Significance of large peat blocks for river channel habitat and stream organic budgets

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SUMMARY

This paper examines the significance of large peat blocks in Trout Beck, an upland gravel-bed river in northern England. An inventory was made of all in-channel peat blocks over a 1.5 km reach of the river in order to characterise the distribution of the blocks, and benthic organic matter and periphyton were sampled from the gravel around an isolated in-channel peat block over a period of four months. Three suspended sediment samplers were installed adjacent to the block to provide estimates of organic drift. At reach scale, peat blocks can be traced to local sources of river bank erosion and show strong downstream fining trends. Analysis of organic matter fluxes indicates that large amounts of peat are eroded from blocks and this substantially increases local organic drift. Microscopic analysis of organic matter particles demonstrates the overwhelming dominance of allochthonous peat in suspension (~ 75 %). Some of this is deposited locally, but in general the amount of organic matter in the drift is substantially greater than that stored in the gravel bed. Therefore, although eroded peat is abundant in the channel system, it is easily transported by the river and thus contributes little to local benthic organic matter storage.

KEY WORDS: benthic ecosystems, Moor House, organic matter, sedimentation, upland streams.

INTRODUCTION

Studies on the effects of obstacles (mainly large woody debris, boulders and ice blocks) and their associated sedimentation in rivers have provided useful information on the geomorphological processes acting around such obstructions. These obstacles create patterns of sediment scour and deposition that arise from the complex flow structures that are created in the channel. Examples have been reported for large woody debris in small streams (Keller & Swanson 1979), ice jams (Smith & Pearce 2002) and boulders in steep mountain channels (Zimmerman & Church 2001, Carling *et al*. 2002). Recent observations and experiments from the North Pennines (northern England) have shown that macro-sized (*b* axis 0.5–2.5 m) peat blocks form a significant stream load component and exert an important influence on sedimentation in gravel-bed rivers (Evans & Warburton 2001) (Figure 1) and narrow peatland streams (Figure 2). In many low order, high gradient upland channels, where large woody debris is sparse, channel obstacles are commonly composed of boulders, cobbles (Carling *et al*. 2002) and, in peatland channels, peat blocks eroded locally from banks and hillslopes (Evans & Warburton 2001).

Ecological studies (Greenwood *et al*. 1999, Rice *et al*. 2001) have shown the importance of flow and sediment in controlling invertebrate ecosystem dynamics. Heterogeneity caused by changes in flow and channel bed topography affects not only aspects of the physical habitat such as sediment size and turbulence, but also food resources and waste removal (Palmer *et al*. 2001). Spatial heterogeneity or ‘patchiness’ is mostly discussed with reference to physical components that describe either the hydraulic (i.e. turbulence, stress) or sedimentary (i.e. particle size, microtopography) conditions. Numerous studies have described the differences between riffle and pool habitats (e.g. Bussock & Brown 1991), and it is now recognised that in-channel conditions are also non-uniform across the channel. Their patchy distribution (Townsend 1989, Passy 2001) can be important in understanding the processes which act during floods and which areas of a channel act as refugia. The idea of *Hydraulic Dead Zones*, originally used to describe the retention of phytoplankton in rivers (Reynolds 1988), has now been used to describe the retention of solutes (*Aggregated Dead Zones*, Wallis *et al*. 1989) and invertebrates and organic matter (*Dispersive Fraction*, Lancaster & Hildrew 1993). Other types of patch habitats include those created by woody debris (Hilderband *et al*. 1997), complex channel structure (Greenwood *et al*. 1999), and

Figure 1 (above). Large peat blocks (long axes up to 2.5 m) deposited downstream of an eroding peat bank in Trout Beck, North Pennines, UK.

Figure 2 (left). Peat blocks deposited in Rough Sike, a small upland stream in the North Pennines, UK. The blocks span the full channel width (*ca*. 1m) and control sedimentation and water levels upstream and downstream of the obstruction.

sedimentary features such as pebble clusters and cobbles (Bouckaert & Davis 1998). In peatland streams, patchiness in the channel environment is also caused by the presence and distribution of large peat blocks (Evans & Warburton 2001). These macro-sized elements have the potential to add significantly to instream refugia and also to increase the range of micro-habitats in upland rivers.

In stream ecosystems, flow brings food (organic matter) (Benke 1996) which can be divided into two types according to its source, namely *allochthonous* (catchment derived) and *autochthonous* (originating within the channel, e.g. epibenthic algae, aquatic macrophytes and macroinvertebrates) (Minshall *et al*. 2000). The majority of deposited and transported organic matter in upland and mountain fluvial systems is allochthonous because the channel has low primary productivity, mainly due to epibenthic algae (Burns 2001). Therefore, upland rivers that run through peatland have potentially enhanced organic matter concentrations due to inputs in solution and as particulate peat from the adjacent catchment, in concentrations that can vary with the degree of catchment damage (Worrall *et al*. 2003, Evans & Warburton 2005).

Downstream fining of mineral sediment occurs through abrasion and selective transport (Ferguson & Ashworth 1991) and is disrupted through lateral inputs of coarse material (Rice & Church 1998). Organic matter similarly undergoes downstream fining through processes such as abrasion, microbial breakdown, hydraulic settling and consumer consumption. Thus, stream organic matter occurs in a wide range of sizes due to the various processes that act on individual particles (Figure 3), and classifying the particles by size provides a useful description. Peat blocks represent the mega-scale fraction of the distribution and can be up to several metres in length (Figure 1). Typically, organic matter concentration is found to increase with decreasing particle size, but the relationship is complicated by variations in organic matter retention with substrate roughness, coarser sediment with more pronounced microtopography retaining most organic matter (Beisel *et al.* 1998). Recently, there has been renewed interest in looking at fluxes of organic matter fractions and organic matter dynamics in stream channels in conjunction with attempts to construct stream organic matter budgets (Benda & Sias 2003). While many studies have

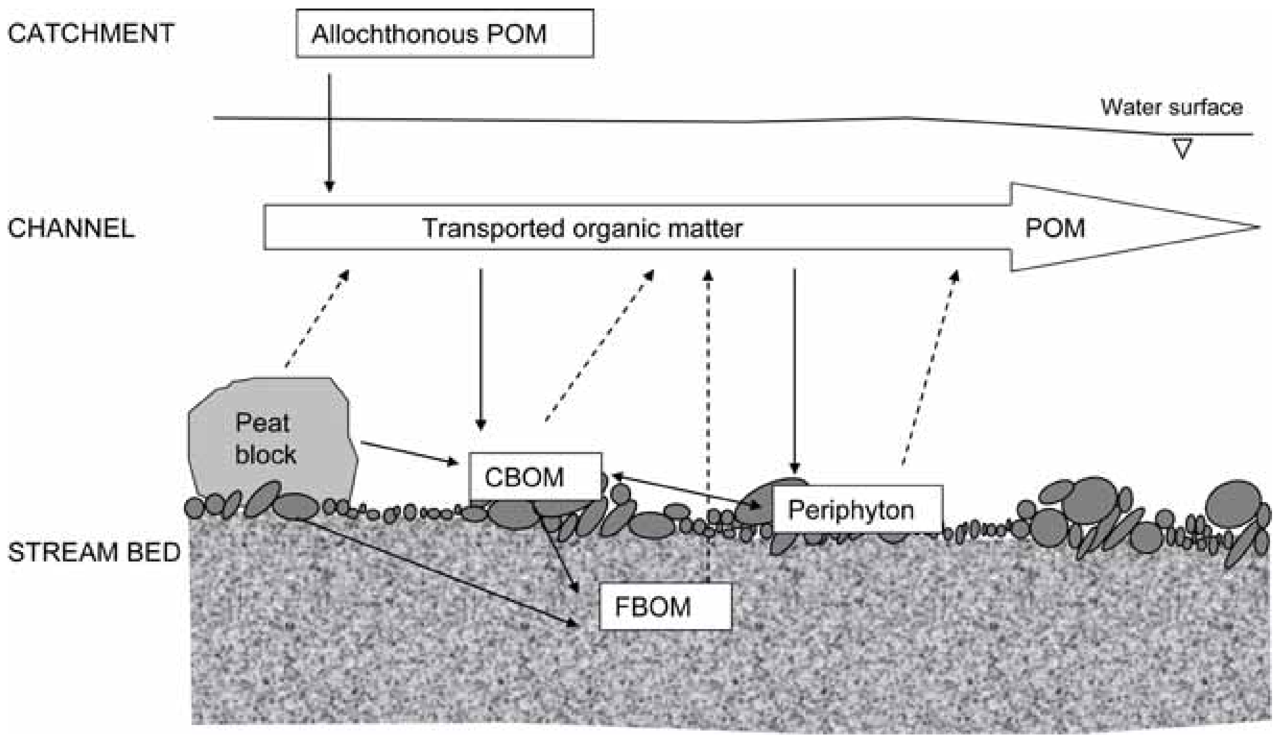

Figure 3. Particulate organic matter (POM) exchanges in an upland gravel-bed stream. The diagram shows the important components considered in this study; in particular large peat blocks, the coarse benthic organic matter (CBOM) and periphyton, and fine benthic organic matter (FBOM). POM can be further subdivided into coarse, fine and very fine fractions (see text). Dissolved organic matter and other pathways are not all illustrated.

incorporated organic matter measurements into assessments of invertebrate communities (Rempel *et al*. 1999, Beisel *et al*. 2000), the characterisation of the organic matter component has often been secondary to the collection of invertebrates. The small number of studies that have included collection of detailed organic matter data have mostly described forested catchments (Webster & Meyer 1997), and very few have looked in any detail at peat catchments (Crisp 1966) or quantified the different sources of organic matter. Egglishaw & Shackley (1971) looked at suspended organic matter (seston – defined as suspended particulate matter such as phytoplankton and organic detritus) in two rivers in Scotland. At low flows, particles tended to be conglomerates of fine material at an advanced stage of breakdown (45–85%) mixed with diatoms derived from stones and plants, and the fraction of terrestrially derived plant matter in the seston increased with flow. Armitage (1977) found that the drift in a North Pennine stream was dominated by peat and mineral particles (99%) derived from the surrounding peat-dominated catchment. Although high percentages of peat have been observed in stream water from other peat-dominated catchments, little attention has been paid to the constituent parts or to calculation of organic matter budgets.

Quantification of the terrestrial carbon budget has become highly significant in recent years, and its fluvial component has been shown to be very important (Worrall *et al*. 2003). There is still, however, a large gap in knowledge about how organic matter is stored and transported within stream channels (Evans & Warburton 2001). The work reported in this paper explored the role of large peat blocks both as sources of organic matter and in creating habitat variety. It is the first study of this kind, and the results have important implications for understanding the geomorphology and ecology of upland peatland channels and the fluxes of organic matter (carbon) from such catchments. The objectives of the research were:

1) to establish the distribution and dimensions of in-channel peat blocks, their local sedimentation patterns and organic contents;
2) to establish the contribution of peat blocks to organic drift by monitoring sediment and organic fluxes and comparing this to channel bed organic matter storage and periphyton concentrations; and
3) to outline a preliminary local organic matter budget for in-channel peat blocks.

METHODS

Study area

Work focussed on the 11.4 km^2 Trout Beck catchment of the upper River Tees (Figure 4), within the Moor House and Upper Teesdale National Nature Reserve in northern England. The bedrock geology of the catchment belongs to the Carboniferous series and is composed of inter-bedded sandstone, shale and limestone. The surficial geology consists of periglacial deposits of re-worked till and river floodplain overbank deposits which are mostly overlain by blanket peat (90% cover) 1–3 m deep. Approximately 17% of the peat blanket is eroded (Garnett & Adamson 1997), with dendritic gullying dominating on lower angled slopes and linear gullying on the steeper slopes (Bower 1961). Annual rainfall is just under 2000 mm and concentrates rapidly into runoff; lag times between peak rainfall intensity and peak discharge can be as little as 30 minutes (Burt *et al.* 1998). Discharge gauged on Trout Beck just below the main study reach was low to moderate during the May–July 2002 study period, with peak flows just over 5 m^3 s^{-1}. The upstream boundary of the study reach is defined by the apex of a river bend where the channel is actively undercutting floodplain sediments consisting of fluvial deposits overlain by thick peat. Erosion of gravels produces cantilever bank failures which deposit large quantities of peat and peat blocks in the stream (Figure 1). As in other upland rivers, the stream bed is composed of coarse, poorly sorted, predominately cobble substrate with D_{50} (50^{th} percentile substrate diameter) values ranging from 8 to 80 mm (median 35 mm).

Reconnaissance survey

A reconnaissance survey of 150 peat blocks was carried out on a 1.5 km reach upstream of the confluence of Trout Beck and the River Tees, in order to establish their pattern of distribution over a representative section of channel. For each peat block, measurements of the *a* (largest), *b* (intermediate) and *c* (smallest) axes, depth of scour in the lee and at the side of the block, the length of the sedimentation tail of the wake (if present) and details of the depositional environment were recorded.

Field experiment

A peat block sourced from a local cut peat bank was placed on a coarse gravel riffle at the left side of the channel. Its dimensions (1 × 1 × 0.5 m) were chosen on the basis of the reconnaissance survey results to represent a typical freshly deposited block, and it was placed in a section of the channel where similar blocks had been recorded previously but in an area where it would not be significantly influenced by

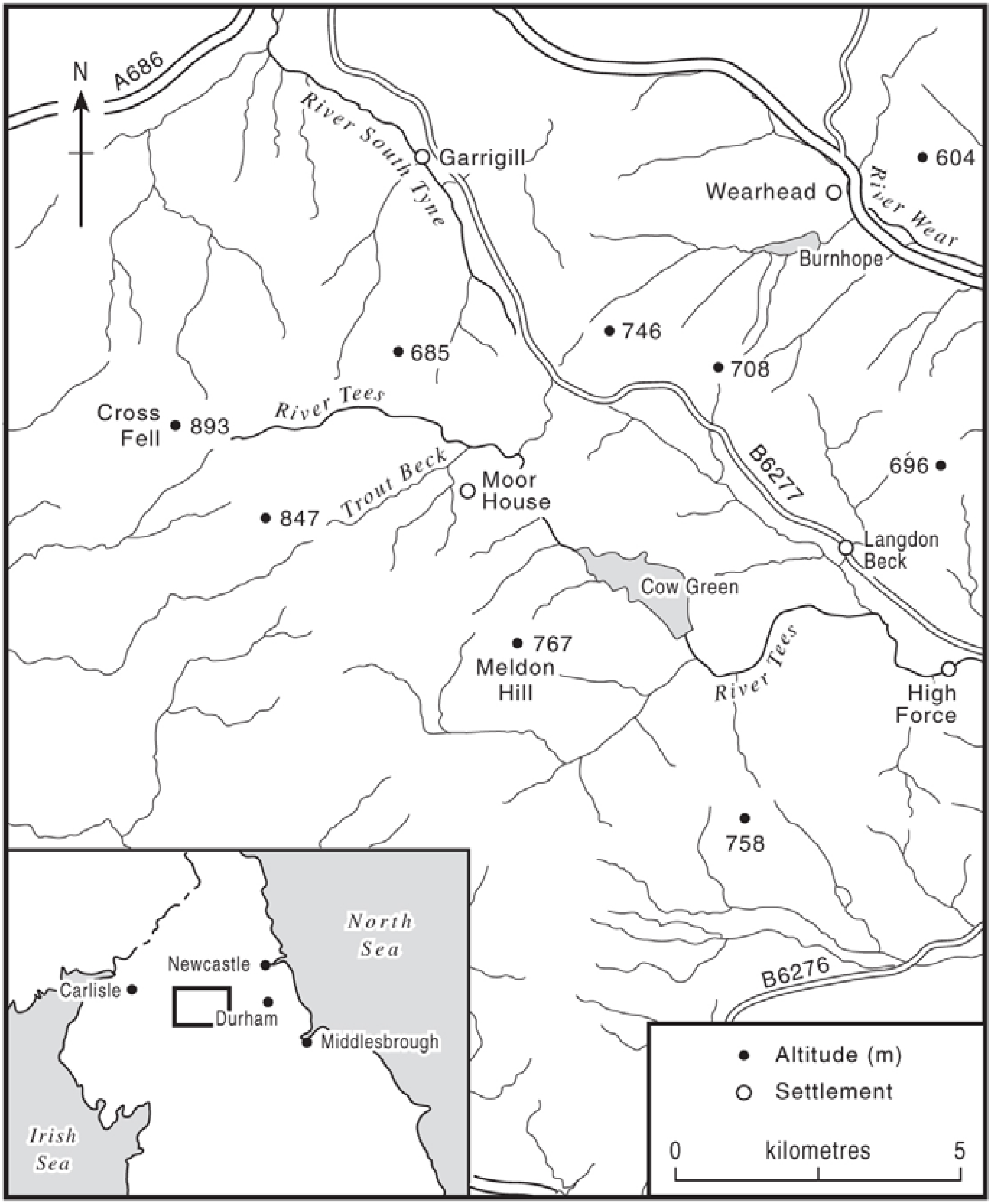

Figure 4. Field site location map showing the position of Trout Beck in northern England.

adjacent blocks (Figure 5). A survey of the channel was conducted before introduction of the block using eight fixed sampling points arranged around its planned position. Once the block had been placed, weekly samples were taken at the same points over a period of six weeks in May–July 2002, taking great care to minimise disturbance of the stream bed and to avoid re-sampling of pre-disturbed areas.

Periphyton samples were taken from rocks using a sampler designed to collect material from a 2.5 cm^2 area (Davis *et al*. 2001). Sample collection followed the method described by Loeb (1981). At each sampling point, five rocks were collected and placed in a tray containing water. The sampler was then attached to a rock and rotated so that the brush removed and collected all the periphyton. This was carried out on all sides of each rock. Samples were transferred to collection tubes for transport to the laboratory where they were stored in a refrigerator. They were then filtered through pre-weighed Whatman GF/C (1.2 μm retention) filter papers which were placed in pre-weighed crucibles for re-weighing.

Benthic Organic Matter was measured in bulk samples of material from the channel bed. The surface armour layer (mainly large cobbles) was collected, measured for grain size calculations, and any organic matter (which typically included a range of organic matter sizes) removed by washing. Approximately 1kg of the subsurface gravel layer was then collected and placed in a strong polythene bag, returned to the laboratory and stored in a refrigerator prior to analysis. Gravel samples were shaken in a nest of 1 mm and 0.25 mm sieves with a bottom base tin to divide them into three parts

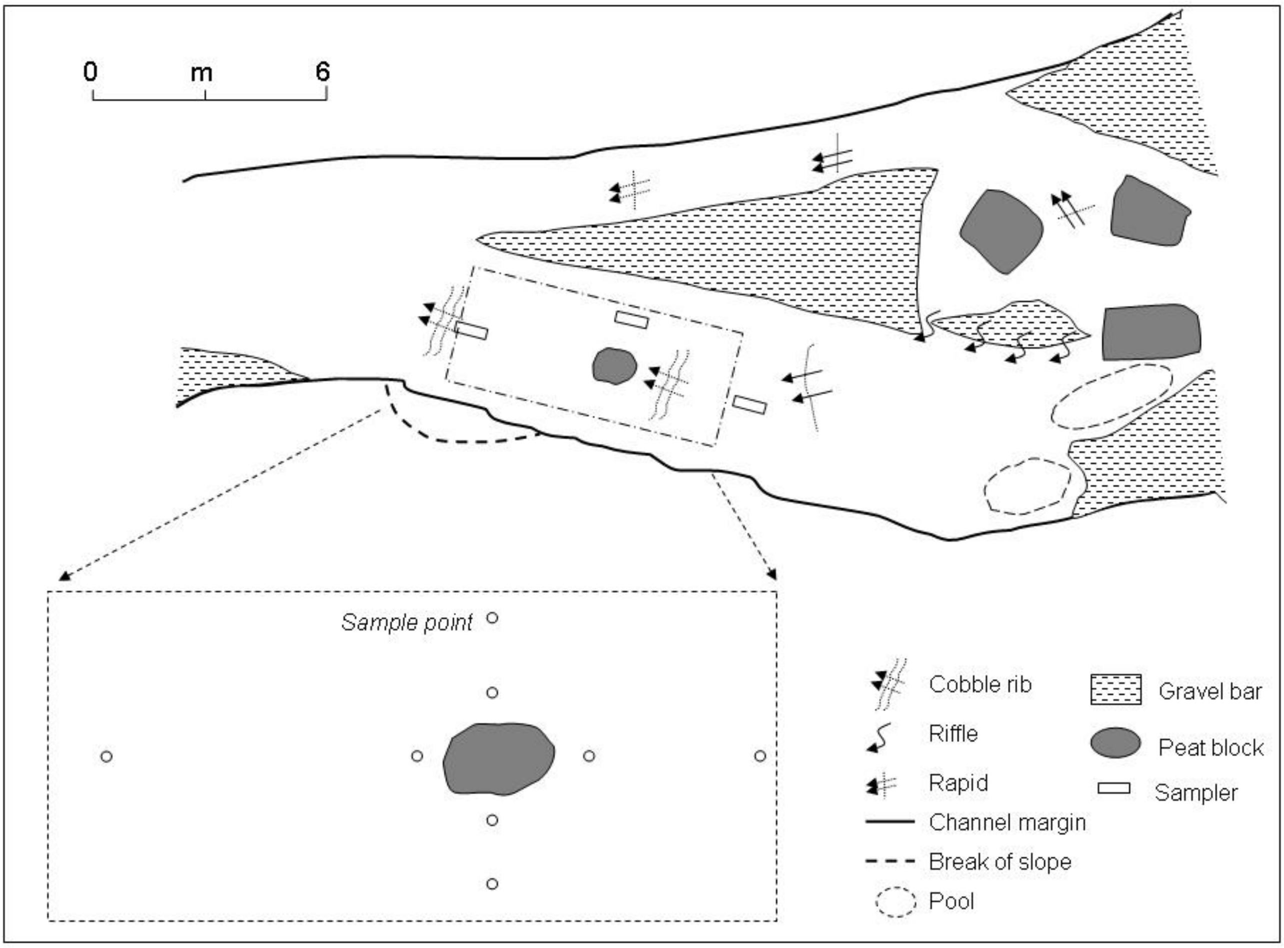

Figure 5. Plan of the experimental reach showing key channel characteristics and the sampling framework. The inlay shows the locations of the stream substrate sampling points at which benthic organic matter and periphyton concentrations were determined. The peat block was placed slightly to the right of the channel centreline and bed sampling was undertaken at eight points around it. Sampling points closest to block (at 0.5 m): block head (right), block tail (left), block left (bottom) and block right (top). Other points: 3m upstream reference (far right), 4 m downstream reference (far left), left bank (far bottom) and right bank (far top).

which included the coarse particulate (1–2 mm), fine particulate (0.25–1 mm) and very fine particulate (<0.25 mm) organic matter fractions respectively. To obtain the weight of the organic matter component, three 1g sub-samples were taken and their Ash Free Dry Mass determined by a standard method involving ashing in a muffle furnace at 550^{o}C for 3 hours.

Seston was sampled using two types of in-channel sampler. The mass flux suspended sediment sampler (Phillips *et al*. 2000) consists of a streamlined 1m polythene tube 0.15 m in diameter with a 0.5 mm nozzle at each end. Three of these samplers were deployed in the channel 3 m upstream, 1.5 m alongside and 4 m downstream of the experimental block and left in place throughout the experimental period. At the end of the experiment, 250 ml of the contents of each sampler was retained for qualitative organic analysis and the remaining material was used for Ash Free Dry Mass determination. Qualitative analysis was carried out on three 50 ml allots of each sample using the method outlined by Winterbourn *et al*. (1986) to determine the proportions of peat, diatoms, mineralogenic and other material. The second method of seston collection was used to monitor short-term organic matter drift during a two day period of varying discharge. The samplers consisted of cylindrical PVC tubes (length 150 mm, internal diameter 98 mm), each fitted with a 1 m long bag with mesh size 250 µm, which was attached using steel cable (Saltveit *et al*. 2001). Three of these samplers were secured in the channel at 1 m adjacent to the peat block, in the immediate tail of the peat block, and 4 m downstream. The samplers were in-channel for three hours on two consecutive days. Their contents were emptied into pre-weighed glass beakers, dried at 102°C and re-weighed to obtain the dry mass of organic matter collected.

RESULTS

Reach-scale patterns of peat block deposition and local sedimentation

The distribution of peat block clusters at reach scale is shown by plotting the mean lengths of the *b* axes of the blocks against distance downstream (Figure 6). This shows that mean block length (*b* axis) tends to oscillate along the channel. The oscillations can

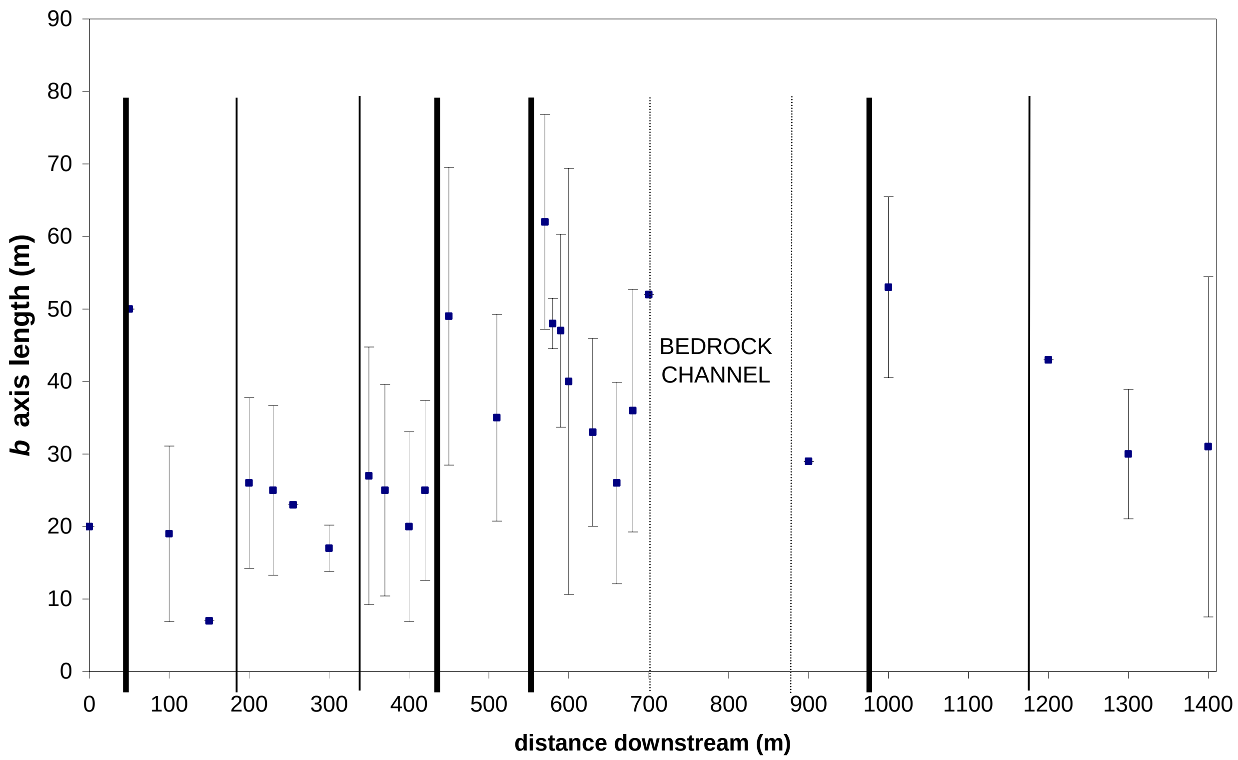

Figure 6. Downstream distribution of mean peat block sizes (*b* axis lengths) and peat block clusters (contiguous blocks) along a 1.5 km length of the Trout Beck study reach. The thick black lines indicate major lateral peat block sources (eroding banks) and thin black lines minor bank sources. Dashed vertical error bars show the standard deviation of the peat block clusters. Number of blocks varied between sites.

be attributed to inputs of peat blocks from major lateral sediment sources associated with actively eroding river channel bends and minor bank sources associated with cantilever failures of small stream banks along straight channel sections. Mean block size increases substantially close to each major lateral input (e.g. large bank failure) then declines rapidly downstream until the next input is encountered.

The supply mechanisms mean that the dimensions of in-channel peat blocks are highly variable (Figures 7, 8), with dimensions 0.12–2.30 m (*a* axis), 0.05–0.70 m (*b* axis) and 0.03–0.60 m (*c* axis). The interaction of the peat blocks with the gravel-bed sediment produces distinct local sedimentation patterns. Scouring occurs at the head and sides of each block, whilst a sediment tail develops in its lee. Sedimentation tail lengths vary widely, between 0 and 0.45 m, and the *b* axis dimension of the block is weakly related to tail length ($p<0.001$, Figure 7). The considerable scatter in the relationship is attributable to the low density of peat (*cf.* mineral sediment); hence re-entrainment and block shift occur periodically resulting in less stable patterns of tail sedimentation. The *b* axis length is correlated with tail length because many peat blocks become aligned across the channel so that their *b* axis lengths correspond to the upstream widths of their lee shadows. Head scour is also a characteristic sedimentation feature around deposited peat blocks, and as with tail sedimentation it varies considerably with block size ($p<0.001$, Figure 8). This variation in head scour is particularly evident for small peat blocks whose *c* axis lengths often correspond to block height. Smaller blocks tend to be removed before scour has developed or larger scour holes may persist where the original peat block has been broken down leaving a smaller peat block remnant. Depth of scour on the sides of the peat block is significantly correlated with peat block *c* axis ($r^2 = 0.508$, $p<0.001$ and $r^2 = 0.569$, $p< 0.001$ respectively for right- and left-side scour depth). This indicates that the height of the block is potentially important in controlling local channel topography and thus that peat blocks are important in controlling local patterns of sedimentation in upland gravel-bed rivers (Figure 1).

Peat blocks are also potentially significant sources of organic matter within the channel system. It has been estimated that the annual organic matter yield from the Trout Beck catchment is 405 tonnes, approximately 90% of the total suspended sediment load (Worrall *et al*. 2003). Based on the peat block inventory collected as part of this study, in-channel storage of organic matter in the form of peat blocks is approximately 375 tonnes, which is roughly equivalent to the annual sediment load. Thus, given their constant renewal by erosion of stream banks and bluffs, and their short residence times due to re-entrainment during high flow events (Evans & Warburton 2001), peat blocks are an important component of the channel organic matter budget.

Local organic matter patterns around peat blocks

Figure 9a summarises the distribution of organic matter fractions at the experimental site prior to block deposition. Samples were taken from the eight fixed sampling points shown in Figure 5. The coarse particulate fraction exceeds both the fine particulate and very fine particulate fractions, and periphyton account for a small proportion of the organic matter (<1 g m^{-2}). This is not unexpected given the dominance of coarse organic matter supply to the gravel-bed river channel from local peat erosion. Introduction of the peat block altered the local hydraulic and sedimentary environment and this affected the spatial distribution of the different organic matter fractions. Figure 9b shows the range of coarse-fraction values measured at the eight sampling points over the study period.

Coarse particulate organic matter is the dominant fraction in upland streams. Its pattern of variability around the isolated peat block, for the entire sampling period, shows important small scale variations which can be explained in terms of the local hydraulic and channel conditions. The block head, block right and downstream positions are associated with areas of local scour and have the lowest coarse particulate organic matter values. The highest coarse particulate concentrations occur on the left and right banks and appear to be influenced by local bank supply of organic matter and greater habitat productivity at the channel margins. There are clear differences between the block head and the block tail. The block tail micro-environment is more effective than the head at retaining coarse particulate organic matter, which presumably originates as local organic rain from the peat block. Quantities at the tail vary widely, indicating considerable variability in this environment that may be related to the development of the tail through time. Upstream of the block, conditions are similar to those measured in the vicinity of the block prior to the experiment (Figure 9a). The left side of the block is more sheltered than the right side and hence has slightly higher coarse particulate organic matter concentrations. Fine particulate organic matter values showed similar patterns.

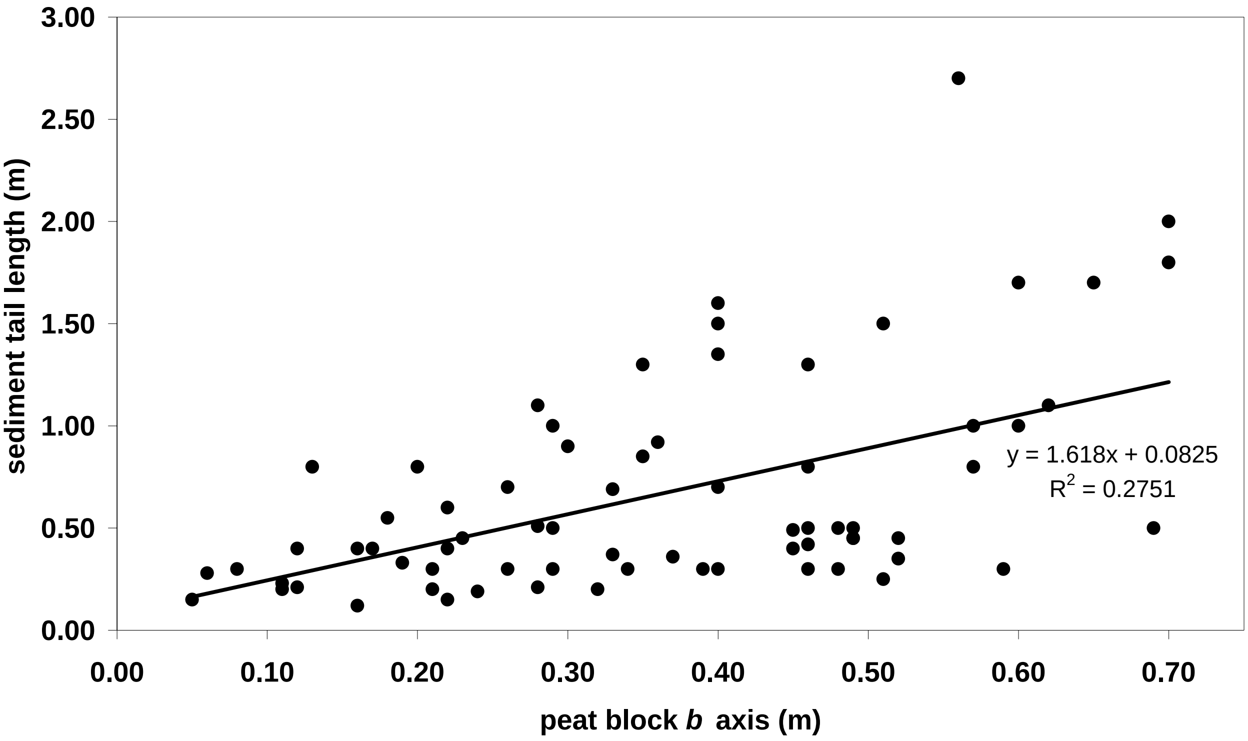

Figure 7. Relationship between peat block *b* (intermediate) axis length and the length of the sedimentation tail developed downstream of the block.

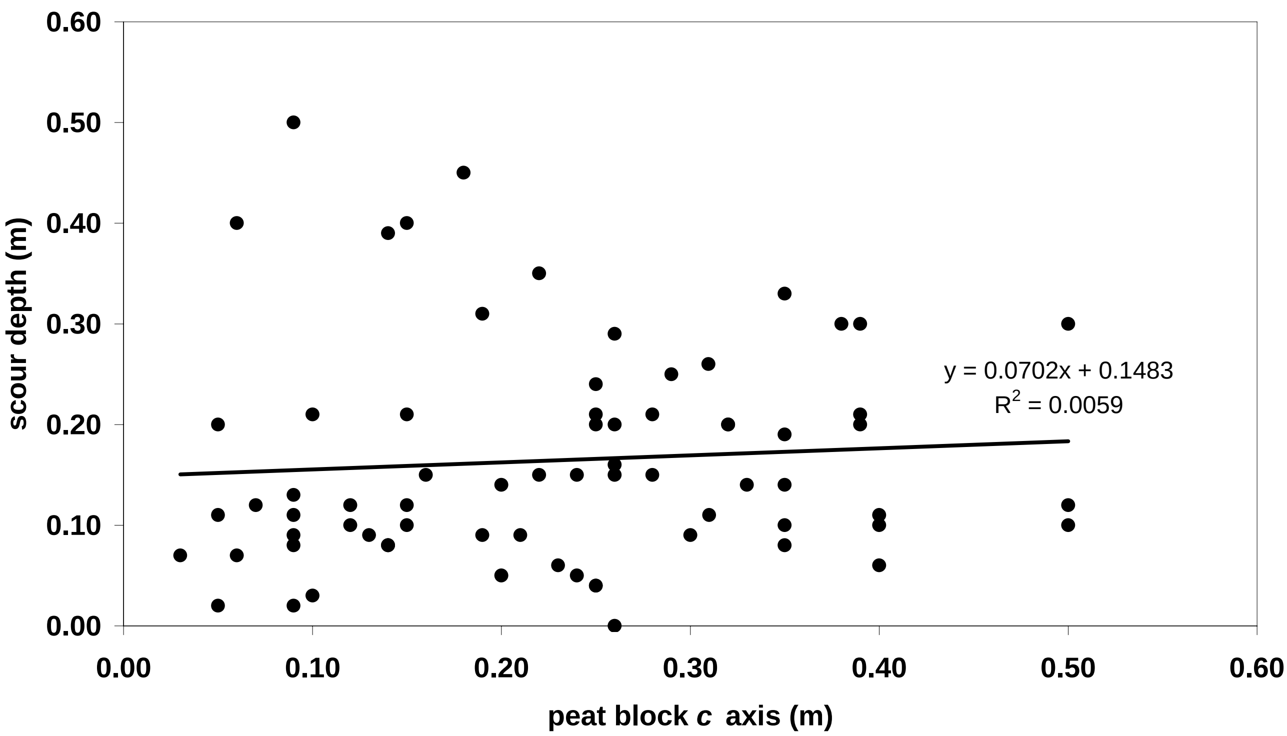

Figure 8. Scattergraph showing the relationship between peat block *c* (smallest) axis length and the depth of sediment scouring around the head of the block.

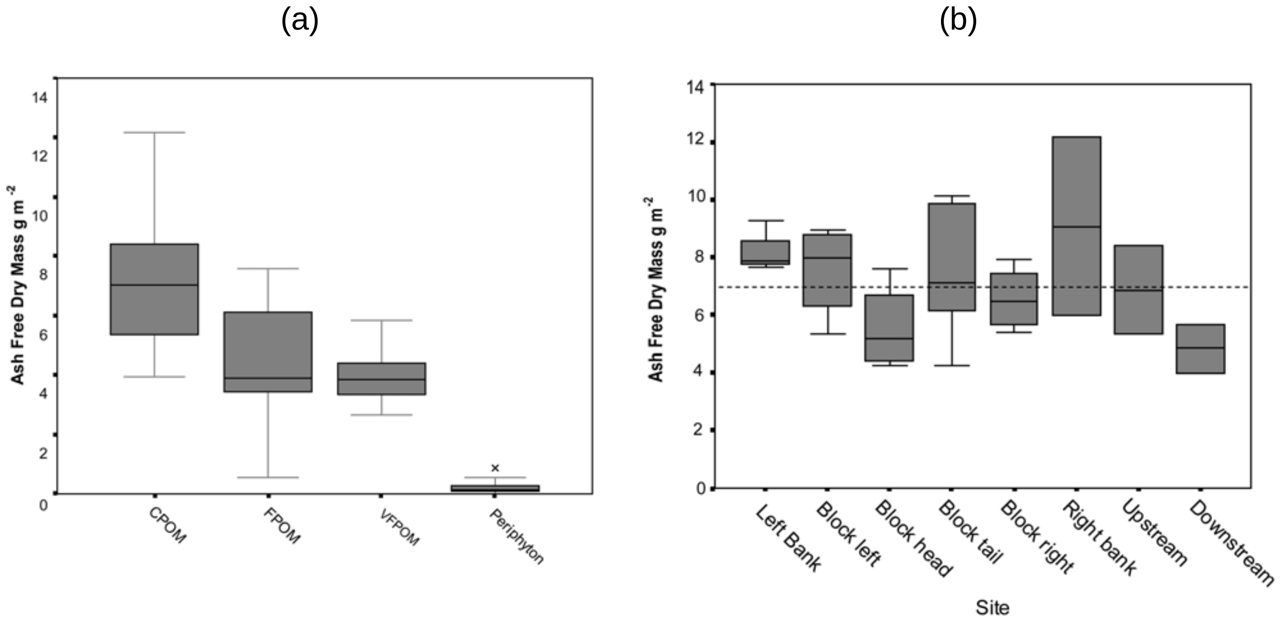

Figure 9. (a) Boxplots of organic matter content (Ash Free Dry Mass, g m^{-2}) of the coarse, fine and very fine organic matter fractions and periphyton on the channel bed before introduction of the peat block to the study reach. (b) Boxplots of coarse particulate organic matter (Ash Free Dry Mass, g m^{-2}) at the eight sampling sites in the local channel environment around the experimental peat block for the entire sampling period; see Figure 5 for locations. The average coarse particulate organic matter content before introduction of the block was approximately 7 g m^{-2} (Figure 9a), indicated by the horizontal dashed line.

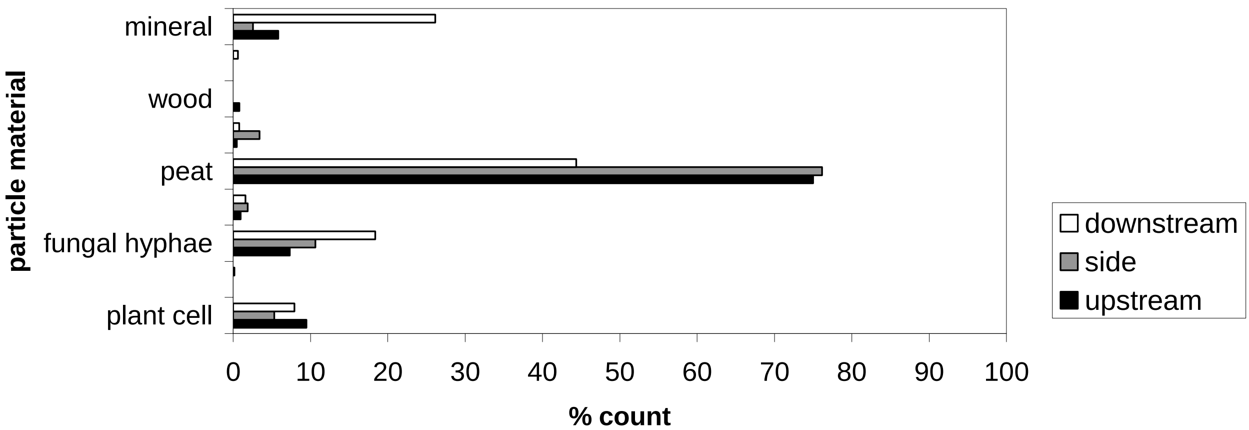

Figure 10. Microscopic counts of suspended organic matter collected in the three mass flux drift samplers over the experimental period.

The quantity of periphyton on the substrate was found to differ between the head and the tail of the block, periphyton apparently growing best on the stable coarse sediment found on the armoured stream bed at the block head. This suggestion is supported by the significant positive correlation that was found between periphyton mass and surface sediment D_{84} ($r^2 = 0.433$, $p < 0.001$).

Suspended and drifting organic matter

The low flow conditions in the channel during much of the study period meant that amounts of suspended solids and organics were fairly low. Nonetheless, there were significant differences between sampler locations. The highest concentrations were alongside, and the lowest downstream of the block. The qualitative analysis of organics caught over the entire study period (Figure 10) showed an overwhelming dominance of peat in all three samplers, the other major components of the drift being fungal hyphae and plant cells. Peat-related plant material (amorphous particles and small plant fragments) was distinguished by the lack of decomposition of plant fragments. The downstream sampler had much less peat than the other samplers. There are two possible reasons. First, this sampler was located at the greatest distance from an immediate organic sediment source (eroding bank or large peat block); and secondly, it was in the main high flow wake of the block adjacent to an area of fresh, reworked mineral sediment which had a fairly open matrix and was largely clean of organics.

For the three drift samplers (Figure 11), which were deployed on only two consecutive days in July, the combined weights of organic matter were greatest in the block tail (0.770 g and 0.545 g, total 1.315 g) and lowest downstream of the block (0.570 g and 0.240 g, total 0.810 g), indicating that organic drift declined by *ca.* 30–58% between these points (Figure 11). The main reason was probably dilution of organic matter 'rain' downstream of the primary source. Interestingly, a similar weight of drift was collected adjacent to the block on each day, but this was less than the downstream drift weight on the first day and more on the second, despite similar flow rates (0.05 $m^3 s^{-1}$). However, the decline from the tail to the downstream sampling point was consistent over the two days. This may reflect a limitation in organic matter supply at the block; for example, perhaps continuous water flow removes loose peat, leaving a more stable block surface.

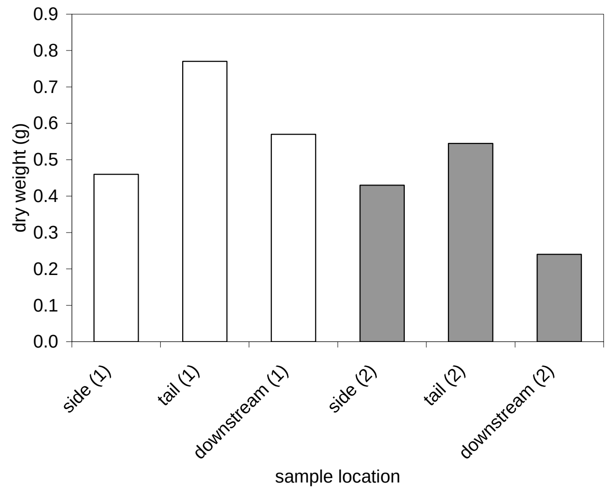

Figure 11. Concentrations of organic matter drift on two consecutive days, (1) 11th July 2002 and (2) 12th July 2002. Samplers were deployed at the side, tail and 4 m downstream of the block.

DISCUSSION

Peat blocks in the Trout Beck fluvial system show large variations in size and sedimentary setting. The largest have maximum dimensions of several metres and are rapidly broken down into smaller pieces which are subject to further hydraulic sorting. The blocks are often systematically distributed, large blocks typically being found at the bases of undercut banks and small blocks imbricated into pebble clusters on channel bars. Evans & Warburton (2001) make similar observations and describe systematic downstream fining of blocks with distance from primary sediment sources. Figure 6 illustrates marked disruptions of the overall fining trend due to inputs of large blocks at major and minor bank sources along the channel. This disruption is consistent with the link discontinuity concept (Rice & Church 1998), which suggests that lateral sediment sources disrupt the overall downstream sediment fining trend.

Previous studies have revealed a range of flow patterns and associated scour/sedimentation structures at the individual block (element) scale (Richardson 1968, Wallerstein *et al*. 2001, Zimmerman & Church 2001, Carling *et al.* 2002). In particular, Maizels (1992) has described in detail the concentric scour marks associated with turbulent flow. In the present study, scour marks both at the head of the obstacle and along the sides were much less distinct and indeed were rarely distinguishable in the field. This may be due to the generally low velocities (≤0.1 $m s^{-1}$), shallow water depths (0.20 m) and coarse armoured substrate typically found in Trout Beck. It is also likely that, at high flow, peat blocks are rapidly entrained before scour occurs and many of the shallow scour features are filled in by moving gravel.

Our preliminary investigations into the stream organic matter budget around an isolated peat block reveal important variations in organic matter distribution within the channel. Mean weights of organic matter were 7.02, 3.91 and 3.86 $g m^{-2}$ for the coarse, fine and very fine fractions respectively, and similar to values obtained by Carling & Reader (1982). These are comparatively small values for a stream that runs through peat deposits, suggesting inefficient storage of organic matter in the bed sediments. Organic matter concentrations, and particularly those of coarse organic matter, were markedly lower than in forested catchments. Richardson (1992) reported coarse particulate organic matter concentrations in two streams to be 32 $g m^{-2}$, almost an order of magnitude higher than those found in Trout Beck. Conversely, the weights of benthic organic matter in Trout Beck are an order of magnitude higher than in poorly vegetated upland catchments. For example Cushing *et al*. (1993) reported values of 0.8 g m^{-2} (fine fractions) compared to 7.77 g m^{-2} for Trout Beck, suggesting that deposition of peat as well as fragments of peat and vegetation does contribute significantly to the standing crop of organic matter in this stream.

The block head, where the proportion of fine sediment was higher, had lower concentrations of all organic matter fractions, suggesting that these conditions are unfavourable for organic matter deposition because fine sediment is poor at organic matter retention (Culp *et al*. 1983). Beisel *et al*. (2000) reported in a comparison of habitats that the richest organic matter environments were those that showed a high degree of substrate microtopography. Conversely, Sutherland (1999) showed an increase in organic carbon with decreasing grain size. These findings indicate that substrate grain size is an influential factor leading to increased organic matter deposition, but that other factors should not be disregarded. Thomas *et al*. (2001) suggest that factors apart from gravitational settling, e.g. periphyton abundance and filter-feeding organisms, affect organic matter settling and retention. However Monagham *et al*. (2001) reported that filter-feeders were responsible for only 10% of the removal of organic matter from the water column that occurs in nature.

Periphyton is frequently the only source of autochthonous primary production in upland streams (Flynn *et al*. 2002) and this was clearly noticeable in the Trout Beck study site under base flow conditions. Periphyton have been reported to be effective accumulators of particulate matter such as metal- contaminated sediment (Dixit *et al*. 1991, Droppo *et al*. 2001). It can be inferred that they accumulate and retain organic matter within their matrix, and this is thought to be the essential factor in determining periphyton accumulation rates. However, observations in the channel indicate that actual periphyton production in Trout Beck is fairly low (Figure 9a). This is attributed to the frequent scouring of substrate during high flows which can be observed after floods.

Our results demonstrate that in-channel peat blocks are important local sources of organic matter in upland stream channels. However, given the relatively low organic matter storage in the stream bed, much of the organic matter released from peat blocks must be exported from the river reach. This is confirmed by microscopic analysis of organic matter particles in the suspended load which has demonstrated the overwhelming proportion of peat in the drift. Together with data from other studies (Armitage 1977, Peterson *et al*. 1985, Francis 1990), this indicates a generally low organic matter trapping efficiency in upland channels. The Trout Beck channel ecosystem can be viewed as a leaky system that does not retain organic matter efficiently, and in this respect it is no different from other upland systems. The significance of Trout Beck and other peatland fluvial systems is that the flux of both dead and living organic matter is an order of magnitude greater than in other types of upland streams and represents a significant loss of terrestrial carbon. Organic carbon stores are currently receiving much attention in the context of global warming and climate change, and peatlands are a major store of organic carbon. Therefore it is important that we understand the organic matter budgets of the stream channels that run through them in order to understand, and possibly control, carbon loss.

CONCLUSIONS

1. At reach scale, the distribution of large peat blocks can be related to local source inputs from eroding organic matter stores (notably cut peat banks). Peat blocks are then transported and hydraulically sorted into downstream fining sequences, eventually being deposited on the channel bed. Therefore they represent a significant macro-scale component of the river system.
2. When they remain *in situ*, distinct patterns of local sedimentation develop around the peat blocks, producing significant local variations in instream habitat. Measured fluxes of organic matter around these patterns and the stream bed indicate large quantities of peat being eroded from the block sides. This creates substantial peaks in local organic matter drift, of which *ca*. 75 % is suspended peat.
3. Analysis of organic matter concentrations in sedimentation patterns and the surrounding stream bed reveals low storage of eroded material and thus indicates high transportation rates out of the fluvial system. This export of organic matter has major implications for the fluvial component of the terrestrial carbon budget. It suggests that the channel bed is not a long-term store for eroded organic matter and hence for organic carbon. The likely destination for the material exported from Trout Beck is a reservoir, but in other streams and rivers it could equally be the estuarine or coastal zone.

4. This paper reports on a preliminary study of a peatland river organic matter budget, and this means that several important limitations should be noted. First, a complete organic matter budget has not been constructed. It will be important to extend future studies over longer periods and to evaluate a full annual budget within which seasonal factors can be quantified (Kiffney *et al*. 2000). Secondly, the pathways for organic matter exchanges in the channel should be better quantified and stable carbon isotope analysis could be usefully applied in this context (Palmer *et al*. 2001). Finally, although the distribution of peat blocks has been documented at reach scale, differences in local organic matter fluxes have been measured at only a single site. Because of the inherent variability of flow processes and local sedimentary conditions in upland river systems, it will be important to determine in future studies how within-site and between-site variations in organic matter fluxes compare with one another. However, these limitations do not detract from the general conclusion that instream peat blocks form an important component of the geomorphology and ecology of upland peatland streams.

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