Understanding moorland aquatic invertebrate ecology to inform biodiversity conservation and sustainable land management

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Executive summary

Headwater streams are major components of river systems with heterogeneous and dynamic hydrological and physicochemical conditions that collectively influence the biodiversity of aquatic fauna. However, there have been relatively few studies of stream ecosystems draining peat dominated catchments, which form the headwaters of many high latitude river systems. The inclusion of the North Pennines AONB as part of Britain's first 'European GeoPark' brings with it a necessity to fully understand the biodiversity of the area. A more complete understanding of the animals inhabiting moorland streams, and their response to habitat variability, is vital to underpin holistic biodiversity conservation strategies, and guide sustainable restoration and management schemes. The aim of this project was therefore to gain a better understanding of how river flow and water quality influence aquatic invertebrates in moorland streams and rivers, to inform biodiversity conservation and sustainable moorland management. For the first part of the study, year-round quarterly sampling was undertaken in ten streams at Moor House National Nature Reserve from June 2007 to June 2008. Analysis of the extensive datasets is ongoing but this report provides an overview of some of our most pertinent findings so far. We found over 100 different aquatic invertebrate taxa; some 25 stoneflies (Plecoptera), over 20 mayflies (Ephemeroptera) and approximately 20 caddis flies (Trichoptera). Comparisons between streams based on their relative size revealed little difference in the abundance of aquatic insect larvae or the number of different taxa. However, there were clear differences in the abundance of some species in different sized streams, with many preferring larger rivers. Macroinvertebrate community abundance and diversity were typically similar across streams but analysis demonstrated turnover of macroinvertebrate assemblages with increases in stream size and over time. In particular, 1st and 2nd order streams hosted small sized stoneflies whilst larger streams (3rd-4th order) supported more mayflies and larger predatory stoneflies (e.g. *Dinocras cephalotes* and *Perla bipunctata*). For the second part of the study, data collected by the Environmental Change Network at Trout Beck from 1997 to 2008 showed clear inter-annual changes in moorland stream aquatic invertebrate communities. For the final part of the project we undertook a pilot study to examine the influence of moorland drainage (gripping), drain-blocking and heather/grass burning on aquatic invertebrates in streams. Our results indicated no significant change in the total abundance or taxonomic richness of stream-dwelling aquatic invertebrate larvae between catchment management types. Critically however, these community level findings masked underlying changes in the abundance of some species, with some apparently sensitive stoneflies and mayflies being lost from systems that remain artificially drained, or where burning was practiced. Our results suggest that drain-blocking may be a suitable catchment-scale remediation practice that benefits aquatic ecosystems.

Final Report (June 1st, 2009)

Outline of progress since Report 3

- Sorting and identification of aquatic insect samples from streams across the North Pennines completed
- Laboratory analysis of water samples for dissolved nutrients and major solutes completed
- Analysis of data for all project aims
- Integration of results from field sampling with data obtained from the Environmental Change Network.

Project context

Headwater streams are major components of river systems and they typically exhibit heterogeneous and dynamic hydrological and physicochemical conditions (Resh *et al.,* 1988, Webb *et al.,* 2008) that collectively influence aquatic fauna. The biodiversity of headwater streams is thought to be strongly influenced by this physicochemical habitat heterogeneity (e.g. Heino *et al.,* 2003) and there have been suggestions that headwater streams are vital for maintaining the ecological function of whole river networks. Moorlands cover a large proportion of the upland areas of Great Britain, and they are particularly prevalent across the North Pennines Area of Outstanding Natural Beauty (AONB). Many hundreds of streams and rivers drain these landscapes, and each of these water bodies is home to an array of animals ranging from invertebrates to fish and amphibians, which in turn can sustain populations of birds and small mammals further up the food web. However, we have relatively little information about the different animal species which inhabit moorland streams and we know little about how their populations vary over time, or between different streams and rivers, in response to changes in flow, water quality and catchment management (for review see Ramchunder et al., 2009).

One of the most diverse groups of freshwater organisms is the aquatic invertebrates. Several studies in the 1970s were concentrated on or around Moor House National Nature Reserve and marked seasonal and inter-annual variations were observed among several species of stonefly larvae, mayfly larvae and aquatic beetles (Armitage *et al.,* 1974) and it was suggested that spatial habitat diversity may account for the relatively high aquatic invertebrate richness of these moorland streams. More recently, Maitland (1999) suggested that moorland aquatic habitats may be important areas for some of the rarest UK insect species. Similarly, Eyre *et al.* (2005) highlighted how small acid peatland streams of the Tyne basin had aquatic insect assemblages different to lowland reaches, being dominated by several beetle species, with low abundances of freshwater shrimps and caddis fly larvae.

The inclusion of the North Pennines AONB as part of Britain's first 'European GeoPark' brings with it a necessity to fully understand the biodiversity of the area. A more complete understanding of the animals inhabiting moorland streams, and their response to habitat variability, is vital to underpin holistic biodiversity conservation strategies, and guide sustainable restoration and management schemes. In addition, there is a pressing need to gain a better understanding of aquatic ecosystems in the North Pennines and beyond because the area of moorland that is intensively managed for agriculture continues to grow year on year (e.g. Yallop *et al.,* 2006; Holden *et al.,* 2007). Additionally, changes to aquatic ecosystems may be imposed by the effects of rising air temperatures, droughts and/or the acidity of precipitation and subsequent soil/stream hydrological dynamics (Evans *et al.,* 2006). The biodiversity of streams in the North Pennines AONB may be vulnerable to such change; therefore, it is important that these ecosystems are studied in more detail to guide conservation and management strategies.

Project aims

The overall aim of this project was to gain a better understanding of how river flow and water quality influence aquatic invertebrates in moorland streams and rivers, to inform biodiversity conservation and sustainable moorland management. This was achieved by:

(1) Documenting aquatic invertebrates of small 1st order (<1m width) streams in moorland headwaters, and comparing them to larger 2nd, 3rd and 4th order rivers to determine the influence of moorland river catchment size

(2) Putting this spatially extensive one year field sampling dataset into a long-term context by analysing the ECN aquatic invertebrate dataset which has been collected three times per year from one site on Trout Beck since 1997, and;.

(3) Undertaking a pilot study to examine the effects of moorland drainage, drain-blocking and grass/heather burning on aquatic invertebrates of streams and rivers.

Study sites

Moor House NNR was designated in 1952 and thus, little to no management has been imposed on this site since that time. For instance, the Trout Beck catchment is currently grazed by sheep at a density of only 0.6 to 1 animal per hectare. Only very small plot areas are now managed via burning for scientific purposes, thus a large proportion of the reserve remains as intact blanket peat, although some areas remain sparsely vegetated (see Warburton, 2003). The streams and rivers draining the Moor House NNR are ideal sites to investigate the environmental drivers of spatial and temporal biodiversity patterns in peatlands.

Ten streams were sampled for this study for project aim 1 (Table 1; Figure 1). Three sites were located each on 1st, 2nd and 3rd order streams. One site was a 4th order stream. The ‘order’ of a stream refers to its relative size based on a hierarchy of tributaries. In the application of the Strahler stream order system (Strahler, 1957), each segment of a stream is treated as a node in a ‘tree’, with the next segment downstream as its parent. When two first-order streams come together, they form a second-order stream, two second-order streams join to form a third-order stream, and so on. Streams of lower order joining a higher order stream do not change the order of the higher stream. Thus, if a first-order stream joins a second-order stream, it remains a second-order stream. Catchment size (upstream of the point of stream sampling) was calculated from a GIS.

Table 1. Intact moorland streams studied at Moor House NNR

Site name	Stream Order
Rough Sike	1st
Cottage Hill Sike	1st
Unnamed 1st Order	1st
Moss Burn	2nd
Green Burn	2nd
Unnamed 2nd Order	2nd
Upper Trout Beck	3rd
Trout Beck ECN	3rd
River Tees 3rd Order	3rd
River Tees 4th Order	4th

Streams were sampled quarterly between June 2007 and September 2008, with all samples collected across two to three days (2007: June, 04 – 05; Sept., 03 – 05; Dec., 04 – 06; 2008: Mar., 05 – 07; June, 04 – 06; Sept., 02 – 04). On each sampling date, 16 stream environmental variables were measured to provide contextual habitat information. These measurements included water temperature, pH, electrical conductivity (EC) and dissolved oxygen (DO) concentration. In addition, 120 ml of stream water was passed through a 0.45µm filter and subsequently analysed for major anions (Cl, SO4 and NO3), dissolved organic carbon (DOC) and trace metals (Al and Fe). A further 500 ml of unfiltered stream water was collected for determination of suspended sediment concentration (SSC) by filtration in the laboratory. Streambed sediments were characterised by randomly sampling 100 clasts, measuring b-axis lengths and calculating the median grain size (D_{50}). To provide a relative indication of flow differences between sites and over time, stream discharge (Q) was measured at the time of sampling using the velocity-area method.

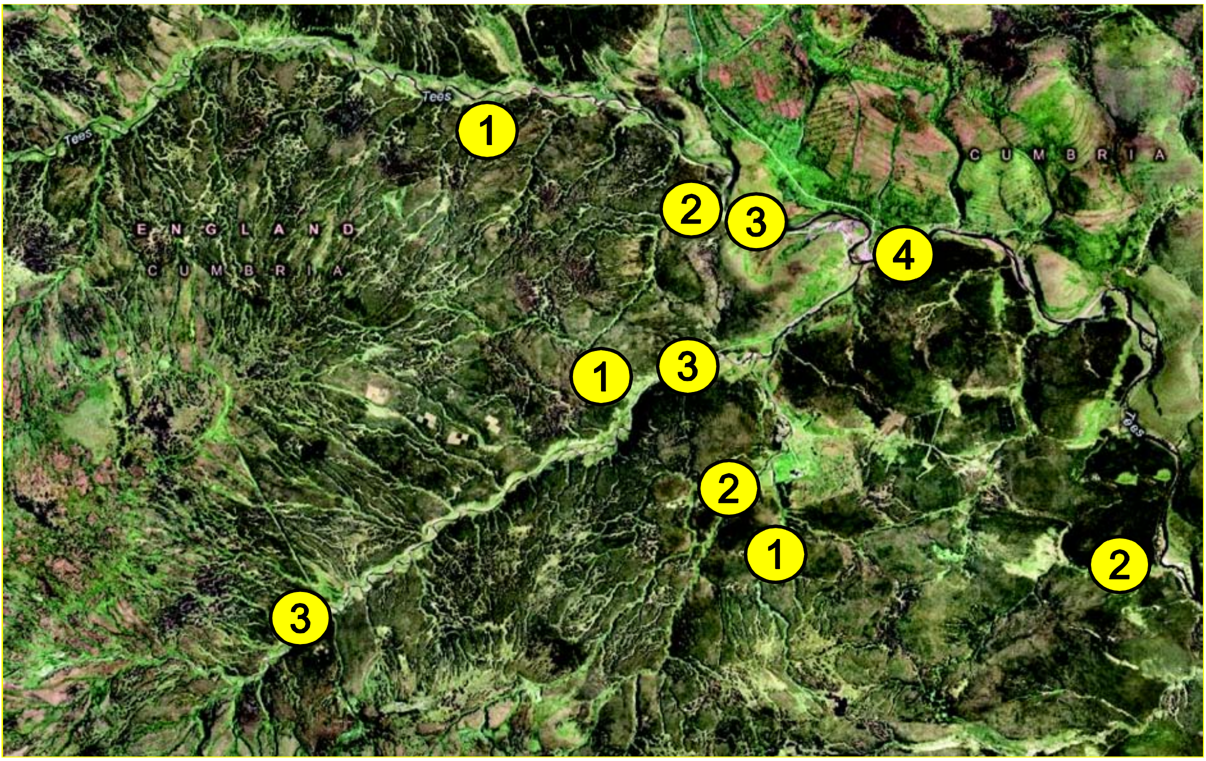

Figure 1. Aerial view of Moor House National Nature Reserve showing location of study sites for aim 1 and 2 on the River Tees, Trout Beck and tributaries. Numbers refer to stream orders 1-4.

For project aim 2, aquatic invertebrate, river flow and stream chemistry datasets were obtained from the Environmental Change Network (ECN) monitoring site (3rd Order stream) located on Trout Beck at Moor House NNR. Here, aquatic invertebrates have been collected three times per year dating back to 1997. These datasets provided an excellent opportunity to put the results of our study from 2007/08 into a longer-term inter-annual and seasonal context.

For project aim 3, three additional streams were monitored in 2nd order streams draining moorlands managed by rotational burning of heather and grass. These sites were spread more widely across the North Pennines as our aim was to study river systems where the effects of burning would not be confounded by other management activities such as artificial drainage or drain blocking. Site 1 was at New Water (Grid ref: NY 597510) and site 2 on Great Eggleshope Beck (NY 962310). Site 3 was just outside the North Pennines AONB near Bowes on Eller Beck (NY 999106). Results from these sites were compared with those from the 2nd order streams sampled at Moor House NNR. For added value beyond what we proposed in our initial proposal for Peatscapes funding, we also collected aquatic invertebrates from streams draining moorlands that are artificially drained: Killhope Burn (NY 806432), Old Water (NY 595533) and Camm Beck (NY 826815) and moorland where drains have been blocked (South Tyne [near Tynehead, NY 758367], Crook Burn (NY 780355) and Oughtershaw Beck [Wharfedale, NY855825]. This additional work formed part of Sorain Ramchunder's PhD which was primarily funded by the Natural Environment Research Council.

Field and laboratory methods

For project aim 1, streams were sampled every three months from June 2007 to June 2008 to allow an investigation of seasonal environmental and aquatic invertebrate community dynamics in addition to spatial patterns. For project aim 3, streams were sampled in September 2007. Five replicate $0.05m^2$ Surber samples for aquatic macroinvertebrates were collected randomly from each stream using a 250µm mesh net. All samples were preserved in 70% ethanol in the field then transported back to the laboratory for sorting and identification. Organisms were sorted and separated from Coarse Particulate Organic Material (CBOM) and sediment by hand and stored in 70% ethanol. Organisms were subsequently identified under a light microscope (x40 magnification) to the lowest possible taxonomic level. Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies) and Coleoptera (beetles) were identified to species. Other groups were identified to genus/family. Voucher specimens of most taxa that were identified to species level were sent to national experts for verification.

Data analysis

The five replicate aquatic invertebrate samples collected for each site/date were pooled to enable clearer elucidation of temporal trends. Macroinvertebrate community structure was summarised using five metrics:

(1) Total abundance expressed. Data were $\log_{10}(x+1)$ transformed to ensure normality and homogeneity of variance for statistical tests,
(2) Number of taxa (i.e. taxonomic richness),
(3) Number of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa,
(4) Taxonomic dominance or evenness (*D*) estimated using the Berger-Parker index:

$$D = N_{\max} N$$

Where *Nmax* is the number of individuals in the most abundant species and *N* is the total number of individuals collected
(5) Taxon relative abundances

Principal component analysis (PCA) was used to examine inter-relationships between the 16 environmental variables across all sampling dates. Principal components (PC) with eigenvalues >1 were retained, and the % variance of each recorded. Association between PC scores and: (i) catchment area (to determine influence of stream size on stream environmental variables), and; (ii) sampling date (to determine temporal dynamics of environmental variables) were assessed using linear and non-linear regression, with the model which produced the highest (and statistically significant) R^2 being retained in each instance.

Main Results

Project aim 1

Mean suspended sediment concentrations (SSC), dissolved organic carbon (DOC), coarse particulate organic matter (CPOM) and particulate organic matter (POM) decreased with increasing stream order, while mean water temperature, pH and D_{50} increased. Minimum pH, increased with stream order while maximum SSC and aluminium (Al) declined. Principle component (PC) 1 had strong positive loadings (>0.5) of SO4, EC, pH and D_{50} and strong negative loadings of SSC and Al. PC2 had strong positive loadings of Cl, NO3, coarse and total particulate organic matter, and a strong negative loadings of water temperature. PC1 showed a positive and significant relationship with catchment area while PC2 showed a unimodal relationship with sampling date (Figure 2).

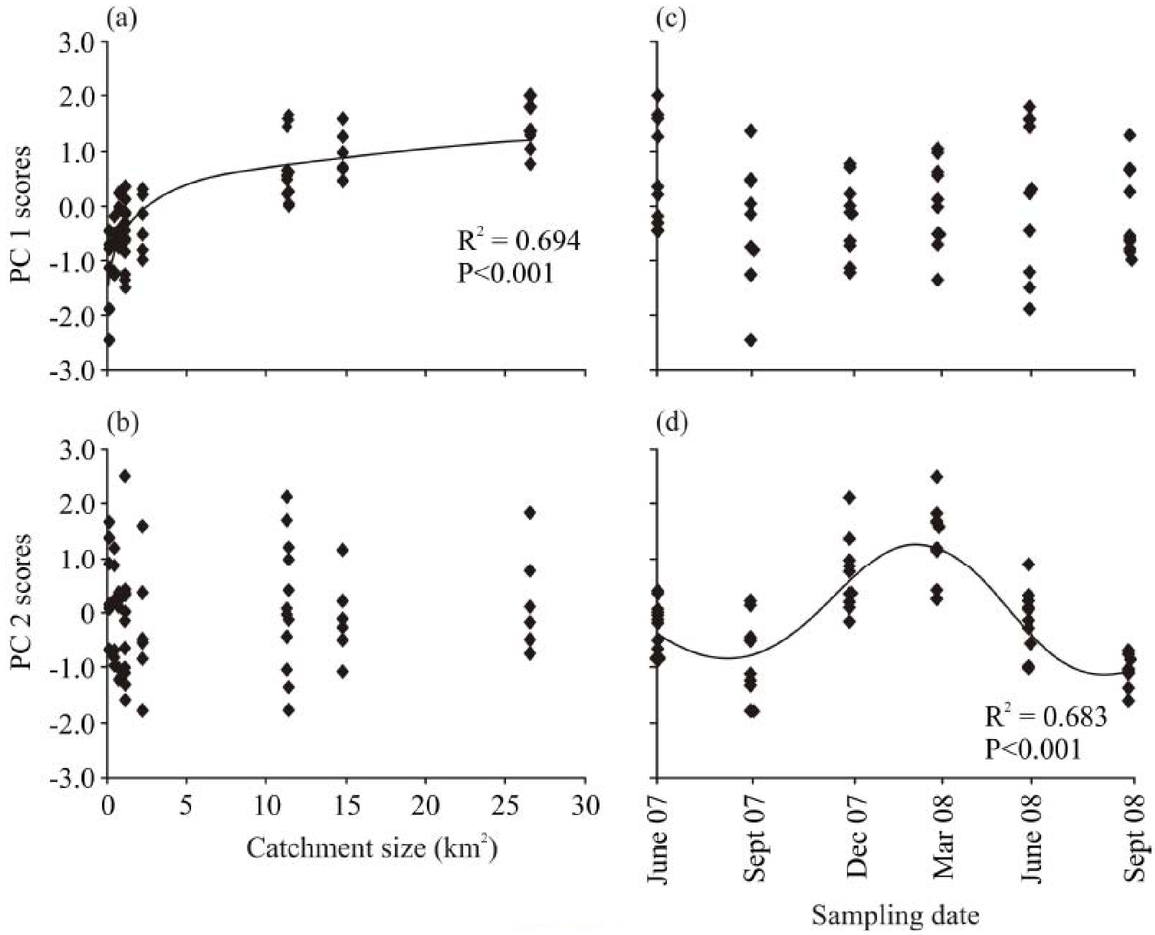

Figure 2. PCA scores as a function of catchment size (a & b) and sampling date (c & d)

We identified over 100 freshwater invertebrate species from the ten streams studied at Moor House NNR, including some 25 stoneflies (Plecoptera), over 20 mayflies (Ephemeroptera), over 20 caddis flies (Trichoptera) and several beetles (Coleoptera). Average taxonomic richness was between 20-33 aquatic invertebrate taxa per 0.25m^2 of streambed sampled (Table 2). The highest total abundance was recorded in the 4th order River Tees while mean richness was highest in the 3rd order streams (Figure 3). Dominance was greatest on average in the 1st and 2nd order streams. The lowest total abundance and richness were documented in the 1st order streams while the lowest dominance was observed in the 2nd order streams. Chironomidae relative abundances were typically highest in the 1st and 2nd order streams although Plecoptera made up large proportion of these streams' invertebrate assemblages from September-March (Figure 4). There were no significant differences in community metrics between stream size (order) nor changes over time. Relative abundances of Ephemeroptera and Other taxa (largely Coleoptera) increased with stream order.

Table 2. Average richness, Total abundance, EPT richness and Dominance of aquatic macroinvertebrates in streams of Moor House NNR.

	Rough Sike	Unnamed 1st	Cottage Hill Sike	Moss Burn	Green Burn	Unnamed 2nd	Upper Trout Beck	Trout Beck ECN	Lower Tees 3rd	Tees 4th
Richness	31	22	23	32	32	20	31	32	33	31
Abundance (# per m^{-2})	183	223	472	227	224	232	275	269	399	466
EPT richness	21	15	14	21	20	14	21	22	23	22
Dominance	0.28	0.50	0.51	0.30	0.32	0.60	0.32	0.27	0.36	0.36

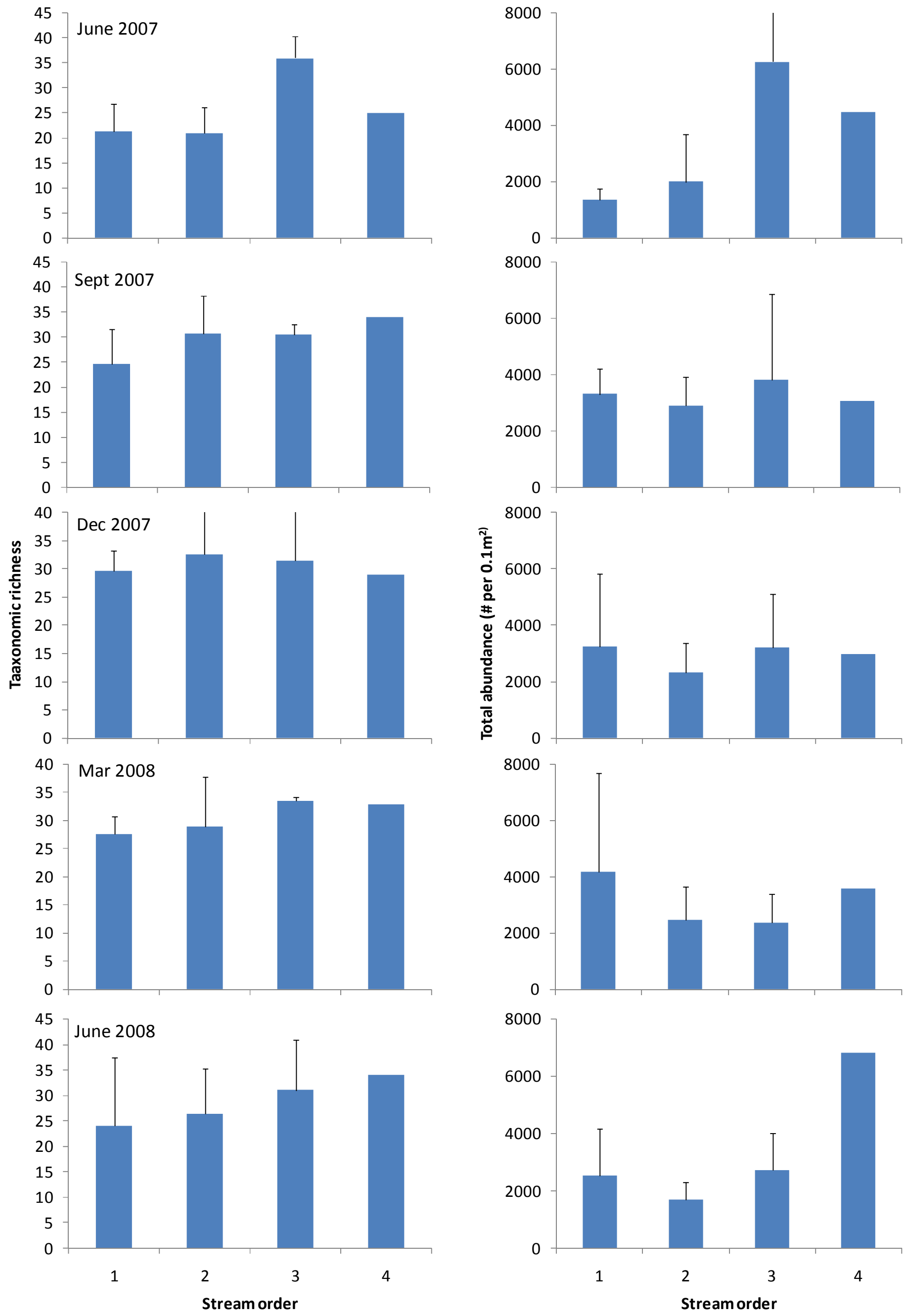

Figure 3. Seasonal (quarterly) changes in taxonomic richness (left) and total aquatic invertebrate abundance (right). Error bars denote one Standard Deviation from the mean

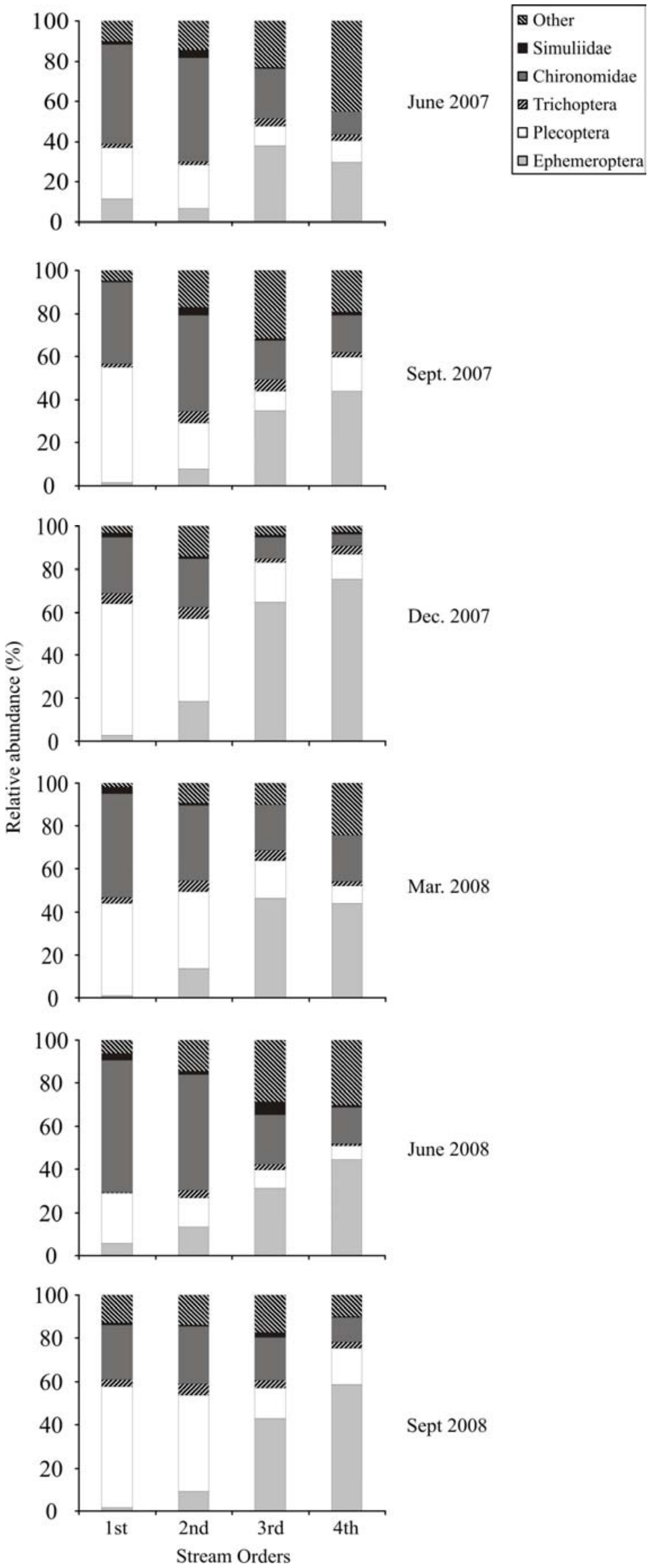

Figure 4. Spatial and seasonal changes in the mean relative abundance of EPT, Chironomidae, Simuliidae and Other taxa

At the species level, our results showed that some mayflies and stoneflies were more closely associated with different sized streams (Figure 5). For example, the Willow Stonefly, *Leuctra inermis* was found across all stream types whilst larger predatory stoneflies *Perla bipunctata* and *Dinocras cephalotes* (both common names = large stonefly) were found at highest abundance in the larger streams (3rd order). Similarly, amongst the mayflies, the Large Dark Olive *Baetis rhodani* was found in all stream orders albeit at higher abundance in 3rd order rivers. In contrast, the Olive Upright *Rhithrogena semicolorata* and the Autumn Dun *Ecdyonurus dispar* were typically found only in 3rd order streams.

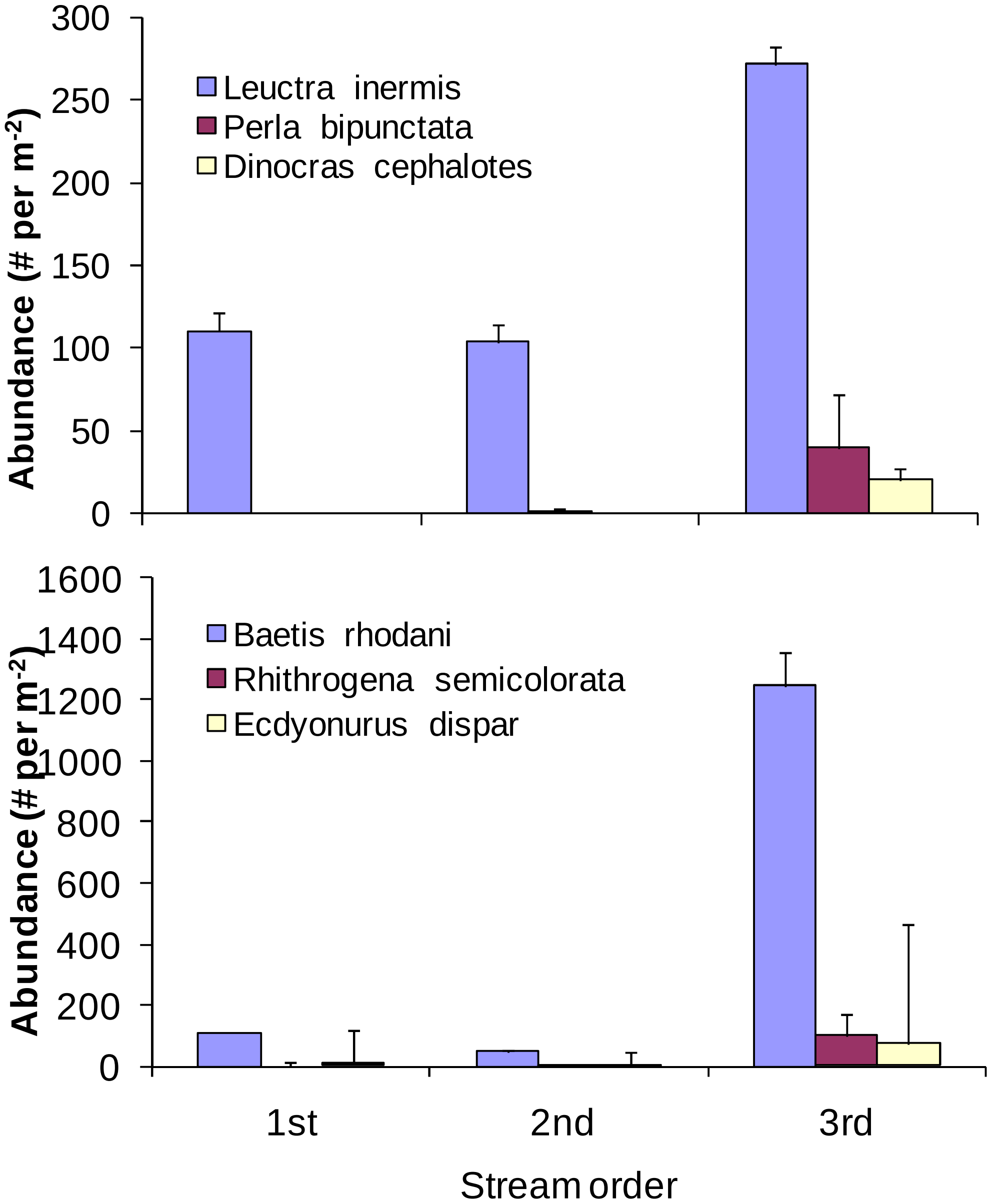

Figure 5. Spatial variations in the abundance of three stoneflies (top) and three mayflies (bottom) in June 2007. Error bars denote one Standard Deviation from the mean

Project aim 2

Data collected by the ECN at Trout Beck within Moor House NNR show a cyclical pattern in the abundance of aquatic invertebrates (Figure 6). The number of taxa appeared to vary little over time, typically ranging from 25 to 30, similar to the level of diversity we found at other streams across Moor House. Our ongoing research will examine these temporal patterns with respect to changes in stream flow and stream chemistry using archived ECN datasets. Individual species showed relatively large inter-annual variability in the size of their populations in Trout Beck. For example, the abundance of *Baetis rhodani* and *Leuctra inermis* varied by approximately one order of magnitude (20 to >200) over the 12 years of data collection (Figure 7). In contrast, abundances of two larger predatory stoneflies (*P. bipunctata, D. cephalotes*) remained relatively low and constant for the duration of the study.

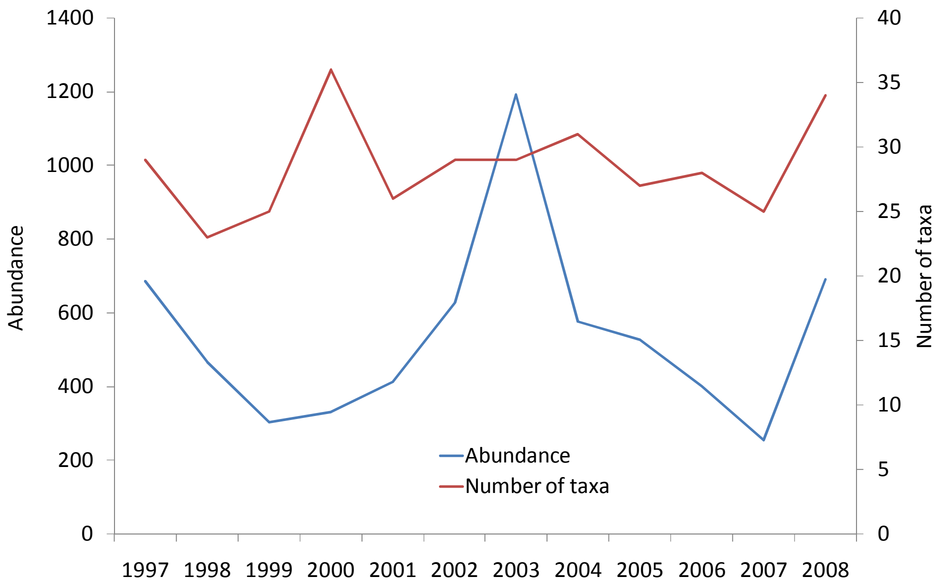

Figure 6. Temporal changes (April; 1997-2008) in the number of species and total abundance of aquatic invertebrates from Trout Beck, Moor House.

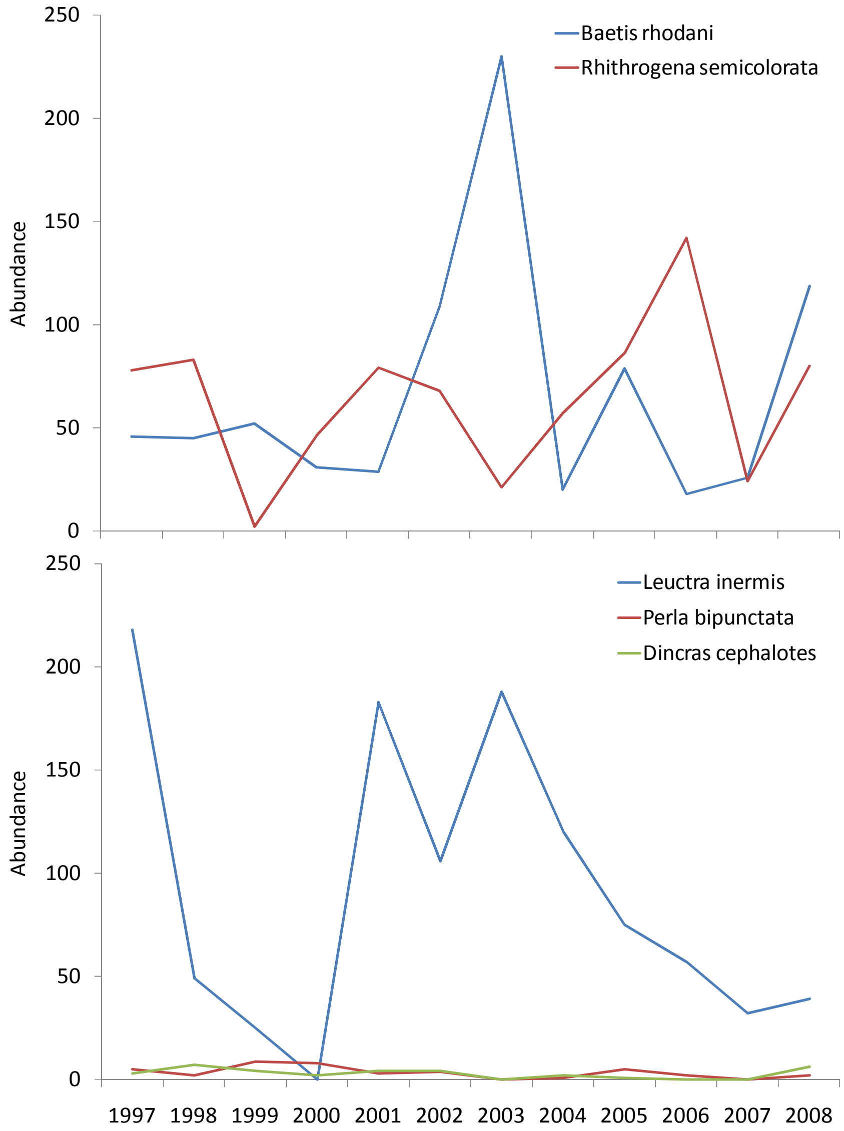

Figure 7. Temporal changes (April; 1997-2008) in the abundance of selected mayflies (top) and stoneflies (bottom) from Trout Beck, Moor House.

Project aim 3

Our preliminary results from September 2007 indicate artificial drainage, drain-blocking and burning to cause no significant differences to the total abundance or taxonomic richness of aquatic invertebrate communities when compared with assemblages from intact moorland (Figure 8). However, analysis at the species level reveals that drainage and burning may be detrimental to some species of aquatic invertebrates (Figures 9-11).

For example, the Autumn Dun Mayfly (*Ecdynurus dispar*) had significantly lower abundance in streams from artificially drained or burned moorland than control sites (Figure 9). Interestingly, drain blocking appears to be beneficial in allowing *E. dispar* abundance to increase back to control site levels. This could be related to reduced levels of fine sediment; Holden *et al.* (2007) for example found drain-blocking could reduce suspended sediment concentrations by two orders of magnitude and that drains that were unblocked in Upper Wharfedale draining only 7% of the catchment produced 18% of the suspended sediment found in the main river channel. Artificial drainage and burning appeared to be detrimental to some species of stonefly (e.g. the Common Yellow Sally [*Isoperla grammatica*] and the Large Stonefly [*Perlodes microcephala*]; Figure 10) while drain-blocking again appeared beneficial. However, some species seemed to be unaffected by such management effects. For example, the Large Dark Olive Mayfly (*Baetis rhodani*; Figure 9) had similar abundances across all four of the moorland management methods. Moreover, some True-Flies (Chironomidae [non-biting midges] and Simuliidae [Black-flies]) appeared to benefit from artificial drainage and burning with increased abundance (Figure 11). However, these aquatic insects that appear not to be impaired by artificial drainage and burning (*Baetis*, Chironomidae and Simuliidae) are typically widespread and tolerant to disturbance in many stream systems.

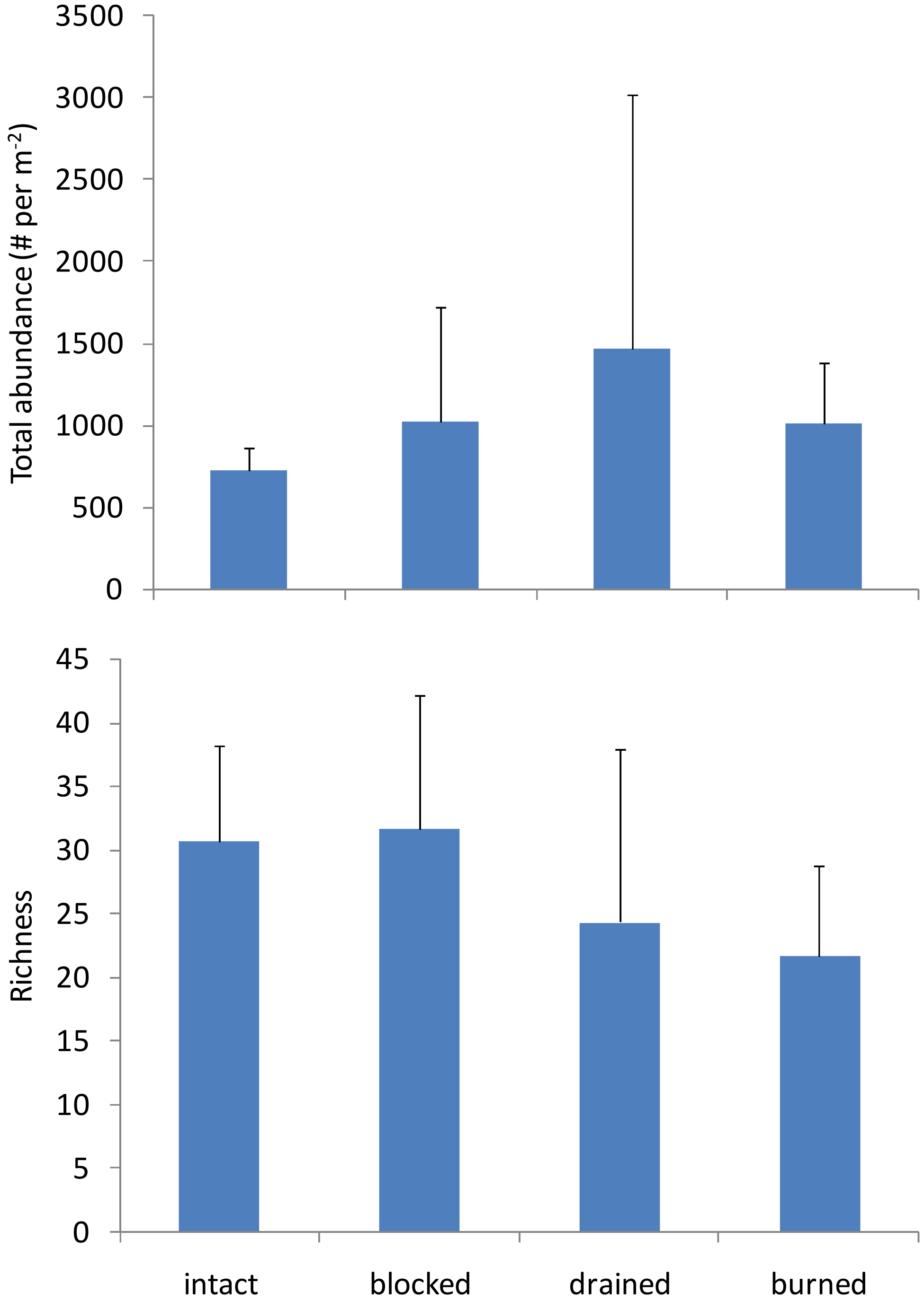

Figure 8. Total abundance (top) and taxonomic richness (bottom) of aquatic invertebrate larvae from streams draining intact (i.e. no management), drain-blocked, drained and burned moorland in September 2007. Error bars denote one Standard Deviation from the mean

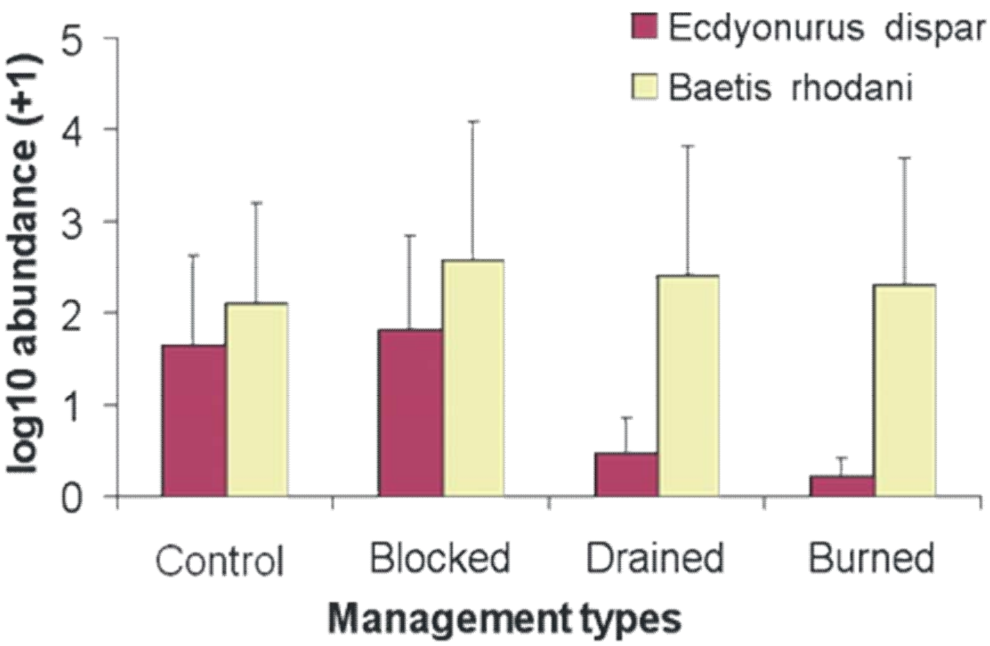

Figure 9. Abundances of two species of Mayfly in streams draining moorland river basins subject to different forms of management, September 2007. Error bars denote one Standard Deviation from the mean

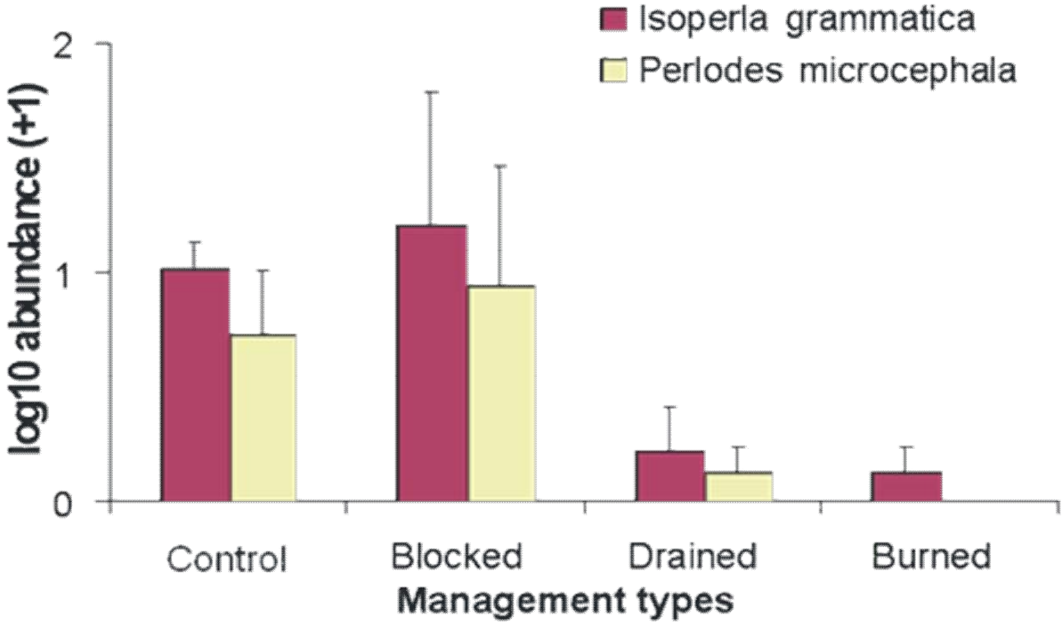

Figure 10. Abundances of two species of Stonefly in streams draining moorland river basins subject to different forms of management, September 2007. Error bars denote one Standard Deviation from the mean

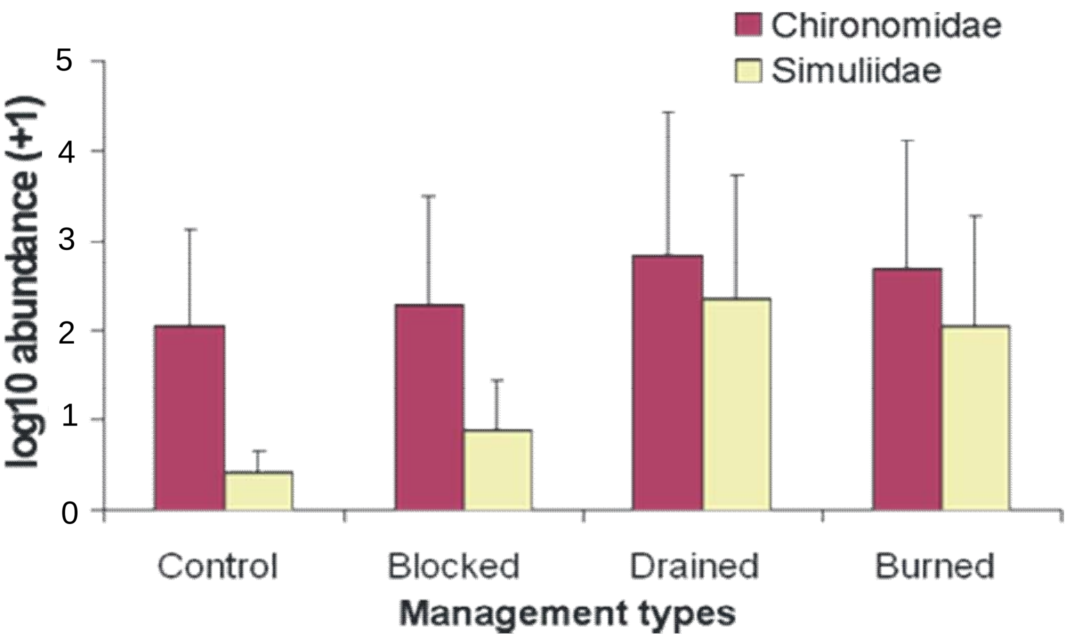

Figure 11. Abundances of two families of Diptera (True Flies) in streams draining moorland river basins subject to different forms of management, September 2007. Error bars denote one Standard Deviation from the mean

Key findings to date

1. *High diversity of aquatic invertebrate larvae at Moor House NNR, with over 100 taxa being documented from just 10 of the many streams*. This underlies the importance of this nature reserve for protecting large numbers of species as suggested by other studies (e.g. Armitage, 1974).
2. *Changes in the abundance of some species as catchment size increased*. This finding might suggest a need for conservation and management to be targeted not only at small headwater streams flowing across peat but those that are larger and flow in the valley bottoms.
3. *Inter-annual fluctuations in aquatic invertebrate larvae were evident from one of our sampling sites (Trout Beck) as measured over 12 years.* This suggests that long-term studies should be carried out more widely to understand the reasons for changes in the size of aquatic invertebrate populations. For example, our studies in 2007-08 were at a time when the total abundance in Trout Beck was at a low point across the last 12 years. There is a possibility that different results could be obtained if samples were collected in years that have conditions favourable for higher abundance of aquatic invertebrates (e.g. 2003; Figure 6).
4. *Moorland management such as artificial drainage and burning appeared to cause no significant change in the abundance or richness of aquatic invertebrate larvae.*
5. *Moorland management such as artificial drainage and burning were associated with changes to individual species' abundances.* This perhaps implies that there are compensatory effects, where some intolerant invertebrates (e.g. certain mayflies or stoneflies) are lost from streams in drained or burned catchments and replaced by more opportunistic taxa such as non-biting midge larvae (Chironomidae) or blackfly larvae (Simuliidae).
6. *These studies on moorland streams invertebrate assemblages are some of the most detailed to date, particularly with respect to the effects of moorland management effects on aquatic ecosystems.* With further analysis and consideration, we hope that the results of this project will serve as important milestones in our understanding of UK upland aquatic ecosystem structure.

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A more detailed analysis of the data for aim 1 can be found in:

Ramchunder, S.J, Brown, L.E. & Holden, J. Spatial and seasonal variability of UK peatland stream ecosystems. *Ecohydrology*. [Accepted for publication, 11/10/10]