The role of organic matter in sediment budgets in forested terrain

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Abstract The production and transport of suspended particulate matter usually are major components of a sediment budget, but the organic and inorganic fractions of this material are not commonly differentiated. In four forested streams in the northwestern United States, the organic content of suspended sediment samples ranged from 10 to 80 weight percent for individual flood events. For a given stream, as a percentage of suspended sediment, organic content was highest during base flows and the early rising and late falling limbs of hydrographs, but on an annual cumulative basis, most organic flux occurred during a few days of high flow. By weight, the inorganic component of suspended sediment dominated the annual sediment flux in three of the catchments, but organics represented more than half the suspended sediment load in an old growth redwood stream. Although commonly minor by weight, organic suspended sediment can have important effects on aquatic biological communities, turbidity measurements, and eutrophication in estuaries.

Key words California; carbon; export; particulate organic matter; redwood; sediment flux; seston; turbidity

INTRODUCTION

The objective of this project was to establish the relative importance of organic components of the suspended load in redwood-dominated catchments in north coastal California, USA. Historically, hydrologists have focused on the inorganic component of suspended sediment in the development of sediment rating curves and the estimation of sediment yields, commonly as an indicator of changes in land use (Beschta, 1996). However, the organic component of suspended sediment can affect turbidity (commonly used as a surrogate for suspended sediment), water quality, nutrient cycling, and biological communities (Minshall *et al.*, 1985). For example, because organic sediments remain in suspension longer than do similarly-sized inorganic components, they may have a greater effect on light reduction and thus, on primary productivity. Particulate organic matter (POM) may also affect eutrophication rates in estuaries, the accuracy of airborne imaging spectrometry, and the formation of disinfection by-products in drinking water.

The POM in rivers is derived from both allochthonous and autochthonous sources, which include litter from the riparian zone, breakdown of large organic matter, transport from upstream reaches, algae, bacteria, and aquatic plants (Wallace & Grubaugh, 1996). POM is a component of the carbon budget of a basin, and the transport of organic matter from headwater channels is important in providing food resources for aquatic biota in downstream reaches (Webster & Golladay, 1984).

Although some previous studies demonstrated low organic content in the suspended load in forested streams (e.g. Walling & Kane, 1982), the organic content of suspended sediment can be high. Organic material represented 64% of the total dry weight of suspended sediment in Bull Run, Oregon, USA (La Husen, 1994) and POM >0.2 mm in diameter comprised 10–50% of the material in transport near the streambed in coastal streams in Oregon (Beschta, 1981). Naiman (1982) found that organic matter frequently represented >80% of the suspended load in streams draining boreal forests. However, to date, POM has not been systematically assessed in catchments dominated by redwood forests.

Although suspended organic content commonly exhibits high variability (Naiman, 1982), use of organic content can help explain variations in total suspended solids and turbidity readings (La Husen, 1994; Madej *et al*., 2005). When data are reported on suspended loads derived from turbidity readings, it is seldom made clear whether reported values have been "corrected" for the organic fraction, or whether, as is the usual case, both inorganic and organic components are combined.

STUDY AREA

This study was conducted in four streams within the Caspar Creek and Prairie Creek catchments in northern coastal California, USA. Basin characteristics are listed in Table 1. A predominantly maritime climate with warm, dry summers and cool, wet winters is common to the Caspar Creek and Prairie Creek study sites. Average annual precipitation is 120 cm (Caspar) and 170 cm (Prairie Creek), with most occurring as rainfall between October and April. The Upper Prairie and Little Lost Man basins (tributaries to Prairie Creek) have never been logged, and redwood trees are commonly 80–100 m tall. The redwood trees dominate the riparian zone in Upper Prairie Creek, but are located farther from the stream in the steeper, more confined Little Lost Man Creek. In contrast, the redwood forests in the South Fork and North Fork of Caspar Creek basin were most recently harvested in the 1970s and 1980s, respectively, so trees in the riparian corridor are much younger and smaller. Dominant bedrock types underlying the catchments are well consolidated marine sandstones and siltstones.

Table 1 Drainage area, gradient, riparian composition, and dominant substrate characterizing the study sites.

Site	North Fork Caspar Creek [a]	South Fork Caspar Creek [b]	Upper Prairie Creek	Little Lost Man Creek
Area (km^2)	3.8	4.2	10.5	9.9
Stream gradient (%)	1.5	0.8	1.0	2.6
Dominant overstory riparian composition	Second-growth redwood (*Sequoia sempervirens*)	Red alder (*Alnus rubra*)	Old growth redwood (*Sequoia sempervirens*)	Old growth redwood (*Sequoia sempervirens*)
Dominant substrate	Pebble, cobble	Pebble	Pebble, sand	Cobble, pebble

[a] at ARF gauging station, [b] at QUE gauging station.

METHODS

Suspended sediment and water discharge were sampled in four fish-bearing streams throughout 2002 and 2003, a period of average rainfall and with peak flows of two- to five-year return intervals. Turbidity (in NTUs) was recorded every 10 min with an OBS turbidimeter. Turbidity measurements were used as a surrogate for suspended sediment concentration, using calibration curves. The US Forest Service Redwood Sciences Laboratory (USFS) and Redwood National and State Parks (RNSP) estimated annual suspended sediment flux by using the relationship between discharge, turbidity and suspended sediment concentration. Suspended sediment samples were processed by the USFS and RNSP. The US Geological Survey determined organic content by mass loss on ignition (Guy, 1969) for sediment caught on 0.7-µm, 1-µm, 63-µm, and 1-mm filters. Samples were filtered onto pre-washed and pre-weighed glass fibre filters, ashed at 400°C for 1 h, then cooled and weighed again. Heating the filters to 400°C instead of 500°C prevented loss of water from clay minerals (vermiculite, kaolinite, chlorite, and mica) in the sediment while still burning off the organic matter. Dried samples were weighed on an analytical balance (±0.0001 g). In this study POM refers to organic matter in the size fraction between 0.7-µm and 1-mm. Organic sediment-discharge rating curves were constructed for each basin. Cumulative organic sediment flux was based on the daily record of water discharge and the organic sediment rating relationship for that discharge.

RESULTS

The organic content in the suspended sediment samples exhibited considerable variation, but some generalizations can be made. POM represented a high percentage (Fig. 1) of the suspended sediment during periods of low sediment concentrations (usually during baseflow, and on the early rising and late falling limbs of storm

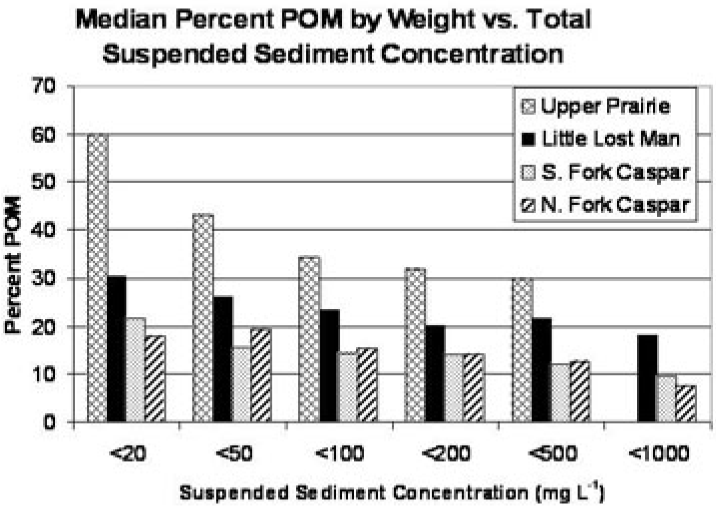

Fig. 1 The median percentage of particulate organic matter by weight in suspended sediment samples with various sediment concentrations at the four study sites.

hydrographs). The transport dynamics of organic sediment are different from that of inorganic sediment because the former are only one-third the bulk density of the latter, and have a higher surface-to-volume ratio (Sedell *et al.*, 1978). As a consequence, organic particles stay in suspension longer than inorganic particles, and so once entrained in the water column, tend to remain suspended for a long time. Organics play a major role in water clarity when sediment concentrations are <50 mg l^{-1}, but their influence becomes less important at higher levels when inorganics are a dominant component of the suspended sediment.

The percentage of POM decreased with increasing sediment concentration in all four streams. Upper Prairie Creek, the stream with the largest riparian trees and widest flood plain, consistently had the highest percentage of POM in its suspended sediment. The relationship between POM and riparian stand composition, flood plain geometry, and other basin characteristics is an area for future research.

The percentage of POM decreased with increasing discharge in all four streams (Fig. 2). At higher discharges, more inorganic sediment is entrained and transported, so organics, as a component of the suspended sediment, are no longer dominant. Even though the percentage of POM decreased with increasing water discharge, the mass transport of POM increased because of the increasing volume of water. In terms of annual organic sediment flux, most transport occurs during high flows. Figure 3 shows an example of the cumulative transport of POM, and the associated hydrograph, for the North Fork of Caspar Creek when 75% of the annual POM transport occurred during one month. This pattern of intense POM transport during storm flows was typical of the streams studied, and is similar to previous studies of POM transport (Cummins *et al.*, 1983).

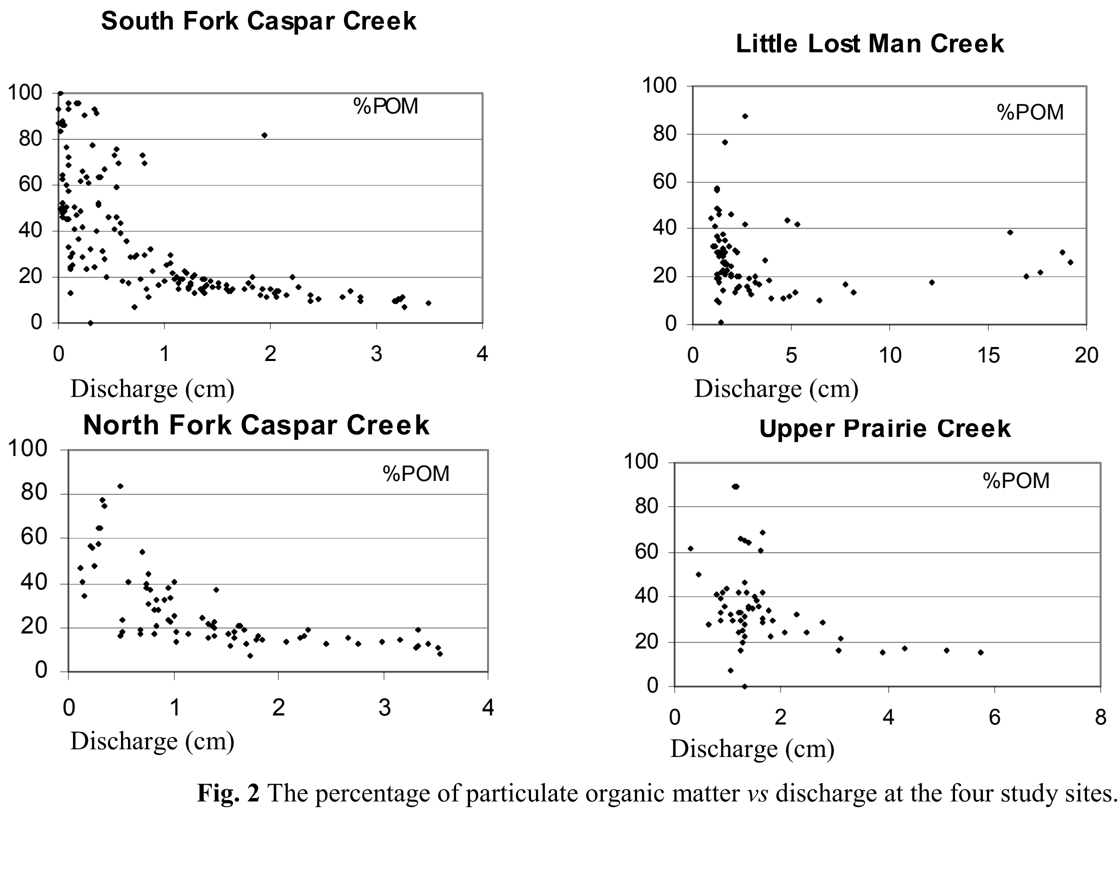

Fig. 2 The percentage of particulate organic matter *vs* discharge at the four study sites.

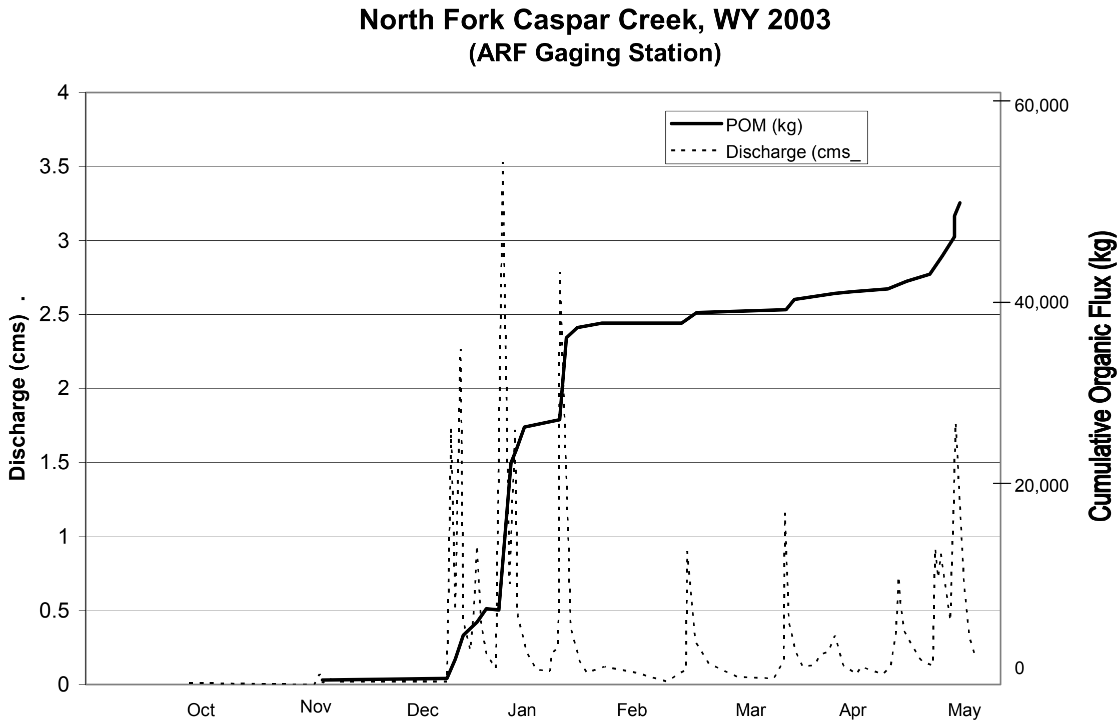

Fig. 3 Example of an annual hydrograph for the North Fork of Caspar Creek, with the cumulative flux of particulate organic matter superimposed.

Organic matter plays a minor, but not insignificant, role in the sediment budgets of three of these catchments (Table 2). For example, Little Lost Man Creek was estimated to have a long-term annual suspended sediment load of 100 t km^{-2} $year^{-1}$ (US EPA, 1999). Organic flux in this basin in 2002 and 2003 ranged from 4 and 20 t km^{-2} $year^{-1}$, or 9–21% of the total annual suspended load. Similarly, in the North Fork and South Fork of Caspar Creek, POM represented about one fifth of the annual suspended sediment flux. However, in Upper Prairie Creek, where a pristine redwood forest dominates the riparian zone, the annual total suspended sediment flux was only 9–15 t km^{-2} $year^{-1}$, with the organic component representing more than half of the flux.

Table 2 Summary of annual suspended sediment yield and percentage of particulate organic matter for two water years at the four study sites.

Catchment	WY2002: Suspended sediment yield (t km^{-2} $year^{-1}$)	POM fraction of annual suspended load	WY2003: Suspended sediment yield (t km^{-2} $year^{-1}$)	POM fraction of annual suspended load
Little Lost Man	~50[a]	9%	100	21%
Upper Prairie	9	65%	15	60%
North Fork Caspar (ARF)	26	24%	53	24%
South Fork Caspar (QUE)	53	19%	72	21%

[a] Sediment yield is an estimate because of several days of missing record due to equipment failure.

CONCLUSIONS

Particulate organic matter constituted about 10–65% of the total annual suspended sediment load in redwood forest-dominated catchments in northern California, USA during a two year period. In such streams, with high organic content, sediment yield estimates should be adjusted to account for organic content. The percentage of organic material in suspended sediment was high during baseflows, but declined with increasing discharge. Most transport of POM occurred during the few large floods that took place during the winter. Organic content can influence water clarity, fish-feeding behaviour, and other biological processes, and should be considered in sediment budgets in forested catchments. In addition, the particle size distribution of POM is important to both transport dynamics and its quality as a food source for aquatic biota. The relationships among particle size, organic content of suspended sediment, and basin characteristics need further research. Long-term monitoring of organic content is also needed to assess the temporal and spatial variability of organic fluxes on a catchment scale.

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