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APPLIED ISSUES

Nutrient and microbiological characteristics of fine benthic organic matter in sediment settling ponds

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SUMMARY

1. Fine benthic organic matter (FBOM, particles <1 mm) was collected eight times in 1995 and 1996 from settling ponds located at the base of five catchments, and assayed for total C, N and P, extractable ammonium, mineralisable N, organic P, labile polysaccharides, denitrification potential, acetylene reduction and respiration rates, and β-glucosidase and phosphatase activities. The five catchments (10–101 ha in size) are located in the Pacific North-west of the United States. They contain either old-growth forests dominated by Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) or stands that were harvested 30 years ago and replanted with Douglas-fir, with riparian zones dominated by red alder (*Alnus rubra*), bigleaf and vine maple (*Acer macrophyllum; A. circinatum*) and understory herbaceous plants.
2. C : N ratios were significantly higher, and mineralisable N, extractable ammonium and labile polysaccharides were all significantly lower, in FBOM from old-growth catchment sediment than in FBOM from catchments containing harvested stands, showing that the chemical characteristics of FBOM were influenced by forest harvest. C and N concentrations were greatest in sediment from old-growth catchments, but microbial activities (respiration, denitrification potential, phosphatase and β-glucosidase) tended to be greater in sediment from the harvested catchments.
3. Levels of certain chemical components of harvested-catchment FBOM were elevated relative to those found in old growth; specifically, organic and total P, extractable ammonium, mineralisable N and labile polysaccharides, suggesting that stream FBOM from harvested basins is more biodegradable than stream FBOM from old-growth basins.
4. In addition to effects of past timber harvest on FBOM characteristics, there were also significant seasonal differences in both logged and unlogged catchments in all variables except mineralisable N, labile polysaccharides and acetylene reduction rates.
5. The results indicate that past timber harvest in five river basins influenced both composition of and seasonal fluctuations in fine benthic organic matter (FBOM) collected from stream sediments in settling ponds, suggesting a linkage between forest harvest and stream productivity.
6. Comparisons between seasonal patterns in stream and settling pond sediment FBOM characteristics suggested that the readily decomposable organic matter entering sediments during a storm event are rapidly transported and decomposed during their movement through the catchment basin. It also showed the validity of studying settling pond sediments as a surrogate for mountain stream sediments.

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Introduction

The study of small basins has been valuable for observing the influence of logging practices on both physical and chemical processes of forest streams and soils, such as sediment load and nutrient loss to streams (Martin & Harr, 1988), soil movement (Mersereau & Dyrness, 1972), soil acidity, N availability (Robertson & Tiedje, 1984; Johnson, Henderson & Johnson, 1989; Dahlgren & Driscoll, 1994) and stream temperature (Johnson & Jones, 2000). Relatively few studies, however, have been conducted on the effects of timber harvest on fine benthic organic matter (FBOM, particles <1 mm) in mountain-stream sediments, and little is known about the effects of harvesting on FBOM microbial activities and chemistry.

Because most organic matter moves through streams in fine-particulate form (<1 mm) (Sinsabaugh, Weiland & Linkins, 1992), it is an important link between terrestrial and aquatic environments (Cummins & Klug, 1979; Cummins *et al*., 1989). In small woodland streams, much of the organic matter that forms the basis of the aquatic food chain originates as allochthonous litter (Ward *et al*., 1994; Richardson, 1991; Wallace *et al*., 1999).

As forest vegetation begins to regrow after clear-cutting, the quantity, quality and timing of allochthonous inputs available as substrate for stream invertebrates and micro-organisms changes (Gregory *et al*., 1987). Herbaceous plants, a high-quality food source with low C : N ratios (Oelbermann & Gordon, 2000), may dominate riparian zones initially until shaded out by deciduous trees such as alder and maple. Red alder (*Alnus rubra*, Bong.), a nitrogen fixer, has N-rich leaves with relatively low C : N ratios of approximately 23 (Valachovic, 1998). Over time, deciduous species lose dominance, and after about 80 years, Douglas-fir [*Pseudotsuga menziesii* (Mirbel) Franco], with needle C : N ratios of about 100, comes to dominate the site. The decomposition dynamics of woody debris and leaf litter have been well studied, but debate exists about whether qualitative differences found in vegetation persist in particles as small as those that make up FBOM (<1 mm). Several studies have found few differences in FBOM microbial activity among streams flowing through different forest types (Ward, 1986; Sinsabaugh & Linkins, 1990; Sinsabaugh *et al*., 1992), suggesting that headwater and riparian vegetation may have little influence on the chemical composition of FBOM.

In 1995–96 we sampled FBOM from 14 first-order streams to examine the relationship between forest vegetation inputs and chemical and microbial characteristics of FBOM (Bonin, Griffiths & Caldwell, 2000). We found higher microbial activity rates and nutrient concentrations in FBOM from streams flowing through regenerating Douglas-fir stands *c.* 10–30-year-old than in FBOM from old-growth Douglas-fir forest (Bonin *et al*., 2000). Because FBOM is a major component of organic matter in small forested streams and thus an important nutritional source for micro-organisms and invertebrates (Vannote *et al*., 1980; Cummins *et al*., 1989; Schlosser, 1991), we concluded that harvesting headwater forests could shift the chemical and microbial characteristics of FBOM in first-order streams and thus alter their food web dynamics.

Concurrently, we sampled settling ponds at the mouths of five small basins that flow through either old-growth coniferous forest or regenerating 30-year-old stands dominated by deciduous trees and shrubs. Our goals were (1) to determine whether FBOM collected in settling ponds below harvested and unharvested basins reflected the same differences in biological and chemical characteristics as sediment taken from the stream beds and (2) to determine whether seasonal fluctuations observed in characteristics of FBOM from stream sediments were also observed in FBOM from settling ponds; and, if so, whether the biogeochemical relationships were the same in both.

Methods

Site description

Study sites were located in or near the H.J. Andrews Experimental Forest, in the western Cascade Mountains of Oregon, U.S.A. Old-growth sites were dominated by Douglas-fir and western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], 250–500+ years old.

Riparian vegetation of the harvested basins consisted mostly of deciduous trees, primarily red alder and vine and big leaf maple (*Acer macrophyllum* Pursh; *A. circinatum* Pursh) and understory herbs. No riparian buffers were left after clear-cutting. Harvested stands were replanted with Douglas-fir seedlings, but at the time of sampling they were dominated by maple and alder. All sites are between 580 and 800 m in altitude.

FBOM samples were collected from settling ponds located below stream gauges at the mouths of five experimental basins. Catchments 1, 2 and 3 adjoin one another and range in size from 60.2 to 101 ha (Swanson & James, 1975). Catchment 1 (100 ha) was clear-cut between 1962 and 1964. Catchment 3 was partially cut in 1959 and experienced a debris flow in 1964. Catchment 2 was left unharvested and is dominated by old-growth forest, as is Catchment 9. Catchment 10 was clear-cut in 1975. Catchments 9 and 10 are each approximately 10 ha in size.

FBOM from the catchments was compared with FBOM collected concurrently from 14 first-order streams, also located in the H.J. Andrews Experimental Forest, at altitudes ranging from 580 to 1280 m. The streams flowed through forest in one of three successional age classes: Douglas-fir stands approximately 10-years-old or 30-years-old or old-growth forest dominated by Douglas-fir and western hemlock. Riparian vegetation of the young stands was dominated by either herbaceous plants (10-year-old stands) or deciduous trees (30-year-old stands), primarily red alder and maple.

Sample collection, preparation and storage

Sediments were sampled on eight occasions: 9 August, 14 October, 28 October, 4 November, 18 November and 9 December in 1995, and 6 April and 12 May in 1996. FBOM from each pool was collected into a 2-L collecting jar with a hand vacuum pump. The intake line was housed in a 1.3-m long PVC pipe and fitted with a 1-mm stainless steel screen, allowing the intake line to wet-sieve benthic material from the sediment surface of each catchment. Samples were transferred to polystyrene jars (500 mL) and stored in an insulated chest with stream water and ice. In the laboratory, a slurry was prepared by decanting excess stream water from the jars and then shaking the jars to keep FBOM suspended while subsampling. Subsamples were drawn into 1-, 3- and 5-mL plastic syringes with enlarged openings and dispensed into 25-mL Erlenmeyer flasks. All laboratory analyses of slurries were begun immediately upon return from FBOM collection (within 8–12 h) (Bonin *et al*., 2000), within the established time constraints on sampling and sample processing (Bonin, Griffiths & Caldwell, 1999).

Laboratory analyses

Denitrification potential was measured as N_2O production in FBOM slurries incubated in an argon atmosphere and amended with glucose and $NaNO_3$ (Martin *et al*., 1988). Duplicate 5-mL FBOM slurry samples in 25-mL Erlenmeyer flasks were capped with rubber stoppers and purged for 3 min with argon at 120 cc min^{-1}. The flasks were gently shaken to remove air bubbles and incubated at 24 °C for 1 h. After this initial incubation, 2 mL of a sterile solution of 1 mM of glucose and 1 mM of $NaNO_3$ was injected through the stopper and 2 mL of headspace removed. Incubation was continued at 24 °C for an additional 3 h. After 1 and 3 h, a gas chromatograph (GC) equipped with an electron capture detector (Hewlett-Packard) was used to measure N_2O concentrations.

Putative nitrogen fixation rates were measured by acetylene reduction (Weaver & Danso, 1994). Samples were prepared as for dentrification potential except that the headspace was replaced with a mixture of 1.5% O_2, 12.5% acetylene and 86% argon. After the samples had been incubated for 24 h, ethylene concentrations were measured on a GC equipped with a flame ionisation detector. A control without acetylene was analysed for endogenous ethylene production.

Respiration was measured on duplicate 5-mL FBOM slurry samples in 25-mL Erlenmeyer flasks capped with rubber stoppers. Slurries were incubated at 24 °C for 3 h. At 1 and 3 h, the headspace was analysed for CO_2 on a GC fitted with a thermal conductivity conductor.

β-glucosidase activities of micro-organisms associated with FBOM were measured using the spectrophotometric assay of Tabatabai & Bremner (1969), as modified by Zou, Binkley & Doxtader (1992). One millilitre of 10-mM p-nitrophenyl β-D glucopyranoside substrate was added to duplicate 1-mL subsamples containing suspended FBOM. The tubes were shaken and then placed in a 30 °C water bath for 2 h, along with duplicate controls with no β-glucosidase substrate added. After incubation, 1 mL of 10-mM p-nitrophenyl β-D glucopyranoside was added to the controls and all reactions were immediately stopped with the addition of 0.5 mL of 0.5-M $CaCl_2$ and 2 mL of 0.1-M tris[hydroxymethyl]aminomethane at pH 12.0. The mixtures were centrifuged for 5 min at 500 *g*. From the supernatant, 0.2 mL of solution was diluted with 2.0 mL deionised water and the optical density measured at 410 nm. A standard curve was prepared from 0.02 to 1.0 μmol mL^{-1} *p*-nitrophenol.

Testing for phosphatase activity followed the same general procedure as that for β-glucosidase activity, except that the substrate used was 1 mL of 500-mM *p*-nitrophenyl phosphate, incubation period was 1 h and 2 mL of 0.5 M NaOH was added to terminate the reaction.

Measurements of mineralisable nitrogen were made with a 7-day anaerobic incubation method (Keeney, 1982). Duplicate 10 mL FBOM samples in 50-mL screw-topped test tubes were filled to the top rim of the test tube with deionised water, capped and incubated at 40 °C for 7 days. After incubation, an equal amount of 4-M KCl was added. The test tubes were shaken for 1 h in the presence of 0.4 mL 10-M NaOH and analysed for NH_4-N with a Corning selective ion ammonium electrode (Orion Research Inc., Boston, MA, USA).

Extractable ammonium was extracted by adding 50 mL of 2-M KCl to duplicate 10-mL samples in 250-mL Erlenmeyer flasks. Flasks were capped and shaken while incubating for 1 h in the presence of 0.4 mL 10-M NaOH. The contents were analysed using a selective ion electrode to determine KCL-extractable ammonium concentration. Net mineralisation was calculated as mineralisable nitrogen – extractable ammonium.

Non-cellulose polysaccharide content of air-dried FBOM was estimated by colorimetric determination of total sugars (Lowe, 1993). Total carbon and nitrogen were determined by oven-drying samples, grinding them finely enough to pass through a 250-μm sieve and burning them in a Carlo-Erba NA 1500 Series II high-temperature combustion furnace and data analyser (Fisons Instruments, Danvers, MA, USA).

Total and inorganic phosphorus were estimated colorimetrically in 1-N H_2SO_4 extracts from dry samples. To estimate total phosphorus, samples were ignited at 550 °C; estimates of inorganic phosphorus were made from unignited samples (Olsen & Sommers, 1982). Organic P was calculated by finding the difference between total phosphorus and inorganic phosphorus.

Statistical analyses

The computer program SAS 6.10 for Windows was used for all analyses of variance (ANOVA) to test for differences between samples from harvested and unharvested basins on each date. Non-parametric Spearman Rank correlations were generated by using all variables for microbial activity and nutrient availability. Multivariate ANOVAS (MANOVA) were used in conjunction with univariate analyses as an additional explanatory tool to detect overall patterns over time; e.g. whether differences in FBOM from logged and unlogged basins were significant over the entire sampling period, and, if so, whether these differences varied from season to season. Repeated-measures MANOVAS used SAS procedure 'proc mixed' and the variance/covariance matrix, resulting in the largest value for Akaike's Information Criterion for each variable (SAS Institute Inc., 1996); some variables were natural log-transformed, as indicated in Table 1. Repeated measures were conducted on those samples where sampling date (TIME) and treatment (old-growth or harvested forest) were explanatory variables (Table 1). The August sampling was excluded from all MANOVA because some settling ponds had recently been emptied.

Results

Mineralisable nitrogen, extractable ammonium and non-cellulose polysaccharide content were significantly greater in pond samples from harvested stands ($P \leq 0.05$), and C : N ratios were significantly lower (Table 1). Respiration, total phosphorus and organic phosphorus were also higher in harvested-basin FBOM ($P \leq 0.10$). No variables showed significant ($P \leq 0.05$) higher-level interactions between time and treatment.

Analysis of seasonal patterns showed that there were consistently higher C : N ratios, nitrogen fixation rates and concentrations of total carbon and total nitrogen in FBOM from old-growth basins (Figs 1 and 2). On some sampling dates these differences were almost significant ($P \leq 0.10$). In general,

Table 1 Least-squared means for log-transformed (*) variables in old-growth (OG) and 30-year-old (30 Y) catchments, and repeated-measures MANOVA with sampling time (TIME) and treatment (TRT) as main effects. Numbers in parentheses are the range of values. n = number of observations.

Variable	Units	OG	30 Y	TRT	TIME	TRT × TIME	n
C : N	No units	25 (22–28)	19 (17–22)	0.0203	0.0009	0.7922	31
Total carbon	%	16.0 (6.7–25.2)	8.4 (0.7–16.1)	0.1395	0.0057	0.2410	31
Total nitrogen	%	0.64 (0.20–1.10)	0.43 (0.07–0.79)	0.3220	0.0416	0.4092	31
Denitrification potential	μg N gOM^{-1} h^{-1}	57 (21–155)	100 (29–236)	0.2690	0.0001	0.0518	22
Mineralisable N*	mg NH_4-N gOM^{-1}	1.8 (1.8–1.9)	2.9 (2.9–2.9)	0.0001	0.1910	0.9815	26
Extractable ammonium	mg NH_4-N gOM^{-1}	0.19 (0.12–0.26)	0.30 (0.24–0.37)	0.0314	0.0082	0.4366	27
Acetylene reduction*	μmol C_2H_4 gOM^{-1} h^{-1}	258 (7–9370)	132 (7–2650)	0.6823	0.3377	0.0622	25
Respiration*	μg C gOM^{-1} h^{-1}	80 (48–135)	138 (89–214)	0.0840	0.0001	0.1236	31
β-glucosidase*	μmol pNP gOM^{-1} h^{-1}	45 (22–91)	82 (35–114)	0.3219	0.0005	0.2783	31
Phosphatase*	μmol pNP gOM^{-1} h^{-1}	117 (73–187)	176 (118–264)	0.1248	0.0418	0.4962	31
Labile polysaccharides	mg glucose equivalent gOM^{-1}	210 (149–270)	320 (267–392)	0.0220	0.0993	0.2959	30
Total P*	mg P gOM^{-1}	6.0 (4.1–8.9)	9.3 (6.7–13.0)	0.0735	0.0017	0.7130	26
Organic P*	mg P gOM^{-1}	2.6 (2.2–3.0)	3.0 (2.6–3.4)	0.0982	0.0162	0.7651	26

denitrification potential, extractable ammonium, mineralisable nitrogen, organic phosphorus, total phosphorus, respiration, β-glucosidase activity, phosphatase activity and non-cellulose polysaccharide content were also greater in harvested-basin FBOM, and on some sampling dates these differences were significant (Figs 2–4).

Over the course of the study, all variables except mineralisable nitrogen, nitrogen fixation and non-cellulose polysaccharide content showed significant sampling-time differences (Table 1). The most dramatic seasonal pulse was in October, and was most obvious as a positive spike in phosphatase activity, β-glucosidase activity, respiration (all microbial activity indicators) and total phosphorus. Negative spikes were seen in C : N ratios and total carbon.

Discussion

Treatment effects on FBOM

Comparisons of FBOM characteristics in streams flowing through old-growth forests with those flowing through harvested stands demonstrate the impact of harvesting on stream sediments and stream productivity (Bonin *et al*., 2000). It is known that allochthonous litter entering mountain streams is influenced by riparian vegetation, which in turn is influenced by land management; specifically timber harvest (Ward *et al*., 1994). In the coniferous forests of the Pacific North-west, when timber is harvested in watersheds surrounding low-order mountain streams, canopy removal results in the early establishment of N-rich alder and herbaceous plants (Valachovic, 1998) and increased periphyton and bacterial biomass and activity (Stockner & Shortreed, 1976; Gregory, 1980; Hudson, Roff & Burnison, 1992). This should result in FBOM that is more enriched in nitrogen and more readily decomposable than that generated in streams passing through undisturbed old-growth and mature conifer stands (King & Heath, 1967; Kaushik & Hynes, 1971). This is reflected in higher C : N ratios in FBOM from old-growth stream (Fig. 1 in Bonin *et al*., 2000) and settling-pond sediments (Fig. 1).

The higher concentrations of mineralisable nitrogen and non-cellulose polysaccharide content in sediments from harvested-basin settling ponds suggest that concentrations of readily decomposable organic matter are higher in these stands. Thus, decomposition rates and associated microbial activities should also be greater (Suberkropp, Godshalk & Klug, 1976). In both of our studies, measurements of respiration, β-glucosidase activity and phosphatase activity, which indicate microbial activity, were elevated in harvested basins (Table 1 and Fig. 4 in Bonin *et al*., 2000).

With higher litter quality and possible increases in algal and bacterial biomass in harvested-stand FBOM, we also predicted an enrichment of P. Both total phos-

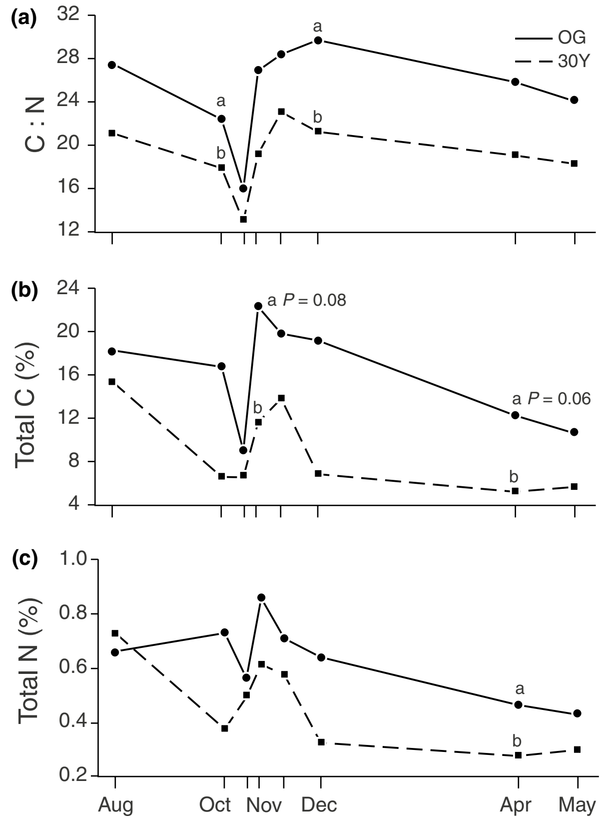

Fig. 1 Mean values for old-growth and harvested stand basins for FBOM: (a) C : N ratios, (b) total C and (c) total N. Different letter for same sample date indicates significant differences by ANOVA at $P \leq 0.05$ except where indicated.

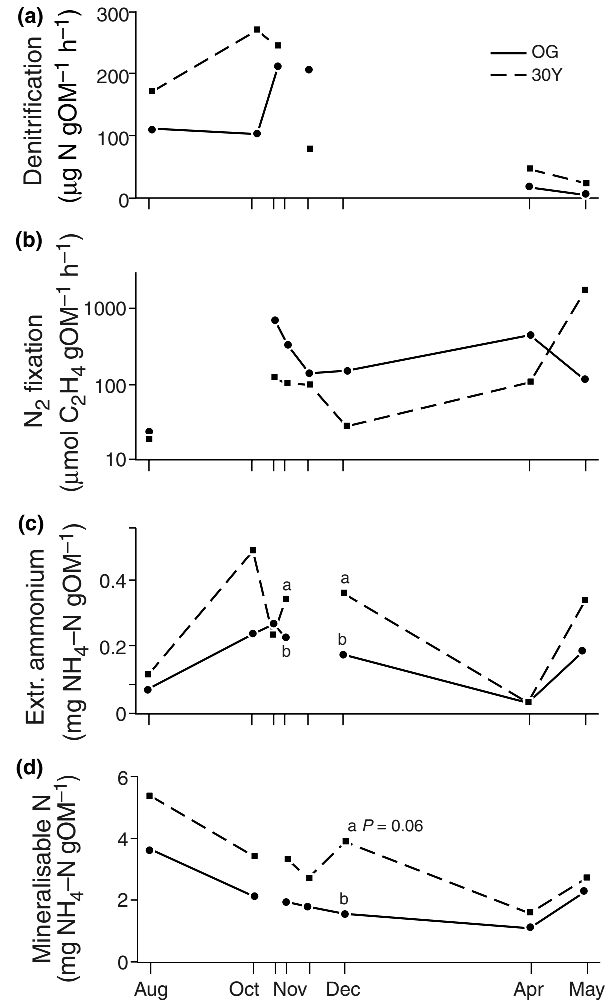

Fig. 2 Mean values for old-growth and harvested stand basins for FBOM: (a) denitrification potential, (b) extractable ammonium and (c) mineralisable N. Different letter for same sample date indicates significant differences by ANOVA at $P \leq 0.05$ except where indicated.

phorus and organic phosphorus were significantly greater in harvested-basin FBOM (Table 1). These sediments were also richer in extractable ammonium; harvested-basin extractable ammonium concentrations were significantly higher than those sampled from old-growth basins.

That denitrification potential rates in harvested-basin FBOM were nearly double those in FBOM from old-growth basins may reflect a greater availability of readily degradable nitrogen (mineralisable nitrogen) and carbon (non-cellulose polysaccharide content) derived from non-coniferous riparian vegetation of the harvested stand and elevated algal and bacterial biomass in these more open stream reaches.

One of the surprises in this study was that nitrogen fixation rates showed the opposite trend from other measures of microbial activity. Acetylene reduction rates in sediment from old-growth settling ponds were about double those in harvested-basin sediments. Essentially the same trend was seen in stream sediments tested by Bonin *et al.* (2000). The mechanism responsible for elevated nitrogen fixation in old-growth forests is not known, but it may be related to reduced N availability in their sediments.

Seasonal patterns

In October, stream and basin FBOM registered a sharp decrease in C : N ratios, total carbon, total nitrogen and organic phosphorus, and concomitant increases in respiration, phosphatase activity and β-glucosidase activity. However, their values returned to prepulse levels by the next collection in November (Figs 1–4 in Bonin *et al.*, 2000). Comparable peak-and-trough pat-

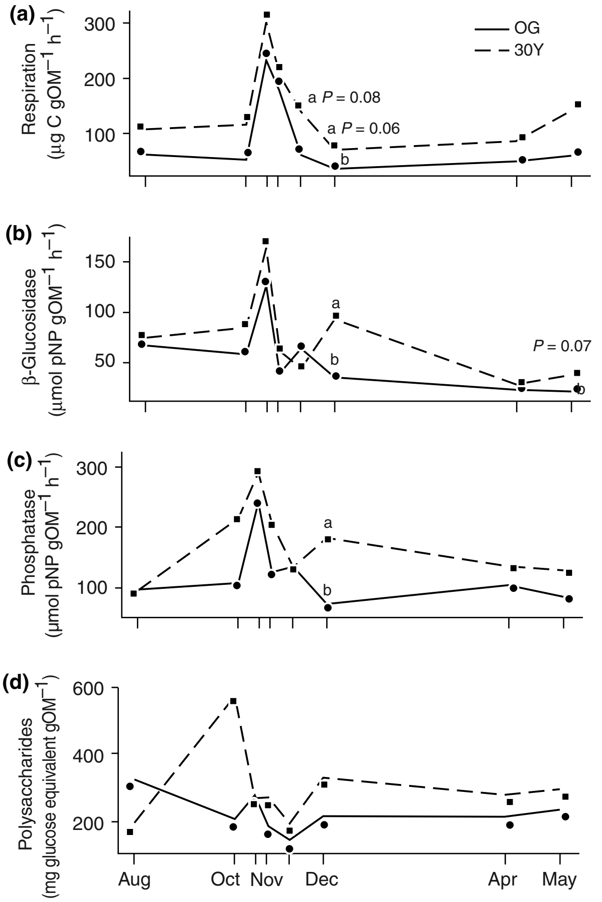

Fig. 3 Mean values for old-growth and harvested stand basins for FBOM: (a) respiration, (b) β-glucosidase, (c) phosphatase and (d) labile polysaccharide. Different letter for same sample date indicates significant differences by ANOVA at $P \leq 0.05$ except where indicated.

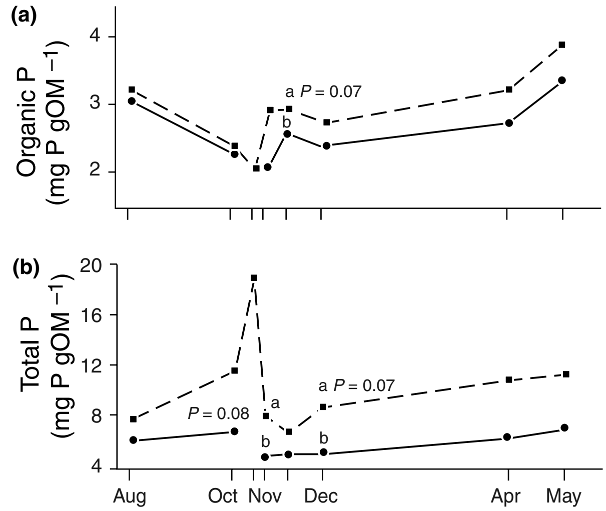

Fig. 4 Mean values for old-growth and harvested stand basins for FBOM: (a) organic P and (b) total P. Different letter for same sample date indicates significant differences by ANOVA at $P \leq 0.05$ except where indicated.

terns in the same variables were also seen in stream sediments (Bonin *et al.*, 2000). Daily precipitation and stream-flow measurements above the settling pond of the old-growth Catchment 2 suggest that a storm during this period may have loaded streams with litter, which caused the observed response.

Although measurements of FBOM characteristics in stream sediments did not always correspond to those in the settling ponds (Bonin *et al.*, 2000), both sets of samples revealed similar seasonal patterns (Figs 1–4). We were surprised that settling-pond sediments varied so greatly over the season. Even though sediments in ponds would be expected to have longer residence times than those in free-flowing streams, the same rapid shifts were seen in both sets of sediments. In the earlier stream-sediment study (Bonin *et al.*, 2000), we hypothesised, based on the work of Cushing, Minshall & Newbold (1993) and others that the rapid return to baseline levels after the dramatic autumn peak happened because new labile carbon was carried out of the streams. This appears to be the case. If these pulses were observed in free-flowing segments of the stream but not in the pools, we would conclude that the rapid return of FBOM to prestorm levels was due to *in situ* decomposition and not to transport. The fact that this pulse was also seen in pond sediments suggests that FBOM introduced into the stream during the storm was rapidly transported along the stream. However, the fact that the pulse was very short lived in both pond and stream sediments suggests that decomposition rates were also very high throughout the system. The high degree of similarity between seasonal patterns in pond and stream sediments also suggests that monitoring settling ponds sediments is a useful surrogate for monitoring upstream sediments.

As predicted, pond-sediment patterns exhibited less-extreme seasonal pulses than those of unrestricted stream sediments. A smaller pulse, similar to the one that occurred on 28 October, was observed on 11 November in streams (Bonin *et al.*, 2000), but did not register in settling ponds. This difference was most pronounced in non-cellulose polysaccharide content concentrations, which registered a dramatic spike in stream FBOM (Fig. 4 in Bonin *et al.*, 2000), but not in pond FBOM, on 11 November (Fig. 3).

In addition to registering major storm-associated pulses in autumn, both pond and stream sediment showed qualitative shifts in FBOM characteristics in spring, when major algal blooms occurred (Gregory, 1980). C : N ratios and denitrification potential rates decreased, and respiration, organic phosphorus, total phosphorus and mineralisable nitrogen rates increased. These responses would be expected with increased algal growth (Suberkropp & Klug, 1980).

Biogeochemical relationships

In ponds, FBOM is not only restrained from movement, but it is in closer proximity to other FBOM particles than FBOM in streams where particles are more likely to be suspended because of the dynamic hydrology of low-order mountain streams. Thus, linkages between biogeochemical transformations may be more easily observed in pond sediments than in sediments from free-flowing streams. Correlations among microbial activity and nutrient availability variables were stronger in ponds than in unrestricted stream sediments in 54 of 74 cases. For example, the relationship between denitrification potential and β-glucosidase activity was more apparent in ponds ($r = 0.81$, $P = 0.05$, Table 1) than in streams ($r = 0.30$, n.s.) (Bonin *et al*., 2000).

Pond sediments would be expected to be more anaerobic than stream sediments because particles settle out, forming relatively stable redox gradients (Christensen *et al*., 1989). Our measurements showed that denitrification potential and nitrogen fixation rates, which both require reduced O_2 concentrations, were higher in pond sediments than in stream sediments (compare Table 1 with Table 1 in Bonin *et al*., 2000). Denitrification potential averaged 57 and 100 μg N gOM^{-1} h^{-1} in old-growth and harvested-basin pond sediments, respectively; the rates in stream sediments were 30 and 50 μg N gOM^{-1} h^{-1} (Bonin *et al*., 2000). Nitrogen fixation rates averaged 258 and 132 μmol C_2H_4 gOM^{-1} h^{-1} in old-growth and harvested-basin pond sediments; 38 and 27 μmol C_2H_4 gOM^{-1} h^{-1} in stream sediments.

With the exception of β-glucosidase activity, differences associated with harvesting treatment in these basins were larger in pond than stream sediments – twice as many variables in pond sediments showed significant effects from harvesting. Because ponds retain sediments longer than streams, harvesting effects are probably reflected more strongly in basin sediments than in free-flowing stream reaches.

Conclusions

Results of this study confirm that clear-cutting old-growth stands alters stream-sediment characteristics; an alteration of FBOM characteristics could have profound effects on other stream trophic levels. The physical, chemical and biological characteristics of FBOM sampled from settling ponds and unrestricted streams exhibited similar broad trends: higher C : N ratios in FBOM from old-growth basins and greater microbial activity and nutrient availability in FBOM from harvested basins. These differences reflect differences in riparian vegetation between the old-growth basins and those that had been harvested.

In addition, both sets of FBOM samples showed similar seasonal trends and biogeochemical relationships. In this study and a previous one (Bonin *et al*., 2000), samples showed higher N and P concentrations in FBOM collected in the spring; these higher levels are probably associated with increased algal production. There was a sharp spike in microbial activity and an associated shift in nutrient characteristics, associated with a autumn storm event, detected in FBOM from both streams and ponds. The fact that temporary spikes in these variables were found in both streams and ponds suggests that this material was rapidly transported along the stream and that the labile components of FBOM are rapidly decomposed *in situ*. If so, then monitoring pond FBOM is a reasonable surrogate for studying rapid changes in FBOM taken from free-flowing streams. This study demonstrates that measurements of settling-pond sediments are useful for documenting differences in headwater streams passing through forests with different riparian vegetation.

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