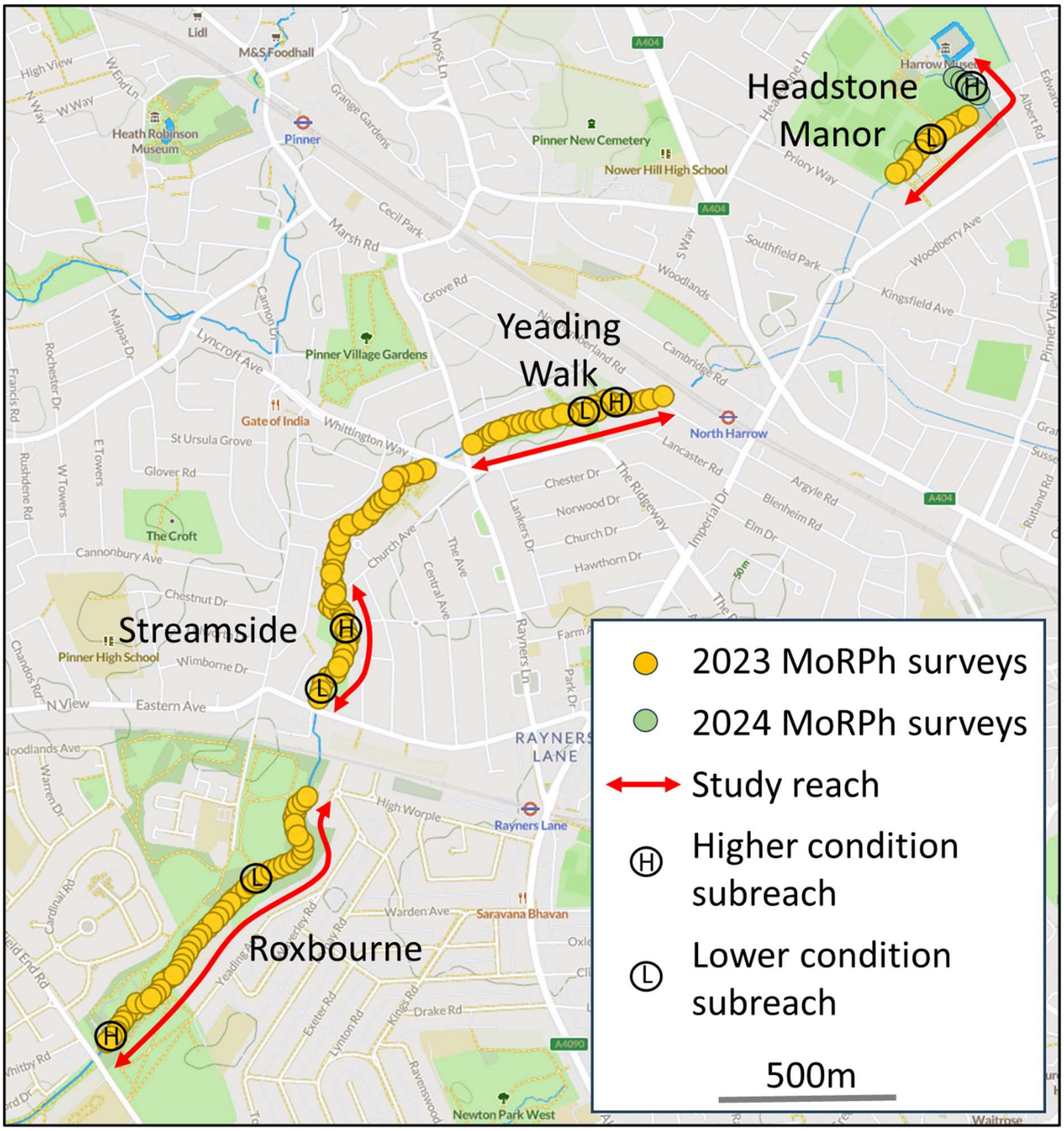

Figure 1: The four reaches (from Headstone Manor (upstream) to Roxbourne (downstream)) considered in this investigation in relation to the 142 20m long MoRPh surveys conducted in 2023.

To select the sampling sites for the present research, we considered the physical 'condition' of the Brook within each of the four reaches. We used the River Condition Assessment (RCA, Gurnell et al., 2020) to assign condition scores to 100 m long channel lengths (i.e. 5 MoRPh surveys or a MoRPh5 survey). From the 32 Condition Indicator Scores computed for each MoRPh5 survey, we extracted three integrated Condition Scores for different parts of the stream channel: (i) the entire stream channel (bank tops, bank faces, water edges, stream bed); (ii) just the bank faces, water edge and bed; and (iii) the water edge and bed only. While the RCA is designed to provide Condition Score (i), Condition Score (iii) is likely to be most relevant for macroinvertebrate communities since they inhabit the channel bed. Based on these three Condition Scores (particularly Condition Score (iii)) we selected the two MoRPh5 subreaches that scored lowest (L) and highest (H) in each of the four reaches. This gave us a total of 8 subreaches within which to conduct field sampling and surveys.

2.2 Field survey

We inspected each of the 8 MoRPh5 subreaches in the field to identify a representative site for sampling. Each site was defined by two MoRPh surveys (i.e. a 40 m subreach length). The eight sampling sites are referred to by their reach name (Headstone Manor, Yeading Walk, Streamside, Roxbourne) followed by H or L depending upon whether they are located within the higher (H) or lower (L) scoring MoRPh5 subreach (the H and L sampling sites are indicated in Figure 1).

At each sampling site, water quality measurements were made at a single free-flowing location, macroinvertebrate samples were collected across a ~30 m length of channel, and two MoRPh surveys recorded contemporary physical habitat conditions across a 40 m channel length enclosing the ~30 m length sampled for macroinvertebrates.

We visited each of the 8 sampling sites on 4th June 2024, following a dry period, to gather macroinvertebrate samples and water quality measurements (electrical conductivity, pH, dissolved oxygen). Water quality probes were placed in free-flowing water and left to stabilize while kick sampling was used to collect a macroinvertebrate sample. An average was computed from three measurements of each of electrical conductivity, pH and DO. Macroinvertebrates were surveyed following the Environment Agency standard sampling protocol (Environment Agency, 1997). Each reach was sampled representatively along its whole length, ensuring that all habitats present were sampled with a standard size D-frame net (500-µm mesh aperture). A total sampling time of three minutes was used, with a further one minute spent inspecting submerged habitats, such as logs and larger stones, for attached animals. For areas of sand, gravel, or cobbles, kick sampling was employed whereby the substrate was disturbed with the foot and the invertebrates washed into the net held downstream. The emergent vegetation and submerged tree roots were sampled using vigorous repeated passes of the net through the habitat. Samples were preserved using 70% IMS (industrial methylated spirits) and later sorted in the laboratory, where the invertebrates were extracted and counted. All invertebrates were identified to species where life history stage allowed, with the exception of the Dipteran families, which were typically identified to subfamily or genus level as is standard for this group. Where counts for a particular taxon exceeded one hundred, subsampling was used to carry out the identification. A subsample of fifty individuals was extracted and identified and the total count then pro-rata'd if it was found that more than one species was present (Environment Agency, 2012). On 5th June 2024, each of the sampling sites was revisited to conduct the two MoRPh surveys.

2.3 Sample and Data analysis

The MoRPh surveys were uploaded into the Cartographer information system. The macroinvertebrate, MoRPh and water quality observations were entered into an Excel spreadsheet for analysis.

Sample-size based diversity curves were constructed for the macroinvertebrate (kick sampling) using the iNext package in R (Hsieh et al. 2017). This approach models the cumulative number of taxa as a function of increasing number of individuals in a sample and therefore provides a robust way of comparing diversity where sample sizes differ (Perkins et al. 2021). Sample-size independent estimates of taxon richness can be achieved by extrapolating the diversity curve to a larger sample size, guided by an estimated asymptotic diversity (Perkins et al. 2021). As recommended, we extrapolated the diversity curves (and 95% confidence intervals around the estimated values) up to double the smallest sample size or the largest observed sample size, whichever was larger (Hsieh et al. 2017). We then compared the estimates of richness and confidence intervals at these fixed sample sizes (Table 1). If the 95% confidence intervals do not overlap for any given sample size in the comparison range, then significant differences among the estimates are guaranteed at a level of 5% (Hsieh et al. 2017).

3. RESULTS

3.1 Selection of sampling sites

All three Condition Scores described in Section 2.1 were computed for all 24 MoRPh5 subreaches and were ranked from highest score (rank 1) to lowest score (rank 24) (Table 1). Condition Score (iii), which focuses on the channel bed and water margins, was used to guide selection of the subreaches within which sampling would be undertaken. At Yeading Walk, Streamside and Roxbourne, the highest and lowest scoring MoRPh5 subreaches were selected. At Headstone Manor, very similar high scores were achieved in two subreaches (subreach 1, Condition Score (iii) = 0.91; subreach 4, Condition Score (iii) = 0.94). Although the score for subreach 4 was slightly higher, subreach 1 was selected for sampling in preference to 4. This was because the subreach had been subject to restoration and as a result its vegetation cover provided contrasts with the remaining 23 MoRPh5 subreaches. In particular, the subreach had few riparian trees and extensive aquatic vegetation along the water margins, offering an opportunity to widen the habitat characteristics offered by the eight selected MoRPh5 subreaches while also representing a high Condition Score for the Headstone Manor reach.

Table 1: The 24 subreaches listed from upstream (top) to downstream (bottom) along Yeading Brook West, showing Condition Scores (i) the bank tops, bank faces, water margins and bed, (ii) the bank faces, water margins and bed, and (iii) the water margins and bed. The rank of each subreach is listed for each Condition Score.

Reach	MoRPh5 subreach (numbered upstream to downstream)	Bank Top-Bank Face-Water Edge-Bed Condition Score (i)	Condition Score rank (1=high)	Bank Face-Water Edge-Bed Condition Score (ii)	Condition Score rank (1=high)	Water Edge-Bed Condition Score (iii)	Condition Score rank (1=high)	Subreach selected for sampling
Headstone	1	0.65	21	0.92	18	0.91	8	H
	2	1.11	10	1.34	8	0.50	13	
	3	0.31	23	0.47	23	0.39	18	L
	4	0.71	19	1.09	13	0.94	6	
Yeading Walk	1	0.94	14	1.11	12	0.91	7	
	2	1.79	1	1.77	1	1.26	1	H
	3	0.45	22	0.72	21	0.63	11	L
	4	1.22	8	1.47	5	0.96	5	
	5	1.14	9	1.32	9	1.10	3	
	6	1.00	12	1.15	11	0.63	12	
Streamside	1	0.81	17	0.84	20	0.29	20	
	2	1.40	4	1.53	4	0.43	14	H
	3	1.01	11	1.07	14	-0.34	24	L
	4	1.29	7	1.26	10	0.43	15	
Roxbourne	1	0.70	20	0.68	22	-0.29	23	
	2	0.96	13	0.95	17	0.39	17	
	3	1.57	2	1.74	2	1.04	4	
	4	0.85	16	1.01	15	0.41	16	
	5	0.14	24	0.07	24	-0.19	22	L
	6	0.80	18	0.86	19	0.33	19	
	7	0.87	15	1.01	16	0.03	21	
	8	1.35	5	1.41	7	0.87	9	
	9	1.33	6	1.42	6	0.74	10	
	10	1.50	3	1.60	3	1.16	2	H

3.2 Water Quality

Table 2 lists the three observations of electrical conductivity, pH and dissolved oxygen that were obtained from each sampling site. Figure 2 shows the average values of these measures for each site, revealing a downstream increase in electrical conductivity and pH (increasingly alkaline) and an initial fall in dissolved oxygen to Yeading Walk followed by a rise.

Table 2: Electrical conductivity, pH and dissolved oxygen observation in the 8 subreaches during 4th June 2024.

	Headstone Manor		Yeading Walk		Streamside		Roxbourne	
Condition Score (iii) (L or H)	**H**	**L**	**H**	**L**	**H**	**L**	**L**	**H**
Electrical conductivity (µS.cm^{-1})								
Observation 1	713	786	849	816	936	893	981	1023
Observation 2	751	765	855	830	913	929	972	1021
Observation 3	630	769	845	846	922	890	989	1009
Average	**698**	**773**	**850**	**831**	**924**	**904**	**981**	**1018**
pH								
Observation 1	7.11	7.50	7.49	7.81	7.64	7.71	7.61	7.83
Observation 2	7.12	7.51	7.49	7.73	7.64	7.69	7.60	7.82
Observation 3	7.17	7.51	7.49	7.79	7.65	7.69	7.60	7.78
Average	**7.13**	**7.51**	**7.49**	**7.78**	**7.64**	**7.70**	**7.60**	**7.81**
Dissolved oxygen (% saturation)								
Observation 1	54.0	55.6	38.3	49.8	54.9	59.7	59.8	53.1
Observation 2	62.0	51.8	41.8	51.6	59.1	51.4	62.4	61.3
Observation 3	65.0	55.0	48.6	51.0	51.8	50.3	59.4	60.6
Average	**60.3**	**54.1**	**42.9**	**50.8**	**55.3**	**53.8**	**60.5**	**58.3**

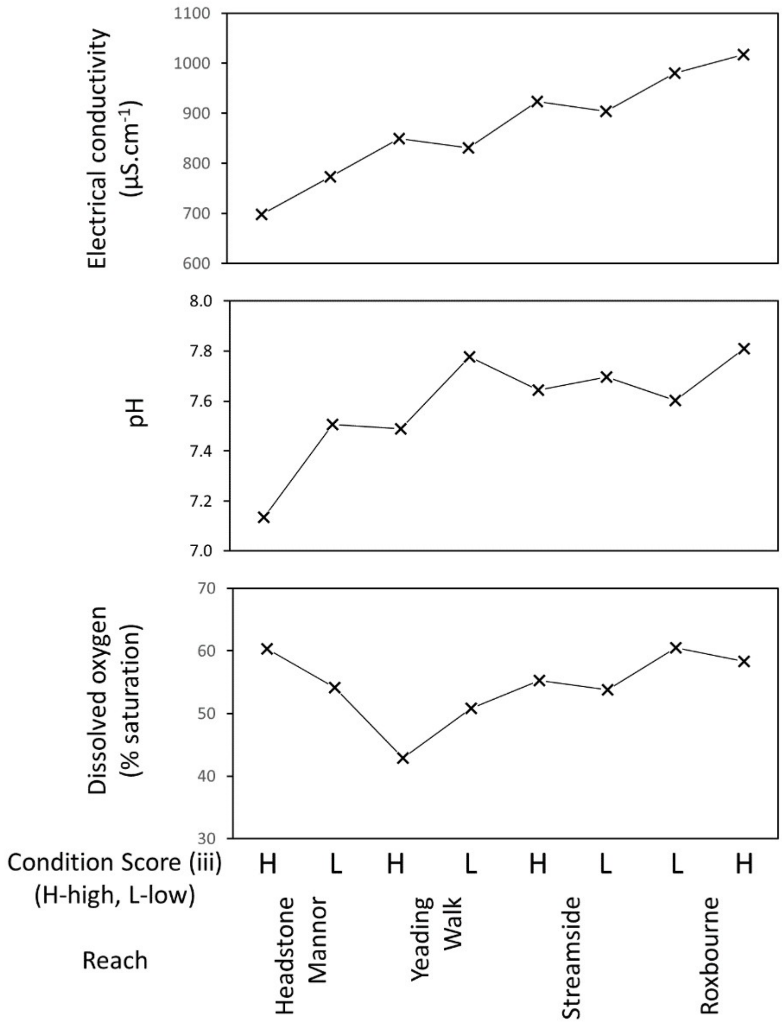

Figure 2: Electrical conductivity, pH and dissolved oxygen (average of three readings) observed at 8 sampling sites during 4th June 2024. (Note: each subreach is labelled L or H to indicate whether it had a relatively high (H) or low (L) value on Condition Score (iii))

3.3 Macroinvertebrates

Over 27000 individuals from 39 taxa were identified in the eight macroinvertebrate samples. Table 3 summarises these across the sampling sites. Table 4 breaks the data down by taxon as well as sampling site and uses colour shading to highlight broad differences in the number of individuals observed by taxon and sampling site.

Macroinvertebrate samples were mostly dominated by the freshwater shrimp (*Gammarus pulex*) and water hog louse (*Asellus aquaticus*). In terms of riverfly taxa, mayflies from the genus Baetis were most abundant. However, generally riverfly diversity and abundance were low (Table 4) indicative of potentially poor water quality / habitat availability. Sample coverage via kicknet sampling was very high, as indicated by the small differences between the observed and predicted number of taxa in each sample (Table 3). Taxon richness differed significantly across subreaches (indicated by the non-overlapping 95% confidence intervals for estimated no of taxa) with the highest estimated richness observed at Roxbourne H and lowest in Yeading Walk L.

Table 3: The number of individuals and taxa identified (and estimated) in the kick samples collected in the eight subreaches (subreaches are arranged from upstream (top) to downstream (bottom)). The number of estimated taxa (and 95% confidence intervals) are derived for a common sample size (the maximum number of individuals observed in a single sample: 5453 individuals) using species-accumulation simulations (Appendix Figure A).

Site	Subreach	No. individuals in sample	No. Taxa (observed)	No. Taxa (predicted)	95% confidence interval
Headstone	H	5354	22	22.19	16.92 to 27.47
Headstone	L	2898	18	19.25	15.57 to 22.93
Yeading walk	H	5453	9	9.00	07.94 to 10.06
Yeading walk	L	4277	13	13.13	10.83 to 15.44
Streamside	H	2244	19	23.10	14.21 to 31.98
Streamside	L	3842	19	21.32	16.77 to 25.86
Roxbourne	L	1592	16	16.00	15.23 to 16.77
Roxbourne	H	1766	19	23.51	16.71 to 30.30
Totals		**27426**	**39**		

Table 4: The number of individuals in each taxon identified in the samples collected from the eight subreaches (subreaches are arranged from upstream (left) to downstream (right)). Note: fish (X.fish) and waterfleas (Daphnia) were excluded from taxon richness estimates (Table 3) since these groups are underrepresented using benthic kicknet sampling.

Taxon	Headstone Manor		Yeading Walk		Streamside		Roxbourne		Grand Total
	H	L	H	L	H	L	L	H	
Agabus nebulosus	1								1
Ancylus fluviatilis								1	1
Antocha					1				1
Asellus aquaticus	75	1024	2632	1707	198	54	345	172	6207
Baetis fuscipes		2					13		15
Baetis rhodani grp	8	2			26	114	42	22	214
Baetis spp	11	5			16	49	41	27	149
Bathyomphalus contortus	1								1
Ceratopogonidae		2							2
Chironomidae pupa					8	4	17	3	32
Chironomini	2	13	9	3	5	3	4	11	50
Corixidae		1							1
Corixidae juvenile	3								3
Daphnia	10								10
Dytiscidae					1				1
Erpobdella octoculata				5	3	13		1	22
Erpobdella spp	1				3			3	7
Erpobdella testacea			99	30	7	10	19	5	170
Gammarus pulex	3666	1607	2660	2412	1735	3392	859	1440	17771
Glossiphonia complanata	1	12	4	9			2		28
Graphoderus cinereus	1								1
Haemopis sanguisuga	1			1					2
Helobdella stagnalis		9				1		6	16
Hydracarina spp					1				1
Lymnaea stagnalis	1								1
Oligochaeta	5	5		2	2	22	8	1	45
Orthocladiinae		3	1	2	160	65	76	13	320
Physella spp	9	1							10
PIsidium spp	1270	70	31	63	5	66	33	22	1560
Planorbis (Planorbis) sp.	4								4
Potamopyrgus antipodarum	245	21		2			14	5	287
Prodiamesinae	5	99	6	21	29	13	32	11	216
Radix balthica	8	1			4	1		1	15
Sigara dorsalis	4								4
Tanypodinae	1	7			1	1	14	4	28
Tanytarsini			11	19	34	30	73	18	185
Tipulidae						1			1
Velia caprai						1			1
Velia immature						1			1
X.Fish	21	14		1	5	1			42
Grand Total	**5354**	**2898**	**5453**	**4277**	**2244**	**3842**	**1592**	**1766**	**27426**

Key	0	1	>1-10	>10-100	>100-1000	>1000

3.4 Physical habitats and human interventions

Observations from the two MoRPh surveys at each sampling site were combined. Several whole channel numerical indicators were extracted from the data for each MoRPh survey. These were averaged or summed across the two MoRPh surveys, as appropriate.

MoRPh surveys record the abundance (linear or areal extent) of many features using an ATPE scale, where A (absent) = 0%, T (trace) = <5%, P (present) = 5 to 33%, and E (extensive) is >33%. Records for these fields were assigned the mid-point percentage for their abundance class (A=0, T=2, P=19, E=67). In the case of bank face features, this gave 4 values (abundance on each of two bank faces in two MoRPh surveys) which were added together giving a maximum achievable value of 268. For bed features there was one value for each of the two MoRPh surveys which were added, giving a maximum achievable value of 164. Other features (e.g. pools, riffles) are counted, so the counts from the two MoRPh surveys were summed.

Figures 3 and 4 illustrate how some of these whole channel numerical indicators and presence/abundance vary across the sampling sites along the bank faces and channel/water margin (Figure 3) and on the bed (Figure 4). The graphs presented in Figures 3 and 4 have a vertical axis extending from zero to the maximum achievable value.

Human interventions at the sampling sites are mainly confined to bank and bed reinforcement (Figure 3A, 4B), although there were a small number of pipes/outfalls at the two Roxbourne sampling sites. The horizontal extent of bank reinforcement (Figure 3A) was quite extensive at the two Headstone Manor sites, Yeading Brook L and Roxbourne L. The reinforcement was comprised of brick/ laid stone (including laid concrete-filled bags) in most cases. While most of the reinforcement was confined to the bank toe, it extended across the entire bank face at Headstone Manor L. Bed reinforcement mainly took the form of bricks, boulders and concrete blocks that had probably originated as part of bank reinforcement measures that had been washed out and deposited across the bed. Significant quantities were present at Roxbourne L, with smaller quantities observed at Headstone L, Yeading Walk H and L, Streamside H, and Roxbourne H. Some of this reinforcement material has become rounded by river flows, accounting for the boulder-sized ‘particles’ observed on the bed of these same sampling sites (Figure 4A). Boulder size particles are not naturally present in the Brook.

Water flows interact with sediments to build physical habitats, so it is important to see these not only as physical (hydraulic, sediment) habitats but also as drivers of the other physical features that are present. Although relative abundances varied, all sampling sites displayed at least four flow types (hydraulic habitats): unbroken standing waves, ripples, smooth and no perceptible flow, with a ‘dry’ exposed area of the bed also present at Roxbourne L (Figure 4C). These are all flow types associated with medium to low flow velocities, but the flow types and velocities would change if observations were made during higher flow conditions. All sampling sites also displayed patches of at least four sediment particle size classes of bed material (Figure 4A), indicative of a diverse alluvial bed. The particle size classes and their relative abundnaces varied between sampling sites.

Bed siltation is present at some sampling sites (Figure 4B). Siltation can smother gravel-cobble bed surfaces and is usually indicative of local silt penetration into the bed. This may adversely affect macroinvertebrate communities (surface and subsurface habitats) and fish (siltation of spawning beds) but fortunately the areal extent of siltation was modest at most sampling sites, with Headstone Manor L and H and Roxbourne L and H showing the greatest areas of superficial silts.

Many different physical features were observed, some of which are illustrated in Figures 3B, 3E and 4D. Pools and riffles (Figure 4D) were present at expected levels for this stream type apart from at Yeading Walk L and H, where riffles were absent. Channel/water margin features were few and of low abundance (Figure 3B). The deep and narrow channels present at most of the sampling sites probably restrict the development of these water-edge features. Tree-related features on the channel bed (not illustrated) were rare apart from tree roots extending across the bed at Yeading Walk H and Streamside L. However, there were a variety of tree-related physical features (habitats) along the bank face (Figure 3E), which were particularly diverse and abundant at Roxbourne H and L.

Terrestrial vegetation on the bank face was structurally complex at all sampling sites (Figure 3D), but there were notable differences between sites in terms of the relative importance of tree/sapling/shrub/scrub cover when compared with mosses/lichens/herbs/grasses. The former showed the highest abundance at Headstone Manor L, Streamside H and L and Roxbourne H and L. Aquatic vegetation was largely confined to the channel/water margin across all sampling sites, where it was dominated by emergent linear-leaved plants and mosses (Figure 3C). In general, the linear extent of aquatic plants along the river banks was small, with the exception of Headstone H.

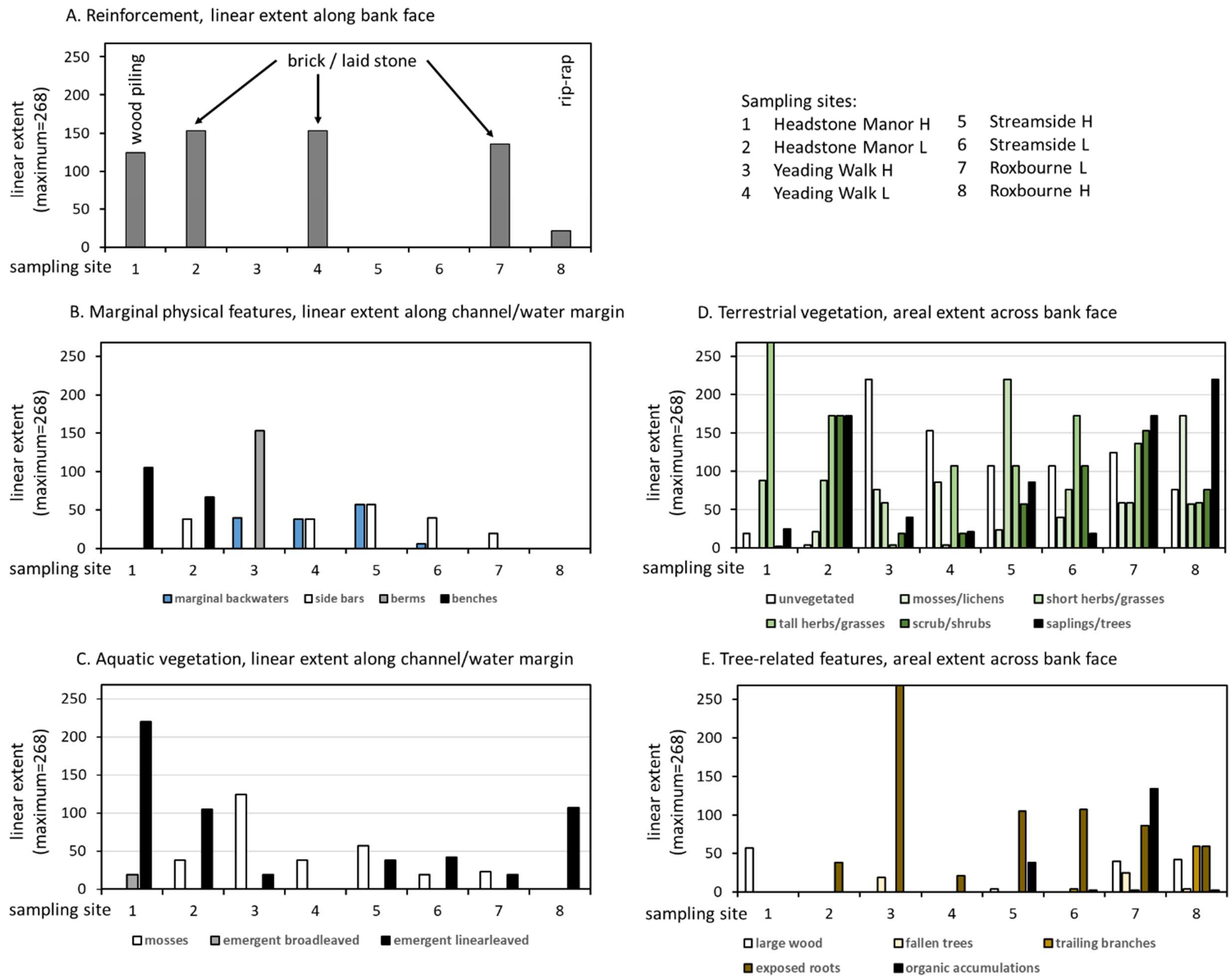
A. Reinforcement, linear extent along bank face
linear extent (maximum=268)
sampling site
wood piling
brick / laid stone
rip-rap
Sampling sites:
1 Headstone Manor H
2 Headstone Manor L
3 Yeading Walk H
4 Yeading Walk L
5 Streamside H
6 Streamside L
7 Roxbourne L
8 Roxbourne H
B. Marginal physical features, linear extent along channel/water margin
marginal backwaters
side bars
berms
benches
C. Aquatic vegetation, linear extent along channel/water margin
mosses
emergent broadleaved
emergent linearleaved
D. Terrestrial vegetation, areal extent across bank face
unvegetated
mosses/lichens
short herbs/grasses
tall herbs/grasses
scrub/shrubs
saplings/trees
E. Tree-related features, areal extent across bank face
large wood
fallen trees
trailing branches
exposed roots
organic accumulations

Figure 3 (preceding page): Changes in the extent of selected features along bank faces and channel/ water margin between sampling sites. A. reinforcement (dominant type); B. physical features (backwaters, bars, berms, benches); C. aquatic vegetation (mosses, emergent broadleaved, emergent linear-leaved); D. terrestrial vegetation (bare, mosses/lichens, short herbs/grasses, tall herbs/grasses, scrub/shrubs, saplings/trees); E. tree-related features (large wood, fallen trees, branches trailing into channel, exposed roots, discrete organic accums.).

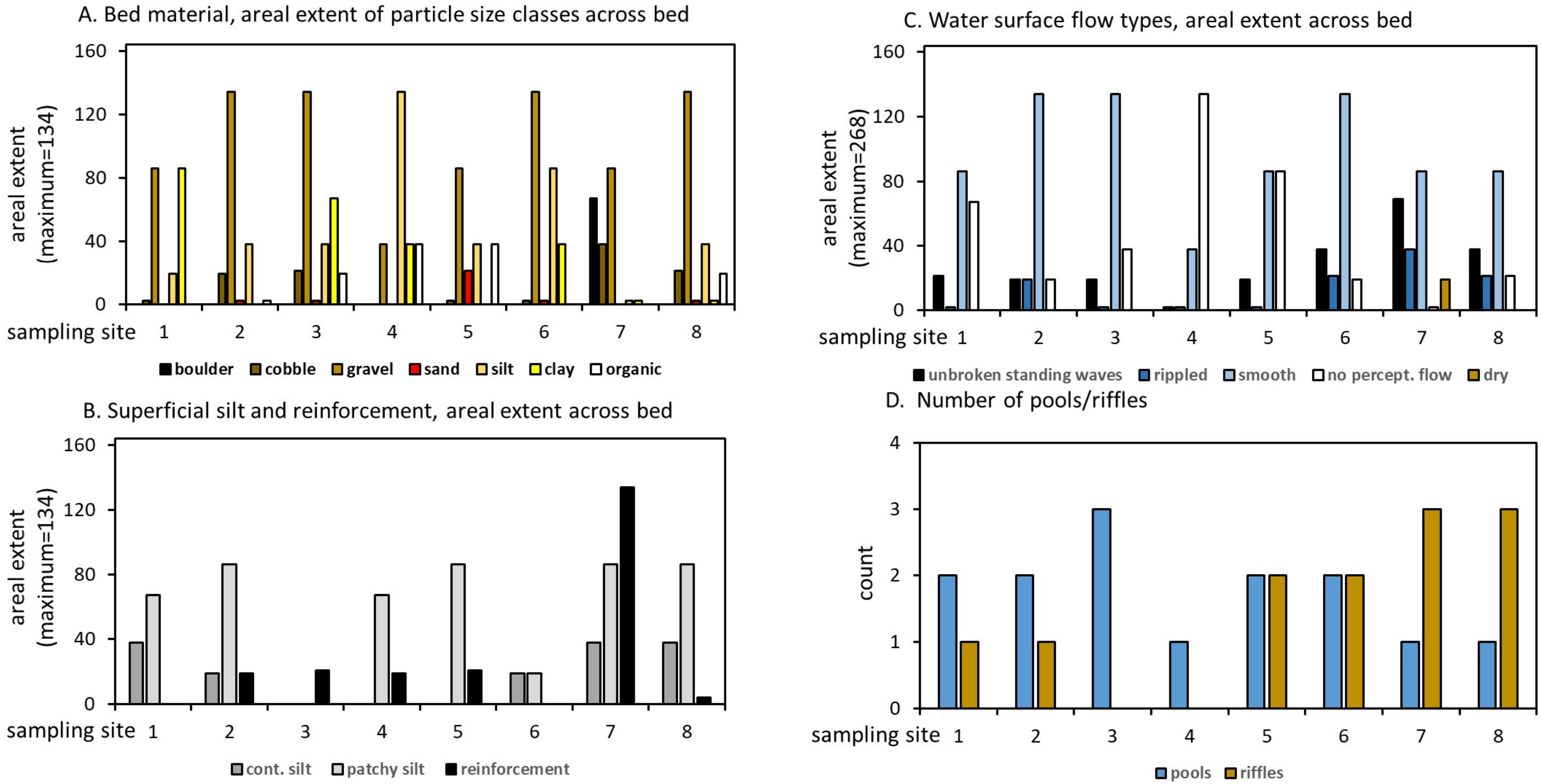

Figure 4: Changes in the extent of selected features across the bed between sampling sites. A. bed material particle size classes; B. superficial silt and artificial reinforcement; C. flow types; D. number of pools and riffles. (For key to sampling site names see Figure 3

4 ASSOCIATIONS AMONG MACRONIVERTEBRATES, WATER QUALITY MEASURES AND PHYSICAL HABITATS

For this analysis, the macroinvertebrate community sampled at each site is summarized by two indicators: the number of individuals and the number of taxa. The three indicators of water quality sampled in the field are included in the analysis to represent water quality conditions. An enormous range of indicators can be extracted from MoRPh surveys. Some key ones are included in the analysis to represent the range of physical properties that are thought to influence macroinvertebrates plus others indicative of the broad character of the channel bed and margins. Many of these are illustrated in Figures 3 and 4 and all are listed in Table 5.

The small number of sampling sites restricts the types of statistical analysis that can be applied to these data. While there may be complex interactions among water quality and physical properties that influence the macroinvertebrate communities, it is only possible to consider the degree to which single properties may be associated with the number of individuals or the number of taxa.

Table 5 shows rank correlations between either the number of macroinvertebrate individuals or the predicted number of taxa and each of the water quality and physical properties listed. Rank correlations were used rather than more powerful product-moment correlations because of the different measurement scales and frequency distributions displayed by the different properties. The value of each rank correlation can vary from -1 (perfect negative association) through 0 (no association) to +1 (perfect positive association). For a sample size of 8, the correlations become statistically significant ($p<0.05$) if they are either less than -0.738 or greater than +0.738. Correlations that fall in these ranges are shown in a bold font in Table 5. Fairly strong but not statistically significant correlations (i.e. >0.6 or <-0.6) are underlined.

In terms of water quality, there was a statistically significant decrease in the number of individuals as electrical conductivity increased (correlation = -0.738). Although not statistically significant there was quite a strong negative correlation (-0.643) between dissolved oxygen and the number of individuals.

Only one flow type (rippled area extent) was significantly negatively correlated (-0.728) with the number of individuals. At low flows this flow type is frequently associated with the broad area occupied by riffles.

In relation to bed material, although there are no statistically significant correlations apart from positive correlations between clay extent (0.764) and average particle size (0.762, meaning an increase in number of individuals with a decrease in average particle size because the latter is expressed in phi units). However, there is a general trend from negative to positive correlations for the association between number of individuals and particle size as the latter decreases, which also supports an increase in the number of individuals as bed material fines. In addition there is a quite strong negative correlation (-0.707) between the number of individuals and the superficial bed siltation index, and a statistically significant negative correlations (-0.856) between the number of individuals and patchy superficial siltation.

The only physical habitats that were statistically significantly associated with macroinvertebrates were the number of riffles, which were significantly negatively correlated (-0.878) with the number of individuals and quite strongly positively correlated with the predicted number of taxa. Pools were also quite strongly positively correlated (0.639) with the number of individuals.

In relation to riparian/aquatic vegetation and tree-related features, the extent of unvegetated areas on the bank face was quite strongly negatively correlated (-0.671) with the number of taxa, and the number of individuals showed quite strong negative relationships with scrub/shrub and sapling/tree cover on the bank faces and also general riparian vegetation structural complexity (-0.695, -0.683, -0.643). The number of taxa were significantly positively correlated (0.743) with the linear extent of emergent linear-leaved macrophytes along the channel/water margins, and the number of individuals was significantly negatively correlated (-0.817) with the extent of discrete organic accumulations on the bank face.

Together, these results highlight the complex and multifaceted links between physical stream habitat and the abundance and diversity of stream macroinvertebrate communities. Despite the small sample size, water quality (electrical conductivity, dissolved oxygen) appears to be influencing macroinvertebrates at the sampling sites. Amongst the physical habitats, bed material size, superficial siltation, and pool-riffles all show notable associations with macroinvertebrates, and bank face vegetation, particularly unvegetated areas and areas under trees/saplings/shrubs and scrub, also appear to be influential.

Future monitoring that adopts the approach used here will increase the statistical power of the analyses and likely uncover further important links between these variables. Furthermore, future monitoring that incorporates additional biological groups (e.g. fish assemblages), or more detailed water quality assessments would be instructive for gaining a more holistic understanding of the ecological health of Yeading Brook West prior to restoration.

Table 5. Spearman's rank correlations between a set of environmental variables and both the number of individuals and the number of taxa (emboldened correlations are statistically significant (p<0.05), underlined correlations are not statistically significant but a quite strong (>0.6 or <-0.6))

Variables	No. individuals in sample	No. Taxa Predicted
WATER QUALITY		
electrical conductivity	**-0.738**	0.333
pH	-0.476	0.310
dissolved oxygen	-0.643	0.548
WHOLE CHANNEL INDICATORS		
channel physical habitat complexity index	-0.073	-0.182
number of aquatic vegetation morphotypes	0.355	0.573
riparian physical habitat complexity index	0.262	0.095
riparian vegetation structural complexity index	-0.611	0.539
human pressure imposed by bank top land cover index	0.060	-0.252
channel bed and bank reinforcement index	-0.347	-0.263
FLOW TYPES		
unbroken standing waves areal extent across bed	-0.552	0.356
rippled areal extent across bed	**-0.728**	0.166
smooth areal extent across bed	0.222	-0.156
no perceptible flow areal extent across bed	0.491	0.036
dry bed arial extent areal across bed	-0.577	-0.247
CHANNEL BED MATERIAL		
average bed material size (phi units – note that large values indicate small particles and vice versa)	**0.762**	-0.143
boulder extent across bed (washed-out reinforcement)	-0.577	-0.247
cobble extent across bed	-0.442	-0.086
gravel extent across bed	0.013	0.130
sand extent across bed	-0.143	0.391
silt extent across bed	0.317	-0.152
clay extent across bed	**0.764**	-0.327
coarse to fine organic material extent across bed	0.062	-0.025
superficial bed siltation index	-0.707	0.515
continuous superficial silt extent across bed	-0.441	0.441
patchy superficial silt extent across bed	**-0.856**	0.511
PHYSICAL HABITATS (CHANNEL EDGE AND BED)		
number of pools	0.639	-0.183
number of riffles	**-0.878**	0.634
marginal backwater linear extent along channel/water margins	0.355	-0.241
side bar linear extent along channel/water margins	-0.246	0.098
berm linear extent along channel/water margins	0.577	-0.577
bench linear extent along channel/water margins	0.296	0.156

VEGETATION (BANK FACE AND WATER MARGIN)		
unvegetated areal extent across bank face	0.240	<u>-0.671</u>
mosses/lichens areal extent across bank face	-0.167	-0.190
short herbs/grasses areal extent across bank face	0.000	0.386
tall herbs/grasses areal extent across bank face	0.024	0.193
scrub/shrubs areal extent across bank face	<u>-0.695</u>	0.060
saplings/trees areal extent across bank face	<u>-0.683</u>	0.323
mosses linear extent along channel/water margin	0.253	-0.578
emergent broadleaved linear extent along channel/water margin	0.412	0.247
emergent linear-leaved linear extent along channel/water margin	-0.060	**0.743**
TREE-RELATED FEATURES (BANK FACE)		
large wood areal extent across bank face	-0.342	0.634
fallen trees areal extent across bank face	-0.300	-0.300
trailing branches areal extent across bank face	-0.573	0.409
exposed roots areal extent across bank face	-0.024	-0.190
discrete organic accumulations areal extent across bank face	**-0.817**	0.383

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APPENDIX

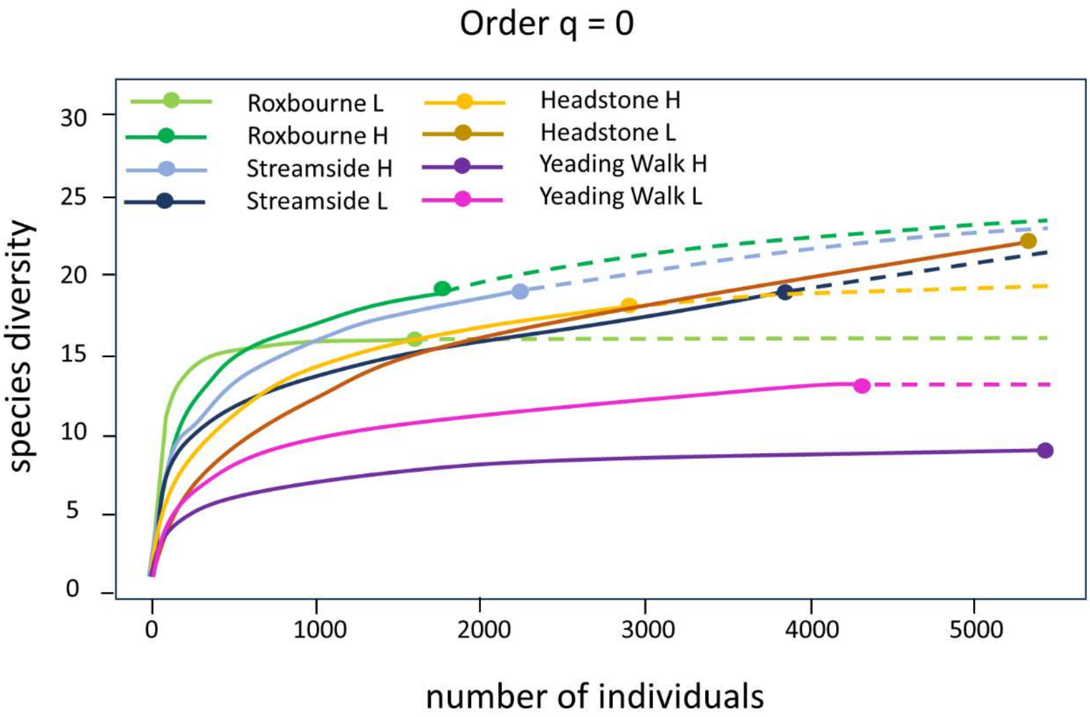

Figure A:. Macroinvertebrate taxon richness rarefaction (solid line segment) and extrapolation (dotted line segments) sampling curves between subreaches. Dots represent the reference samples.