TRANSPORT AND RETENTION OF DETRITUS IN UPLAND STREAMS: A COMPARISON OF AN OPEN STREAM AND AN ADJACENT WOODED SITE.

H. Cariss & M. Dobson
Department of Environmental and Geographical Sciences, Manchester Metropolitan University, Chester Street, Manchester, MI 5GD, UK.
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SUMMARY

Retention of detritus on the bed of a river is crucial to the effective functioning of biological breakdown processes. It is now well understood that increasing retention of detritus within a stream channel leads to a higher standing stock of detritus and greater numbers of detritivores. What is less clear, however, is the proportion of leaf litter that is retained, particularly in non-wooded catchments, although anecdotal evidence suggests that, in open country and in channels managed for flood control, the vast majority of detritus entering the stream is washed downstream without being retained. This was investigated in the upper catchment of the River Goyt in north-west England. Detritus settling on the bed was compared with that in transit in the water column in an open moorland site (River Goyt) and an enclosed, forested site (Stake Clough). The total mass in transit in both rivers was similar but retention was higher in Stake Clough. Furthermore, indirect evidence suggests that detritus was retained for shorter periods in the River Goyt. Mass of detritus in transit was significantly correlated with rainfall in the River Goyt, though not in Stake Clough. The differences can be related to channel structure and the type of detritus entering each river: the River Goyt is a turbulent river. Its catchment is devoid of trees and the main detrital inputs are grasses. Stake Clough is low gradient, with an input of leaves from broadleaved and coniferous trees. The results presented have implications for community processes because the dominant detrital inputs to the River Goyt are refractory forms, and their breakdown will be hampered by their short retention times. There are also implications for water quality in reservoirs further down in the catchment, as most of their inputs are from low retention streams carrying large volumes of incompletely processed detritus.

INTRODUCTION

The importance of retention in leaf litter processing is well established. Detritus of terrestrial origin is acted upon by aquatic biota which, through conditioning and feeding activities, contnbute to its breakdown. Optimal litter breakdown requires, however, that it is retained upon the river bed, often for several weeks or months, to allow this biotic activity to occur. Detritus retention is a function of structural heterogeneity, creating patches of reduced flow in which detritus may accumulate (e.g., DOBSON & HILDREW, 1992). The most widely studied source of this heterogeneity is coarse woody debris (CWD) in the form of branches and logs. Addition of CWD results in an increased detrital standing stock (SMOCK *et al.*, 1989), while, conversely, its removal significantly lowers detrital standing stock (BILBY & LIKENS, 1980).

The rapid increase in detrital standing stock associated with the addition of retention devices (DOBSON & HILDREW, 1992) demonstrates that a large amount of detritus may be in transit in forested nvers, fed by vertical input from riparian trees and also by lateral inputs from the surrounding catchment (WEIGELHOFER & WARINGER, 1994). Very little is, however, known about the actual quantities carried by rivers (although much preliminary data on inputs, standing stock and outputs has been summarised by WEBSTER & MEYER [1997]). Models of longitudinal linkages along river systems, such as the River Continuum Concept (VANNOTE *et al.*, 1980; MINSHALL *et al.*, 1985), depend upon downstream transport of organic matter but, crucially, also require it to be retained until broken down into fine particulate organic matter (FPOM). Coarse particulate organic matter (CPOM), such as leaves, is assumed to be retained close to its point of entry (WEBSTER *et al.*, 1994). while its breakdown products are exported as FPOM (e.g., IVERSEN *et al.*, 1982; WALLACE *et al.*, 1982, 1995),

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and export of CPOM is limited to storm flows or to periods when inputs exceed storage capacity (GOLLADAY, 1997).

But what about rivers without riparian trees? These, obviously, lack a source of CWD so debris dams are absent, and large seasonal inputs of detritus are less likely to occur (YOUNG & HURYN, 1997). Furthermore, leaf litter inputs may be very low: the vegetation of non-wooded catchments is generally of low stature, reducing the potential volume of lateral inputs, while the so-called 'soft margins' of such rivers, the dense growths of herbaceous vegetation along their banks (RUNDLE *et al.,* 1992), may impair lateral inputs. However, a study carried out on open moorland in South Wales by DOBSON *et al.* (1995) demonstrated that rivers draining almost treeless catchments may be transporting large volumes of grass-derived detritus, despite very low standing stocks of CPOM on their beds. Without retention structures, the vast majority of this detritus will be carried downstream and lost to the headwaters.

The aim of this study was to provide data on retention efficiency of a stream devoid of riparian trees and therefore with no inputs of CWD. We report here a preliminary survey of mass and composition of detritus in transit and retained in this stream and in an adjacent, wooded stream.

METHODS

Site descriptions

This study was carried out in the upper Goyt Valley of the Peak District in central England. The open site was Goyt's Moss, a stretch of the River Goyt, a circumneutral river (pH 6-7) which drains open moorland dominated by grasses (typically *Molinia caerulea* (L.) Moench. and *Nardus stricta* L.) but with extensive areas, generally away from the river channels, covered by bracken *(Pteridium aquilinum* L.) and heather (*Calluna vulgaris* L.). During the summer, the river channel supports extensive, though patchy, growth of filamentous algae. The wooded site was Stake Clough, an acid (pH 3.5-5) tributary of the River Goyt, which drains open moorland for the first 1000 m of its length and then, for a further 500 m above the study site, runs through mixed woodland including oak (*Quercus rohur* L.), rowan (*Sorbus aucuparia* L.) and birch (*Betula pendula* L.) in the riparian zone but with a plantation of larch (*Larix decidua* L.), spruce *(Picea sitchensis* (Bong.) Carrière) and pine (*Pinus sylvestris* L.) in the rest of the catchment. Ground vegetation is sparse but includes some moorland grasses and clumps of *Juncus* **sp.** No macrophytes or filamentous algae grow within the river channel. Further details of the catchments and streams are given in table 1.

Table 1. **Site** descriptions.

Site	River Goyt	Stake Clough
British National Grid Reference	SK016 728	SK 011 736
Altitude (m)	350	340
Distance from source (km)	3.5	1.5
Stream order	2	1
Width (m)	2.25	1.35

A 10 m stretch of each river was used for the study, which commenced in March 1995 and was completed in March 1996. The study sites were approximately 1 km apart.

Detritus in transit

Detritus in transit was measured at two week intervals by placing traps into each river channel. Each trap consisted of a curved length of plastic mesh, with aperture size 1 mm, which was suspended between two steel poles 20 cm apart with its concave face pointing upstream. Two such traps were employed in each river stretch. Every two weeks, they were placed into the river, ensuring that they were flush with the river bed and protruded above the water surface, and left for 72 h, after which meshes were removed and their contents carefully collected in a net. Detritus collected was returned to the laboratory where it was dried at 55 °C for 48 h and then divided into identifiable fractionc, which were weighed separately. The detritus types distinguished were broadleaves, conifer needles, grasses, bracken, moss and wood. Small particles, which were too small to separate or identify, were classed as 'miscellaneous detritus'.

Detrital standing stock and retention

At the beginning of the study, five quadrats, each 25 x 25 cm, were chosen at random in each river stretch. The position of each of these quadrats was marked using pegs on the bank and precise measurement. The same quadrat positions were used for all subsequent collection of standing stock data. Approximately every four weeks during the study (except for mid-December 1995), detritus was removed from these quadrats using a Surber sampler. After 72 h, detritus was collected using the same method and returned to the Iaboratory, where it was processed in the same way as the detritus in transit.

Mean retention of detritus was estimated **by** using the mass that had aggregated in the ctudy quadrats 72 h after clearance. Standing stock was estimated by using the mass cleared from each quadrat at the beginning of each 72 h period, although, as this was normally only 20-25 days since these quadrats had been cleared previously, these may be underestimates of true standing stock.

Analysis

Mass in transit per day (mT) was estimated for the entire river channel width, while detritus retained was converted to an areal ectimate per m^2 (mR).

Detrital mass wac compared between the two sites using Wilcoxon's matched pairs signed-ranks test, in which macc calculated from data collected from each river on the same date were matched. Correlation between **macs** of detritus and rainfall was also determined. All statistical analyses were carried out using SPSS (Version 6).

RESULTS

Measurements obtained for **masc** of detritus ranged widely over the dates of collection (fig. 1, 2; table 2) and therefore mean values should be interpreted with caution

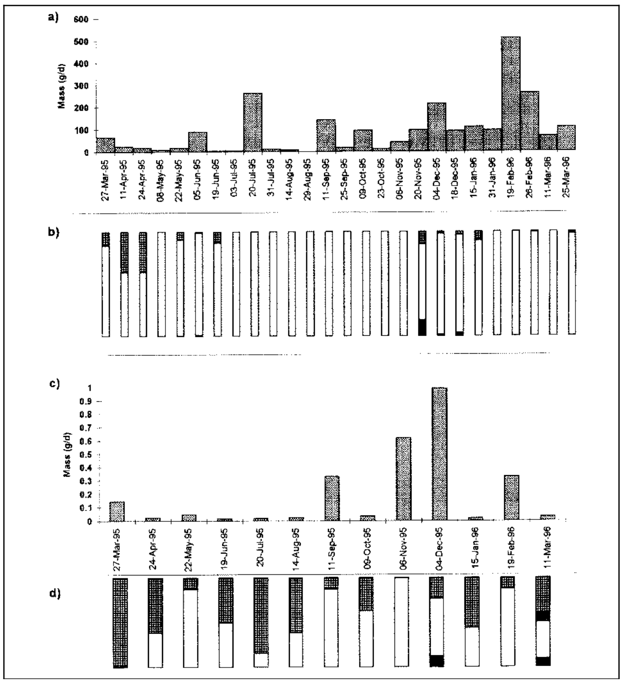

Figure 1. Detritus ın the study stretch of the River Goyt a) mass in transit through the study stretch (g d^{-1}); b) relative proportion **of** different components of detritus in transit; c) mass entrained in the study stretch (g m^{-2} d^{-1}); d) relative proportion of different coinponents of detritus retained. Key to shading in figures 1b, 1d, 2b and 2d: black = broadleaves; white = grasses, rushes and bracken; grey = conifer needles; cross-hatching = algae, moss and miscellaneous fine particles.

Table 2. Mass of detritus recorded from study sites. Figures given are the mass recorded over three days; figures quoted in the text are adjusted to give measurenientn per day.

	Site	Mean	Standard deviation	Range
Mass in trancit (g)	River Goyt	99.80	127.23	0.90-576.39
	Stake Clough	124.88	186.49	0.24-892.38
Mass retained (g m^{-2})	River Goyt	0.74	2.19	0.02-7.99
	Stake Clough	12.62	10.41	0.52-32.78
Standing stock (g in ^{2})	River Goyt	0.8	0.8	0.01-2.40
	Stake Clough	17.96	12.44	7.22-48.36

River Goyt

Standing stock in the River Goyt was always very low, averaging 0.8 g m^{-2} (table 2). Masc of detritus in transit averaged 33.3 **g** d^{-1} (fig. 1a), and was dominated by grassec and bracken, although a few windblown broadleaves were recorded during November and December 1995 (fig. 1b). Net mass retained was 0.3 g m^{-2} d^{-1} (fig. 1c). This, too, was generally dominated by gracses and bracken, although miscellaneous fragments. consisting of pieces of moss and filamentouc algae, were important and. on several campling occasions, constituted the majority of the detritus (fig. 1d).

There was no seasonal pattern evident in masc of detritus in transit. Mass of entrained detritus wac higher over autumn and winter than cpring and summer, although the mass involved was always very low (fig. 1).

Stake Clough

Standing stock in Stake Clough averaged 18.0 **g** m^{-2} (table 2). Mass of detritus in transit averaged 41.6 g d^{-1} (fig. 2a). Detritus in transit contained a high proportion of broadleaves during late summer and autumn, grasces during the winter and moss over the summer; conifer needle trancport was evenly spread throughout the year (fig. 2b). Net mass retained wac 4.2 g m^{-2} d^{-1} (fig. 2c). Entrained detritus showed no clear patterns, although broadleaves formed a low proportion of the total throughout the year (fig. 2d).

As in the River Goyt, there was no seasonal pattern for masc in trancit. Mass of entrained detritus was generally highest during autumn and winter (fig. 2).

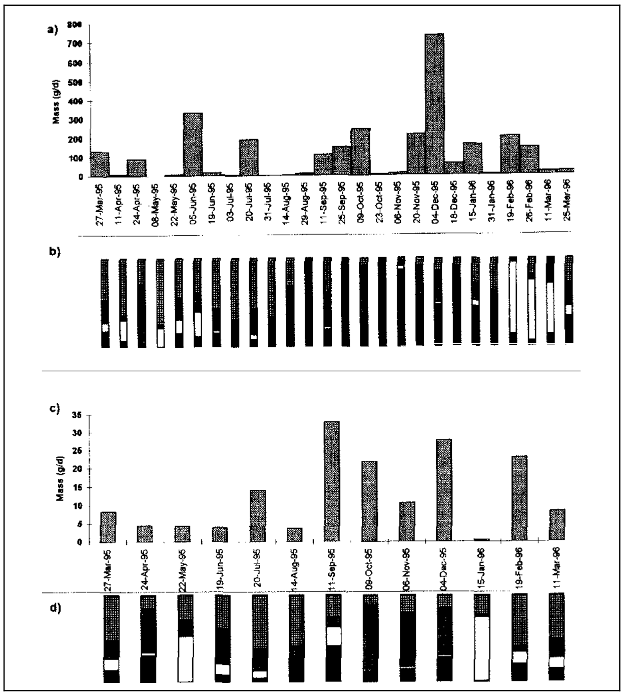

Figure 2. Detritus in the study stretch of Stake Ciough a) mass transit through the study stretch (g d^{-1}); b) reiative proportion of different components of detritus in transit; c) mass entrained in the study stretch (g m^{-2} d^{-1}); d) relative proportion of different coinponents of detritus retained. For key to shading in figures 2b and 2d, see legend to figure 1.

Comparison between sites

There was no significant difference between the two rivers in terms of mass of detritus in transit ($Z = 0.0381$; $p = 0.970$). The mass retained was, however, significantly different ($Z = 3.1798$; $p = 0.002$), with greater retention in Stake Clough.

Mass of detritus in transit in the River Goyt was significantly correlated with rainfall ($R^2 = 0.34$; $p = 0.002$), whereac no such relationship was evident in Stake Clough ($R' = 0.07$; $p = 0.186$). Mass of detritus retained showed no significant relationship with rainfall in either site (The River Goyt: $R^2 = 0.06$; $p = 0.440$; Stake Clough: $R^2 = 0.15$; $p = 0.194$).

DISCUSSION

Though we did not sample the entire river channel and probably underestimated actual inputs, our results demonstrate that similar amounts of detritus were being carried by both the open river (River Goyt) and the wooded river (Stake Clough). The total input per unit area of river channel is probably much lower in the River Goyt than in Stake Clough, the match in mass in transit being a result of the difference in retention capacity. Sample quadrat locations were left for 20-25 days after each sample of detritus retained, before being cleared for the next sample. Detritus on the bed in the River Goyt probably has a residence time measurable in hours or, at most, a few days, hence the lack of difference between standing stock when allowed to settle for three days and when left for 20-25 days. In Stake Clough, in contrast, the longer time period allowed more detritus to aggregate (table 2), suggesting that retention times are much longer at this site. As a result, the overall retention in Stake Clough was significantly higher than in the River Goyt.

In the absence of a gauging station in the upper Goyt Valley, rainfall was used as an indicator of discharge in these headwater streams. Mass of detritus in transit or removed from the bed of a river channel is expected to correlate well with discharge and this, was, indeed, the case in the River Goyt. The absence of correlation in Stake Clough is, therefore, perhaps surprising. A probable explanation for this is the coarse resolution of the rainfall data. The contents of the rainfall gauge in the upper Goyt Valley are only measured every 3 or 4 days, whereas short bursts of rainfall can make the rivers very flashy, with devastating floods caused by stormc that do not register as unusual in the rain gauge reading (DOBSON *et al.*, 1997).

Using the detritus figures obtained after 20-25 day intervalc allows an approximate estimate **of** standing stock to be made, to allow comparison with other sites. Both rivers, according to this, are at the low end of published readings: SCARSBROOK & TOWNSEND (1994), for example, found standing stock in a grassland river in New Zealand to be in the range 0.17-6.53 g m^{-2}, while estimates of standing stock in rivers draining broad-leaved woodland in North America fall in the range 118-740 g m^{-2} (WEBSTER & MEYER, 1997). Annual export rate of CPOM per m^2 could also be estimated, as:

$$\text{Export rate} = \frac{(mT \times 365)}{(\text{stream area})}$$

Few studies have pubiished data on export rates of CPOM but, once again, Stake Clough and the River Goyt appear to be at the lower end of the range (table 3). What is notable, however, is the absence of such data from grassiand or moorland streams. Of the sites listed by WEBSTER & MEYER (1997), which include tundra and prairie streams, all except one had at least come woody vegetation in the riparian zone. The exception was Canada Creek in Antarctica (MCKNIGHT & TATE, 1997), a stream with a catchment devoid of all terrestrial vegetation and therefore not comparable with the River Goyt. Rivers such as the Goyt, from whose catchments almost all trees have been cleared by human activity, often as much as 5000 BP

Table 3. Comparison of standing stock and outputs of CPOM in various rivera. Mass is quoted as ash free dry mass. This was estimated for Stake Clough and the River Goyt by multiplying the calculated figure by 0.9, i.e. assuming a 10% ash content.

Site and location	Vegetation type	Stream order	strearn area (m^2)	standing stock ($g\ m^{-2}$)	Output ($g\ m^{-2}\ y^{-1}$)	Source
Breitenbach, Gerrnany	Broadleaf	1	3173	310[1]	>129.2	MARXSEN *et al.* (1997)
Buzzards Branch, Virginia, USA	Broadleaf	1	12,250	1730	11.3	SMOCK (1997)
Keppel Creek, Victoria, Australia	Broadleaf	4	16,450	105	77.3	TREADWELL *et al.* (1997)
Satellite Branch, North Carolina, USA	Broadleaf	1	373	739.5	23.2	WALLACE *et al.* (1997)
Kuparuk River, Alaska, USA	Tundra (low shrubs)	4	490,000	28.5[2]	15.2	HARVEY *et al.* (1997)
Stake Clough. UK	Mixed woodland/ moorland	1	2,000[3] (667[4])	16.1	6.8 (20.4[4])	This study
River Goyt, UK	Moorland	2	7,900[3]	0.1	1.4	This study

(1) Approximation based upon total standing stock of FPOM and CPOM quoted as 621 gm^{-2} and notes on relative proportions given by MARXSEN *et al.* (1997).
(2) Organic matter in the size range 0.335-100 mm.
(3) Mainstem iength from source to study stretch multiplied by mean width at the atudy stretch (HARVEY *et al.*, 1997).
(4) Estimated output from the wooded stretch alone, as oniy the lower third of the river channel above the study site is wooded.

(MOORE, 1993), are common in the upiands of the British Isles and yet there is a paucity of information about their detritus dynarnics. Outputs per unit area in the River Goyt are very low in cornparison with wooded sites (table 3), although this is in part a consequence of low levels of inputs, rather than effective retention and breakdown.

These results have important implications for litter processing in open grassland rivers. Processing rates of grasses have been relatively poorly studied, but the data available (e.g., BIRD & KAUSHIK, 1987; YOUNG *et al.,* 1994) suggest that they are refractory and therefore slow to condition and of low nutritional value to rnacroconsumers, and there is no reason to suppose that the grasses dominating the upiands of Britain are any different. Their effective breakdown is further hampered by their short retention times in the river, itself a result of the paucity of retention featurec, along with the widely fluctuating discharge and often turbulent flow of such rivers. Furthermore, the upper River Goyt, in comrnon with many such upland rivers in Britain, flows along most of its length close to, or even directly over, bedrock, reducing the capacity for interstitial storage of detritus. Detritus-dependent organisms are, therefore, uncommon, and the primary breakdown mechanisrns for CPOM are probably terrestrial decomposition before it enters the river channel and then mechanical breakage as it is transported.

The detritus in Stake Clough, in contrast to that in the River Goyt. contains a high proportion of less refractory broadleaves and, furthermore, ic likely to be retained for long periods, allowing biological litter breakdown processes to operate effectively. The output from the wooded site is appreciably higher than that from the open site, on an areal basis (table 3), but it is likely to be retained again further downstream, whereas the probability of this happening in the River Goyt is much lower.

The fate of the detritus that is not retained in the River Goyt is worthy of specuiation. Export over the year of the study totalled around 12 kg, all of which, unless retained, will eventually end up in a water supply reservoir approxirnately 2 km downstream from the study site where, presumably, it is incorporated into sediment and decornposes. This annual export appears to be small, certainly in comparison with wooded streams, but several cuch rivers discharging into a single, highly oligotrophic water supply reservoir, may, over a period of years, have an effect upon water quality. In the artificially treeless environment of upland Britain, litter breakdown is transferred frorn the upland river channels themselves to potentially less desirable locations further downstream.

Finally, the results of this study provide some evidence for the reduction in river productivity in Britain following deforestation. Stake Clough, although now with a large proportion of exotic conifers in its lower catchment, is probably closer in its riparian vegetation to the pnmeval environment of most of the Peak District than is the River Goyt, and its standing stock of detritus, most of which will eventually be broken down somewhere within the aquatic system, is correspondingly much higher. Following deforestation, therefore, detrital stocks must have declined considerably in the River Goyt, and it is doubtful whether this loss has been matched by a corresponding increase in algal production within the stream channel.

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REFERENCES

BILBY, R.E. & G.E. LIKENS, 1980. Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology,* 61: 1107-1113.

BIRD, G.A. & N.K. KAUSHIK, 1987. Processing of maple leaf, grass and fern packs and their colonization by invertebrates in a stream. *J. Freshwat. Ecol.,* 4: 177-189.

DOBSON, M., H. CARISS & B. MURRAY, 1997. Effects of a flash flood on channel morphology and some insects of a small stony stream in the Peak District, Derbyshire. *Freshwater Forum*, 9: 2-13.

DOBSON, M. & A.G. HILDREW, 1992. A test of resource limitation among shredding detritivores in low order streams in southern England. *J. Anim. Ecol.,* 61: 69-78.

DOBSON, M., A.G. HILDREW, S. ORTON & S.J. ORMEROD, 1995. Increasing litter retention in moorland streams: ecological and management aspects of a field experiment. *Freshwat. Biol.,* 33: 325-337.

GOLLADAY, S.W., 1997. Suspended particulate organic matter concentration and export in ctreams. In: Stream organic matter budgets (J.R. WEBSTER & J.L. MEYER, eds.): 122-131. *J. N. Am. Benthol.* Soc., 16: 3-161.

HARVEY, C.J., B.J. PETERSON, W.B. BOWDEN, L.A. DEEGAN, J.C. FINLAY, A.E. HERSHEY & M.C. MILLER, 1997. Organic matter dynamics in the Kuparuk River, a tundra river in Alaska, USA. In: Stream organic matter budgets (J.R. WEBSTER & J.L. MEYER, eds.): 18-23. *J. N. Am. Benthol. Soc.*, 16: 3-161.

IVERSEN, T.M., J. THORUP & J. SCRIVER, 1982. Inputs and transformations of allochthonous particulate organic matter in a headwater stream. *Holarct. Ecol., 5:* 10-19.

MARXSEN, J., H. SCHMIDT & D.M. FIEBIG, 1997. Organic matter dynamics in the Breitenbach, Germany. In: Stream organic matter budgets (J.R. WEBSTER & J.L. MEYER, eds.): 28-32. *J. N. Am. Benthol. Soc.*, 16: 3-161.

McKNIGHT, D.M. & C.M. TATE, 1997. Canada Strearn: a glacial meltwater stream in Taylor Valley, South Victoria Land, Antarctica. In: Stream organic matter budgets (J.R. WEBSTER & J.L. MEYER, eds.): 14-17. *J. N. Am. Benthol. Soc.*, 16: 3-161.

MINSHALL, G.W., K.W. CUMMINS, R.C. PETERSEN, C.E. CUSHING, D.A. BRUNS, J.R. SEDELL & R.L. VANNOTE, 1985. Developments in stream ecosystem theory. *Can. J. Fish. aquat. Sci.,* 42: 1045-1055.

MOORE, P.D., 1993. The origin of blanket mire, revisited. In: *Climate change and human impacts on the landscape* (F.M. CHAMBERS, ed.): 217-224. Chapman & Hall, London.

RUNDLE, S.D., E.C. LLOYD & S.J. ORMEROD, 1992. The effects of riparian management and physicochemistry on macroinvertebrate feeding guilds and comrnunity structure in upland British streams. *Aquat. Cons.-Mur. Freshwut. Ecosystems, 2:* 309-324.

SCARSBROOK, M.R. & C.R. TOWNSEND, 1994. The roles of grass leaf litter in streams draining tussock grassland in New Zealand: retention, food supply and substrate stabilization. *Freshwut. Biol.*, 32: 429-443.

SMOCK, L.A., 1997. Organic matter dynarnics in Buzzards Branch, a blackwater stream in Virginia, USA. In: Stream organic matter budgets (J.R. WEBSTER & J.L. MEYER, eds.): 54-57. *J. N. Am. Benthol. Soc.*, 16: 3-161.

SMOCK, L.A., G.M. METZLER & J.E. GLADDEN, 1989. Role of debris dams in the structure and functioning of low-gradient headwater strearns. *Ecology,* 70: 764-775.

TREADWELL, S.A., I.C. CAMPBELL & R.T. EDWARDS, 1997. Organic matter dynamics in Keppel Creek, southeastern Australia. In: Stream organic matter budgets (J.R. WEBSTER & J.L. MEYER, eds.): 58-61. *J. N. Am. Benthol. Soc.*, 16: 3-161.

VANNOTE, R.L., G.W. MINSHALL, K.W. CUMMINS, J.R. SEDELL & C.E. CUSHING, 1980. The River Continuum Concept. *Can. J. Fish. aquat. Sci.,* 37: 130-137.

WALLACE, J.B., T.F. CUFFNEY, S.L. EGGERT & M.R.

WHILES. 1997. Stream organic matter inputs, storage and export for Satellite Branch at Coweeta Hydrologic Laboratory, Nortli Carolina, USA. In: Stream organic inatter budgets (J.R. Webster & J.L. Meyer, eds.): 67-74. *J. N. Am. Benthol. Soc.*, 16: 3-161.

WALLACE, J.B., D.H. ROSS & J.L. MEYER. 1982. Seston and dissolved carbon dynamics in a southern Appalachian stream. *Ecology*, 63: 824-838.

WALLACE, J.B., M.R. WHILES, S. EGGERT. T.F. CUFFNEY, G.J. LUGTHART & K. CHUNG, 1995. Long-term dynamics of coarse particulate organic matter in thrce Appalachian mountain streams. *J. N. Am. Benthol. Soc.*, 14: 217-232.

WEBSTER, J.R., S.W. GOLLADAY, E.F. BENFIELD, D.A. D'ANGELO & G.T. PETERS, 1994. Effects of forect disturbance on particulate organic matter budgetc of small streams. *J. N. Am Benthol. Soc.*, 9: 120-140.

WEBSTER. J.R. & J.L. MEYER (eds.), 1997. Stream organic matter budgets. *J. N. Am. Benthol. Soc.*, 16: 3-161.

WEIGELHOFER, G. & J.A. WARINGER. 1994. Allochthonous input of coarse particulate organic matter (CPOM) in a 1st to 4th order Auctrian forest stream. *Int. Rev. ges. Hydrobiol.*, 19: 461-411.

YOUNG, R.G. & A.D. HURYN, 1997. Longitudinal patterns of organic inatter trancport and turnover along a New Zealand grassland river. *Freshwat. Biol.*, 38: 93-107.

YOUNG, R.G.. A.D. HURYN & C.R. TOWNSEND, 1994. Effects of agricultural development on proceccing oí tussock leaf litter in high country New Zealand streams. *Freshwat. Biol.*. 32: 413-427.