# Effects of litter exclusion and wood removal on phosphorus and nitrogen retention in a forest stream

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## Introduction

Many studies in the past have shown indirect evidence of the importance of terrestrial detritus in woodland streams, but recently WALLACE et al. (1997b) eliminated leaf and wood inputs to a small stream and directly demonstrated the importance of this material to stream food webs. Additionally, this whole-stream experiment has shown that terrestrial detritus is more than just food for invertebrates. TANK & WEBSTER (1998) found accelerated wood biofilm development and wood decomposition in the litter exclusion stream, and MEYER et al. (1998) used the litter exclusion experiment to estimate that leaves contribute approximately 30% of dissolved organic carbon exports. Previous studies have also suggested that leaf litter in streams is important to nutrient retention (MULHOLLAND et al. 1985, ELWOOD et al. 1988). The purpose of the current study was to examine the effects of litter exclusion and wood removal on retention of dissolved nutrients.

## Site description

The two streams we studied are located at Coweeta Hydrologic Laboratory, North Carolina, U.S.A. Both are small, first-order streams and drain catchments of mature hardwood forest (WALLACE et al. 1997a). Like other streams at Coweeta, these streams are heavily shaded, have very low primary production, and are dependent on allochthonous inputs (WALLACE et al. 1997b, WEBSTER et al. 1997). The reference stream (C53) was treated with insecticide in 1980 in a study of the role of macroinvertebrates in streams (WALLACE et al. 1982), but it rapidly recovered from that experiment (WALLACE et al. 1986) and has been undisturbed since that time. Dissolved nutrient concentrations are low in these streams. During this study soluble reactive phosphorus concentrations ranged from 1 to 3 $\mu$g P L$^{-1}$, ammonium from 1 to 9 $\mu$g N L$^{-1}$ and nitrate from 1 to 14 $\mu$g N L$^{-1}$. A canopy of 1.2-cm mesh netting was placed over the litter exclusion stream (C55) in August 1993. This canopy began at the headwaters of the stream and extended over the bankful channel. A 20-cm high screen fence was placed along both sides of the 170-m canopy reach to exclude lateral inputs of litter. Additionally, in August 1996, we removed by hand all small woody material (<10-cm diameter) from the stream channel.

## Methods

To measure nutrient retention, we used the technique described by the STREAM SOLUTE WORKSHOP (1990) and WEBSTER & EHRMAN (1996). After collecting samples for background solute concentrations, we used a Mariotte bottle to release a solution of a conservative solute (Cl as NaCl) and a nutrient (P as Na$_2$HPO$_4$ or N as NH$_4$Cl or NaNO$_3$) for 1–3 h (depending on flow) into the stream. Concentrations of Cl were monitored during the release with either ion-specific electrodes or conductivity meters. Once Cl had reached a stable plateau, three water samples were collected at each of five to seven sites in the stretch 100 m below the release site. These samples were analyzed for nutrient concentrations in the laboratory. Nutrient concentrations were divided by Cl concentrations to correct for downstream increases in discharge and the logarithms of the resulting values were regressed against distance downstream from the point of release. The inverse of the slope of this regression is the nutrient uptake length (STREAM SOLUTE WORKSHOP 1990, NEWBOLD 1992). While this method undoubtedly underestimates actual nutrient retention (MULHOLLAND et al. 1990), it is useful for relative comparisons of streams (D'ANGELO et al. 1991, WEBSTER et al. 1991). Measurements of phosphorus retention were begun in 1993 prior to litter exclusion from C55 and continued three to six times each year since. Ammonium retention measurements were not started until 1995. Nitrate retention was measured twice in 1996.

## Results and discussion

Uptake lengths for phosphorus in the reference stream (C53) ranged from 1.9 to 21.4 m. These very short uptake lengths are similar to what has been reported for other small Coweeta streams (MUNN & MEYER 1990, D'ANGELO & WEBSTER 1991, WEBSTER et al. 1991, MULHOLLAND et al. 1997) and clearly indicate that these undisturbed streams are highly retentive of dissolved phosphorus. Phosphorus uptake lengths in C55 were longer (i.e. less retentive) than in C53 on all sampling dates. However, discharge in C55 was also greater than in C53 (3.39 versus 1.85 L s$^{-1}$, 5-year average). To account for differences in discharge, we plotted uptake lengths versus discharge (Fig. 1). These results clearly suggest that litter exclusion decreased phosphorus retention and that phosphorus retention was further reduced after we removed the small wood from the stream.

Results of ammonium retention were similar, with uptake lengths ranging from 3.0 to 24.3 m in C53. Ammonium retention was also decreased by litter exclusion and wood removal (Fig. 2). On the two dates when we measured nitrate retention, there was no retention of nitrate in C55, i.e. nitrate concentration did not decrease downstream from the release site (linear regression, P > 0.05). In C53 nitrate uptake lengths were 174 and 14 m. MUNN & MEYER (1990) and WEBSTER et al. (1991) also found little retention of nitrate in Coweeta streams. Similarly to what was measured in Hubbard Brook (RICHEY et al. 1985), during ammonium releases we observed downstream increases in nitrate (Fig. 3). Thus, not all ammonium uptake was used for anabolic processes. A significant fraction appeared to be rapidly used in the process of nitrification.

We also calculated actual phosphorus and nitrogen uptake from uptake lengths, discharge, and ambient concentrations (STREAM SOLUTE WORKSHOP 1990, NEWBOLD 1992). Phosphorus uptake was highly variable in C53 and did not change over the study period (Fig. 4). In C55, phosphorus uptake was less variable and tended to decrease during the period of litter
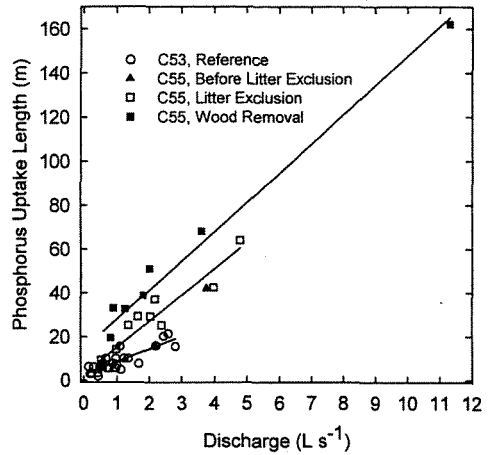


Fig. 1. Phosphorus uptake lengths (S) versus discharge (Q) in C53 and C55. Linear regressions: reference, S = 2.6 + 5.9Q, r$^2$ = 0.73; litter exclusion, S = 3.1 + 12.0Q, r$^2$ = 0.90; wood removal, S = 14.6 + 13.3Q, r$^2$ = 0.97.
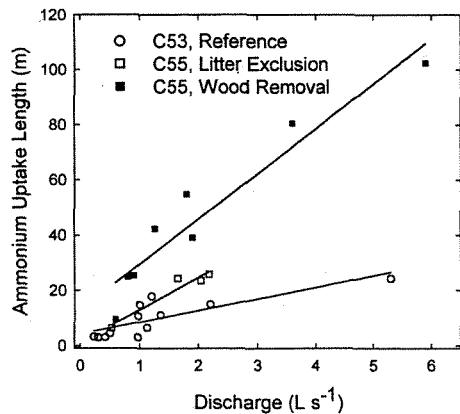


Fig. 2. Ammonium uptake lengths (S) versus discharge (Q) in C53 and C55. Linear regressions: reference, S = 4.3 + 4.2Q, r$^2$ = 0.66; litter exclusion, S = 1.2 + 11.7Q, r$^2$ = 0.93; wood removal, S = 13.1 + 16.4Q, r$^2$ = 0.92.

exclusion and wood removal (linear regression, P = 0.058). During the litter exclusion and wood removal period, phosphorus uptake was higher in C53 than in C55 (paired t-test, P = 0.001). However, on four occasions phosphorus uptake was greater in C55 than in C53. One of these times was before litter exclusion. The other three times were in September and Octo-
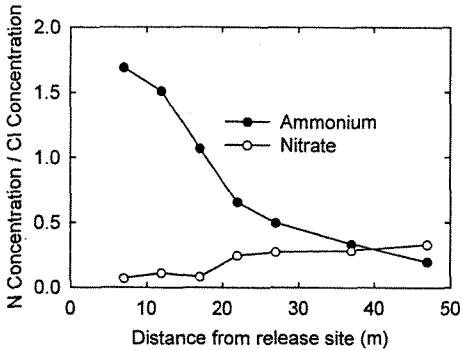
Fig. 3. Background corrected nitrogen concentration ($\mu g \, L^{-1}$ as ammonium or nitrate) divided by chloride concentration ($mg \, L^{-1}$) versus distance downstream from the point of ammonium and chloride release. Division by chloride corrects for downstream increase in discharge. This example is from C53 in June 1997.
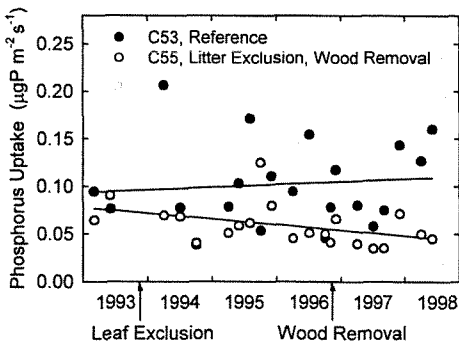


Fig. 4. Phosphorus uptake in C53 and C55 versus date. Lines are linear regression lines.

ber, just before leaf fall. This is a time when leaf standing crops are lowest in Coweeta streams (GOLLADAY et al. 1989). Ammonium uptake was also greater in C53 than in C55 (paired t-test, P = 0.001), though on one occasion, again in September, uptake was slightly greater in C55.

The phosphorus uptake in C53 and C55 was very similar to the 0.15 $\mu g \, P \, m^{-2} s^{-1}$ measured by MULHOLLAND et al. (1997) in another Coweeta stream. Our values are somewhat less than the average 0.31 $\mu g \, P \, m^{-2} s^{-1}$ measured by MUNN & MEYER (1990), but they calculated uptake based on release concentrations rather than applying uptake rates to ambient phosphorus con-

centrations.

Though ammonium uptake lengths in C53 were not significantly different to phosphorus uptake lengths (paired t-test, P = 0.33), uptake of ammonium was greater than uptake of phosphorus (paired t-test, P = 0.001). Ammonium uptake averaged 0.36 $\mu g \, N \, m^{-2} s^{-1}$ compared to 0.10 $\mu g \, P \, m^{-2} s^{-1}$ for phosphorus for the same period. The atomic N/P ratio for these uptakes is 7.9, considerably lower than the usual 16 (REDFIELD 1958). It may be that stream benthic bacteria and fungi have lower N/P than algae (the basis of N/P = 16) or the low N/P may reflect luxury uptake of phosphorus. These calculations do not include nitrate uptake, which is probably small, or nitrification, which would further reduce nitrogen going into anabolic processes.

## Summary

Experiments by MUNN & MEYER (1990) and D'ANGELO et al. (1991) indicated that nutrient uptake in Coweeta streams is primarily biotic. Our study shows that this process is greatly influenced by the presence of leaves. Leaves are undoubtedly a source of nutrients when they first fall in the water, but immobilization of dissolved nutrients by heterotrophic organisms associated with leaf decay is probably of greater significance (GREGORY 1978, MEYER 1980). Leaves also slow the flow of water allowing more time for biotic processes. Further, leaves can affect the form of nitrogen by being a large surface area for colonization by nitrifying organisms, and if the leaves become buried in the substrate they may be a site for denitrifying bacteria (SWANK & CASKEY 1980). The consequences of these processes are lower dissolved nutrient concentrations downstream. Also, leaves are competing with other nutrient-demanding processes such as microbial wood decay (TANK & WEBSTER 1998) and primary production. Recent measurements suggest that algal standing crop and primary production in C55 are greater than before litter exclusion (MEYER, EGGERT and WALLACE, unpublished data).

The biomass of small wood in Coweeta streams is generally less than that of leaves; however, the surface area can be quite significant and metabolically active (TANK et al. 1993). Small wood is also important in modifying water flow and streambed stability. Our results suggest that removal of small wood in 1996 reduced nutrient retention perhaps as much as did the exclusion of leaves in 1993.

## Acknowledgements

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