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River Nar Restoration at Castle Acre:
Final report of pre- and post-restoration monitoring

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Final report of pre- and post-restoration monitoring

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1. Summary

Before-After-Control-Impact habitat and invertebrate assessment has been undertaken across two control and two restored sites along the River Nar at Castle Acre (Figure 1). This approach has enabled the assessment of both habitat and ecological restoration following the installation of large woody debris (Lwd). We have combined data from multiple stream Lwd restorations in order to assess how the project on the Nar is performing. Relative to other streams in the database, the Nar had the highest invertebrate species richness (74) and there were encouraging trends in density between habitats, but large variation within restored sites suggests that the restoration signal has been limited by large-scale factors including siltation.

Figure 1 River Nar monitoring design has an upstream (A) and downstream (D) control in relation to the two restored sites (B, C). Contains OS data © Crown copyright [and database right] (2015)

2. Methods

Annual sampling took place during July 2014 and 2015, once before and once following restoration. Substrate proportions (i.e. %silt relative to other substrate), coarse (<10cm) and large (>10cm) wood and plant percentage volume infested (PVI) were estimated using a bathyscope at each invertebrate survey point (Figure 2).

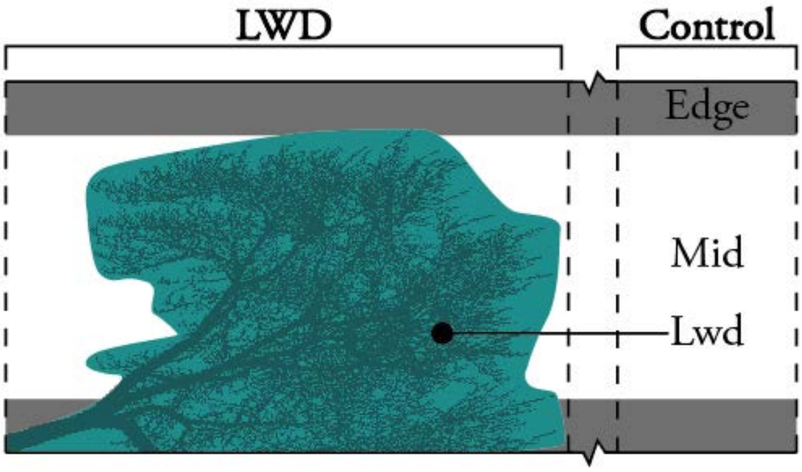

Figure 2 Plan view of the replicated reach-scale sampling design. Habitat measures were recorded and invertebrate samples taken randomly from the three habitats (were present) across all reaches before and after restoration.

2.1. Biotic characterisation

A bespoke 152.4mm diameter Hess sampler with 335 microns mesh was used to collect invertebrates. Unlike a kick net survey, Hess samples are quantitative meaning population densities can be estimated. A row of teeth at the base of the Hess and robust handles enabled it to cut through branches when used within woody structures. Samples were immersed immediately in 70% IMS to preserve contents for identification in the laboratory. Invertebrates were identified to the lowest possible taxonomic resolution (i.e species in most cases) using a 40-100x magnification microscope and counted to give the density per sample.

Estimates of species mean body size (dry mass [mg]) were made using at least five individuals of each taxon per sample, selected at random. Individuals were measured with regard to the body dimension required for existing length-mass regression equations using an eye-piece graticule with a scale bar containing 100 units scaled to 10mm at 40x magnification. Regression equations were obtained from Baumgäertner & Rothhaupt [1], Benke *et al.* [2], Burgherr and Meyer [3], Calow [4], Edwards *et al.* [5], Hildrew and Townsend [6], Johnston and Cunjak [7], Meyer [8], Sabo *et al.* [9], Smock [10] and Towers [11].

2.2. Statistical methods

Spatial and temporal variation (i.e. besides the treatment effect) was not of primary interest in this study, but rather, the amount of variation explained by Lwd restoration after the differences caused by site characteristics had been estimated. Therefore, the statistical techniques used here have been designed to focus on the effect of Lwd restoration after accounting for other potentially confounding temporal and spatial variation. We assess restored (i.e. those with treatment trees; TT) sites vs controls (i.e. those with no trees; N) which encompass all pre-restoration sites and post-restoration control sites. This grouping has enabled us to demonstrate whether invertebrates increased in density, for instance, in restored sites relative to unrestored sites after accounting for natural spatial and temporal variation. We also assess local within site differences between Lwd habitat and adjacent mid and edge habitat. This combination of analyses provides critical information on the scale of the restoration effect.

We use principal components analysis (PCA) and non-metric multidimensional scaling (NMDS) with the Bray–Curtis dissimilarity index to assess changes in environmental parameters and invertebrate composition, respectively. Estimates of species richness were made using the most up to date methodology recently developed and published as the R package iNEXT [12]. This approach provides information on the sampling efficiency (i.e. estimates what percentage of the community we are capturing) and provides a robust means of comparing samples where different sample sizes occur. Treatment and habitat were fixed terms and site a random term in general linear mixed effects models (GLMM) to assess differences in invertebrate density, biomass and diversity.

3. Monitoring Results

In total we made 54 habitat recordings and processed 54 corresponding invertebrate samples which contained a total of 10,706 individuals and 80 unique taxa (74 to the lowest described morphtype or species given available taxonomic keys, e.g. Figure 3; Table 1), of which 5457 individuals were measured for biomass estimates. Sampling efficiency was high with an estimated >97% coverage of invertebrate species sampled in the target communities within each sampling location each year. Chironomids, Annelids, Pisidium and Hydracarina were not identified to species and so were removed from analyses of species diversity.

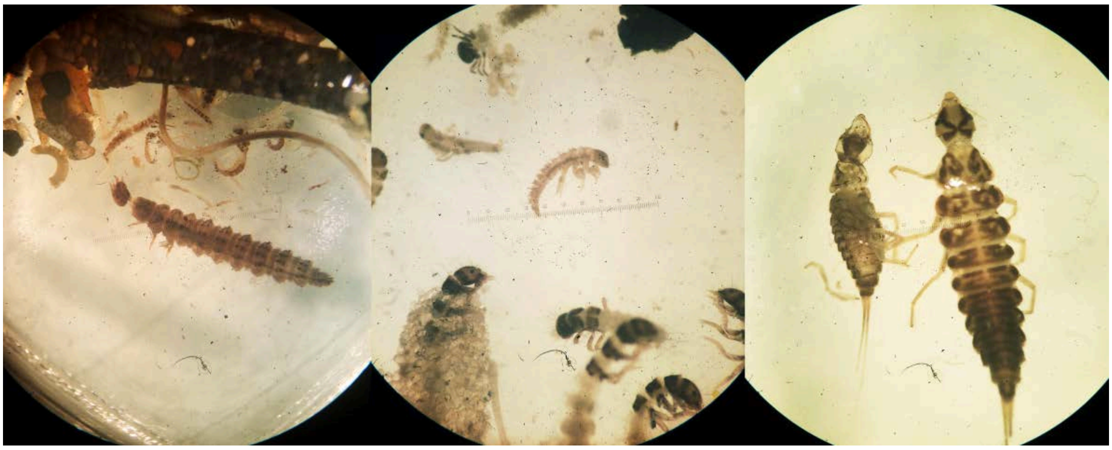

Figure 3 The Nar contained some interesting Coleoptera larvae. From left to right: Helophorus sp; Haliplidae sp (below are the cased Trichoptera larvae of Hydroptila sp); Stictotarsus sp.

PCA of environmental data revealed significant differences between sites and no statistical difference between years at control sites (Figure 4a, b). This indicated that site differences needed to be accounted for statistically but, crucially, there was no evidence of confounding temporal habitat change unrelated to the restoration. After accounting for variation associated with site and year differences we were able to demonstrate that the habitat restoration was successful at increasing woody habitat and that the restored reaches habitat diverged significantly from control and pre-impact conditions (Figure 4c, d).

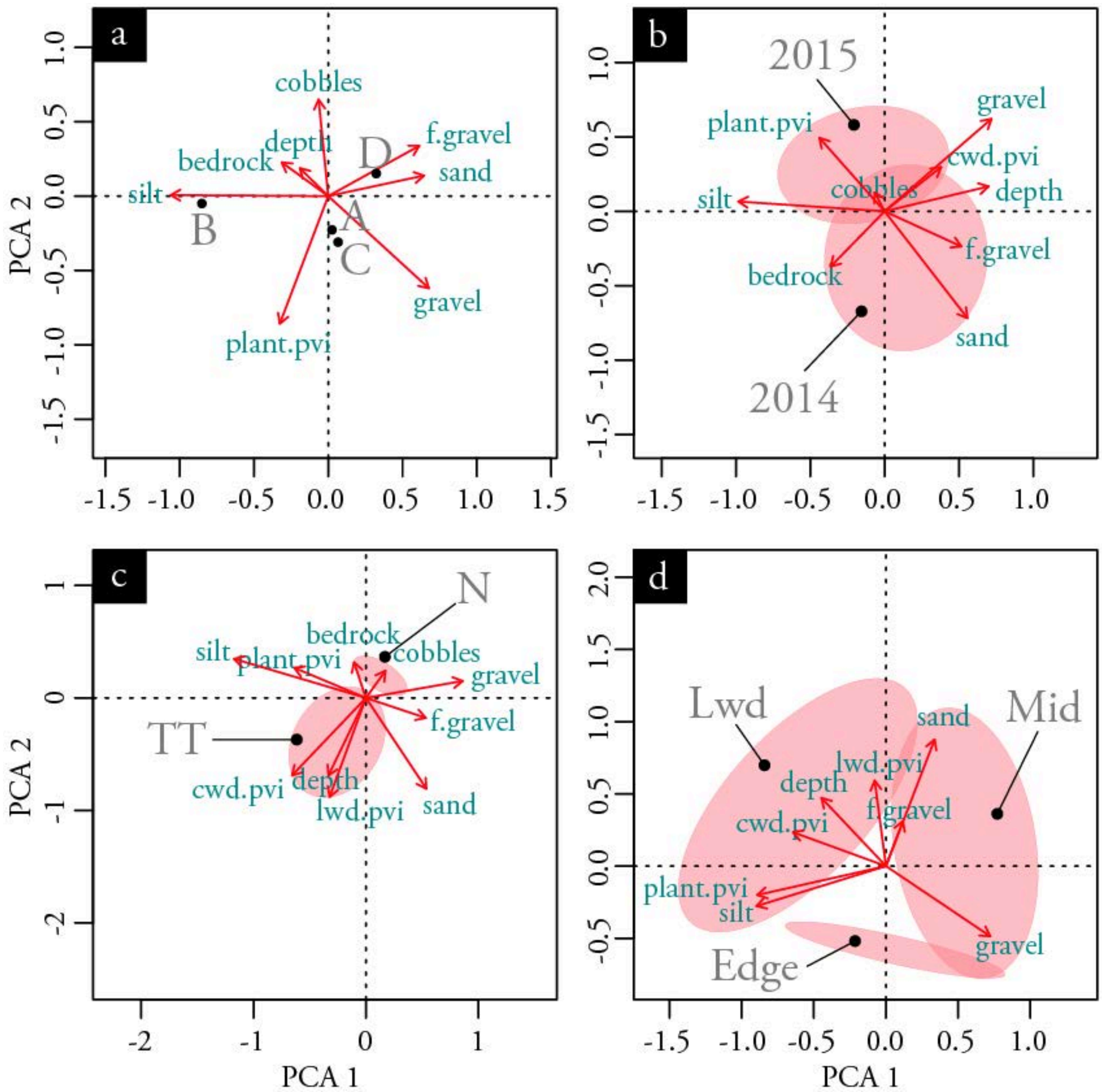

Figure 4 PCA of the Nar habitat data

Ellipses in the above figure represent standard error: a) silt was the primary driver of site differences in 2014, site B had the highest proportion of silt relative to other substrates; b) there was no significant difference between years across the control sites demonstrating that there was no confounding temporal habitat change unrelated to the restoration; c) there was a significant treatment effect within restored sites (i.e with treatment trees; TT) relative to reaches with no trees (N) caused by increasing large and coarse woody debris PVI (lwd.pvi and cwd.pvi respectively) and associated increases in water depth; d) Lwd habitat was generally deeper, with relatively higher proportions of silt and high plant PVI (plant.pvi), coarse and large woody debris PVI compared to the mid-stream and stream-edge, whereas there were higher proportions of sand and gravel mid-stream.

Invertebrate community composition was not significantly different between sites and there was no statistical difference between years at control sites (Fig 5a, b), indicating that there was no evidence of confounding temporal effects unrelated to the restoration. Invertebrate composition did not change in response to the restoration at the reach level, but related significantly to increasing silt (Fig 5c).

Invertebrate communities at the stream-edge and mid-stream were different from one another and the invertebrate community within Lwd appears to integrate these two communities (Fig 5d).

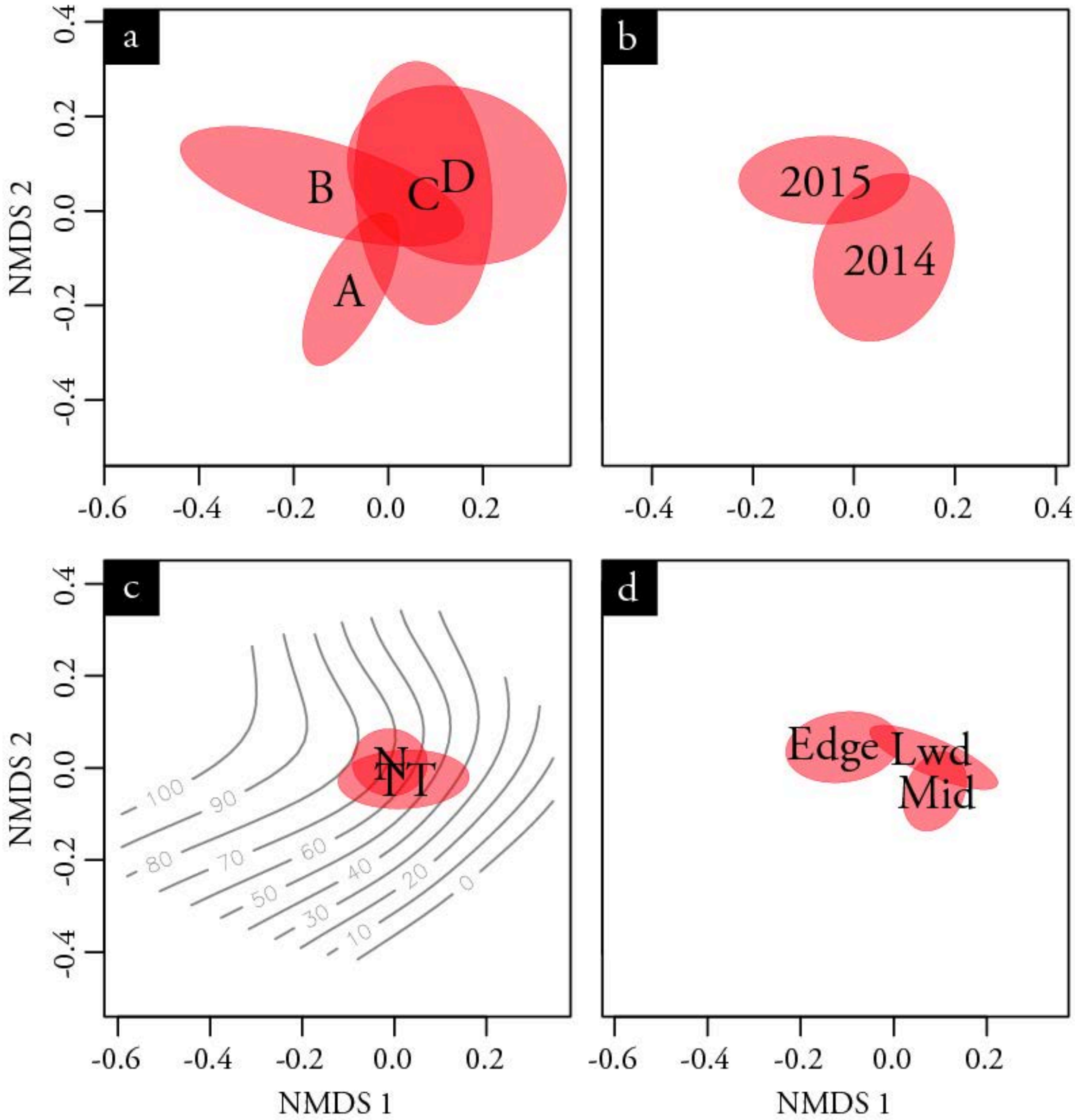

Figure 5 NMDS of invertebrate community composition:

In Figure 5, a) differences between sites in 2014 were not significant; b) control site communities were not statistically different between 2014 and 2015; c) nor were communities within restored sites (i.e. with treatment trees; TT) relative to reaches with no trees (N), but rather differences were related to increasing silt; d) and there were significant differences between habitats.

There was no clear response in invertebrate density, biomass or diversity at the reach scale or between habitats (Figure 6a-f). Despite the lack of a significant result, there was an encouraging increase in density and biomass within site C (Figure 6a, c), Lwd habitat (Figure 6b, d) which is similar to those detected in other stream restorations (Figure 7a) and invertebrate species richness was highest in the Nar, Test and Wensum (Figure 7b).

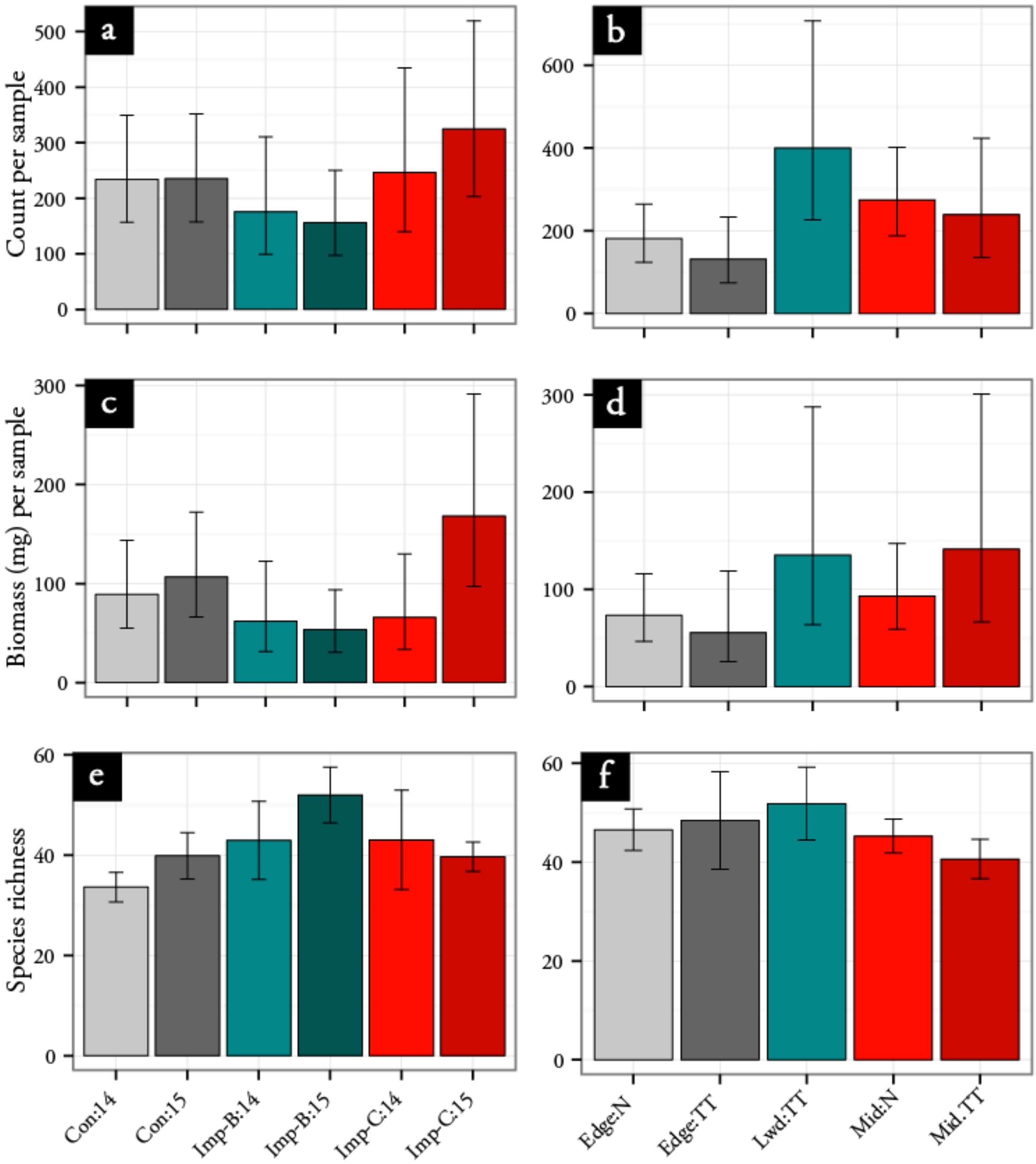

Figure 6 Results from general linear mixed effects models, error bars represent 95% confidence intervals:

In Figure 6, a) invertebrate density did not significantly increase in the restored sites (Imp-B:15 and Imp-C:15) relative to pre-impact (Imp-B:14 and Imp-C:14) or control sites (Con:14 and Con:15); b) density was highest only in Lwd samples when compared to adjacent Edge samples collected from restored reaches (i.e. with treatment trees; TT) relative to reaches with no trees (N); c) there was no significant increase in invertebrate biomass caused by the restoration between sites; d) or habitats; e) and there was also no significant increase in invertebrate species richness caused by the restoration between sites; e) or habitats.

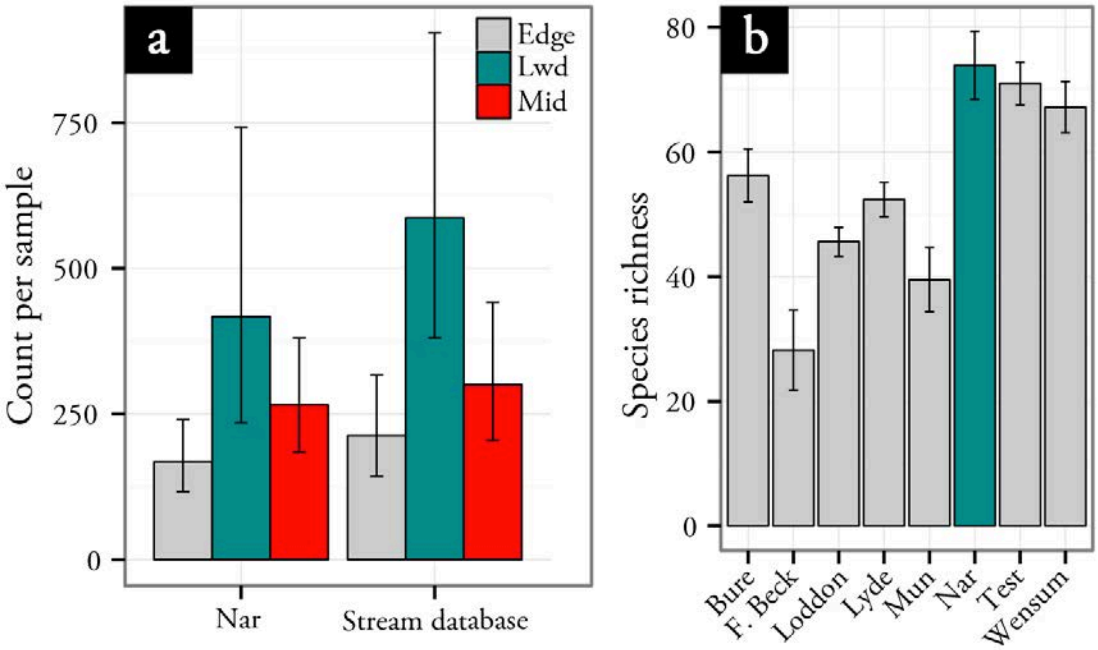

Figure 7 Data were combined across restorations to demonstrate the relative effectiveness of the Nar project using general linear mixed effects models, error bars represent 95% confidence intervals.

The data presented in Figure 7 show: a) within the Nar, invertebrate density was significantly higher in Lwd when compared to stream-edge but not mid-stream, whereas in the stream database Lwd had the highest overall; b) invertebrate species richness was highest in the Nar, Test and Wensum.

4. Comments and Recommendations

The limited response of the invertebrate community to the habitat restorations on the Nar is likely due to ongoing environmental factors such as silt pollution (Figure 5c). This is in stark contrast to the restoration on the Mun where a clear restoration signal was apparent (See Mun report). Thus a similar approach to the Mun, whereby water quality issues are tackled alongside habitat enhancements, could be applied on the Nar in a future restoration and data from this report, alongside those from the Mun and the stream database provide evidence to justify this approach. However, there may be other factors limiting the response of the invertebrate community, such as the limited time for ecological recovery and increasing fish predation if fish stocks have increased following restoration. Longer-term monitoring could be key in this case and electrofishing was undertaken by Norfolk Rivers Trust before the restoration and is planned again.

We recommend then that the relationship between fish and invertebrate populations are explored in the longer-term. A further possibility would be to combine these data with diatom data using samples collected during this work which, if funds became available, could be processed and combined with the invertebrate and fish data to assess food web metrics and thus demonstrate how multiple trophic levels (i.e. algae-invertebrates-fish) respond to restoration.

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6. Supplementary information

Table 1 Species list and total count.

Taxa	Count
Agapetus fuscipes	319
Anabolia nervosa	5
Ancylus fluviatilis	123
Baetis rhodani	110
Baetis scambus	143
Baetis vernus	18
Bezzia solstitalis	124
Bithynia tentaculata	1
Brychius sp	4
Centroptilum luteolum	125
Chaetopteryx villosa	4
Chironomid	3640
Clinocera sp1	1
Clinocera stagnalis	15
Coleoptera sp1	2
Coleoptera sp2	1
Colymbetinae sp	1
Corixidae sp	1
Dendrocoelum lacteum	1
Dicranota bimaculata	69
Diptera sp1	1
Diptera sp2	1
Dixa sp	16
Elmis aenea	525
Empididae sp1	1
Ephemera danica	131
Erpobdella octoculata	4
Galba truncatula	4
Gammarus pulex	1298
Glossiphonia complanata	18
Haliplidae sp	7
Helobdella stagnalis	4
Helophorus sp	1
Hemerodromias sp	2
Hemiclepsis marginata	1
Hydracarina	364
Hydraena gracilis	2
Hydropsyche pellucidula	102
Hydroptila sp	44
Lepidostoma hirtum	26
Leuctra geniculata	22
Leuctra hippopus	199
Limnephilus lunatus	15
Limnius volchmari	225
Lype reducta	1
Muscidae sp	3
Mystacides azurea	30
Nemouridae sp	35
Oligochaeta	743
Orectochilus villosus	2
Oulimnius sp	21
Oxyethira sp	12
Paraleptophlebia submarginata	29
Parapoynx stagnalis	2
Piscicola geometra	7
Pisidium	191
Planorbis contortus	1
Planorbis vortex	14
Platambus sp	10
Polycelis tenuis	7
Polycentropus flavomaculatus	49
Potamopyrgus jenkinsi	370
Potarnonectes depressus depressus	6
Psychodidae sp1	6
Psychodidae sp2	5
Ptychoptera lacustris	3
Radix peregra	27
Rhyacophila dorsalis	25
Riolus cupreus	4
Scirtes sp	2
Serratella ignita	80
Serricostoma personatum	67
Sialis lutaria	9
Silo nigricornis	107
Simulium equinum	1
Simulium lundstromi	174
Simulium ornatum	101
Stictotarsus sp	31
Tanypod	734
Theromyzon tessulatum	1

Taxa	Count
x.Baetis indet	30
x.Coleoptera indet	1
x.Gastropod indet	2
x.Hydropsyche indet	2
x.Hydroptilidae indet	9
x.indet	9
x.Limnephilidae indet	1
x.Plecoptera indet	1
x.Simulium indet	7
x.Springtail indet	2
x.Trichoptera indet	12
TOTAL	**10706**

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