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Intra-annual variation in benthic organic matter in a saline, semi-arid stream of southeast Spain (Chicamo stream)

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Abstract

During 1994 and 1998–1999, temporal changes in the benthic organic matter (BOM) and its fractions (CBOM = coarse; FBOM = fine; UBOM = ultrafine) were studied in a 354-m reach of Chicamo stream, a saline (9.5 g l^{-1}), temporary semi-arid stream located in southeast Spain. Both time periods differed in their frequency and intensity of spates occurring before sampling. BOM at all sites was dominated by FBOM, followed by UBOM and CBOM. Significant differences in total BOM and its fractions occurred among sampling sites, years, months and dates, illustrating the complex temporal variation of benthic organic matter. Positive correlations were found for FBOM and TBOM with discharge, for CBOM with water depth, and between total BOM, FBOM and UBOM and biomass of periphyton. Principal Component Analysis and Cluster Analysis revealed five different groups, each characterised by different patterns of dominance by fractions of BOM.

Introduction

Benthic organic matter accumulations in streams are an important habitat providing food and refuge for many sediment organisms (Benke et al., 1984; Huryn & Wallace, 1987). Benthic organic matter (BOM) storage is a function of inputs such as allochthonous matter from the riparian zone (Minshall et al., 1983; Gurtz et al., 1988) and autochthonous matter from primary producers (Bison & Bilby, 1998), and outputs depending on the hydrology of the stream (Hill et al., 1992b), retention controlled by channel morphology (Smock, 1990) and rates of biotic processing by microbes and invertebrates (Wallace et al., 1982; Power et al., 1985). Variations in riparian conditions, organic matter influx from tributaries, location-specific lithology and geomorphology, extent of floodplain and location along the river continuum all influence BOM storage (Minshall et al., 1983).

In spite of the great importance of BOM to stream ecosystem function, benthic detrital storage is one of the most poorly understood components of stream organic matter budgets (Webster & Meyer, 1997; Stagliano & Whiles, 2002). Jones (1997) claimed that several aspects limit our understanding of organic matter storage, including our limited knowledge of temporal dynamics of BOM because studies are usually limited to 1 year, even though BOM storage varies across years. In arid and semiarid streams, the factors influencing the dynamics of organic matter are very complex, and differ from those in streams in temperate regions (Jones et al., 1996). Arid streams are characterized by low allochthonous input of organic matter (Webster & Meyer, 1997), high primary production *in situ* (Fisher, 1995), and highly variable discharge (Jacobson, 1997). For these streams, seasonal and annual changes in BOM are typically higher than in forested streams.

Chicamo stream is a saline and spatially intermittent stream, located in the arid southeast region of Spain, where we have been intensively researching aspects of production and biogeochemistry. Our results indicate that it has high primary production (Suárez & Vidal-Abarca, 2000) because of the dominance of periphyton communities throughout the year. So compared with others primary producers (e.g. *Chara vulgaris*) the periphyton assemblage is dominant in terms of biomass (about 82%) and contribute with 84% of gross primary production total (GPP) and 86% of community respiration (Velasco et al., 2003).

BOM is dominated by the fine fraction and we have detected an over-abundance of detritus (Martínez et al., 1998). Shredders are absent from the stream due to the scarcity of the coarse fraction of BOM. Detritivorous feeding groups are dominant (Guerrero, 1996; Martínez, 1996; Martínez et al., 1998). Moreover, DOC (dissolved organic carbon) is the most abundant fraction of organic carbon flowing in the Chicamo stream (98%). Finally, the dynamics of particulate and dissolved carbon (POC and DOC), via discharge and floods, provide pulses of allochthonous organic carbon and nutrients (Vidal-Abarca et al., 2001).

This paper reports temporal variations in storage of benthic organic matter (BOM) and its fractions (coarse = CBOM, >1 mm; fine = FBOM, 56 μm–1 mm; ultrafine = UBOM, 0.7–56 μm) in a 354-m section of the middle-reach of Chicamo stream during two year-long time periods. Differences in standing stocks of BOM are hypothesized to result from variations in both frequency and intensity of flash-floods or high rates of growth of periphyton. Our second objective was to assess some physical, chemical and biological parameters that may explain the benthic intra-annual dynamics of organic matter to derive a model of annual dynamics of BOM.

Study site

The Chicamo stream is a spatially intermittent stream in southeast Spain (30XSH7029, UTM). It drains a watershed of 502 km^2 and is 59.4 km long, with reaches of flowing water separated by several discontinuous reaches that only flow during rainy periods (Fig. 1). The climate is arid Mediterranean with a mean annual temperature of 18 °C and an annual precipitation of less than 250 mm. Flooding may occur in autumn and spring whereas low flows predominate in summer. Unpredictable flash floods can occur at any time.

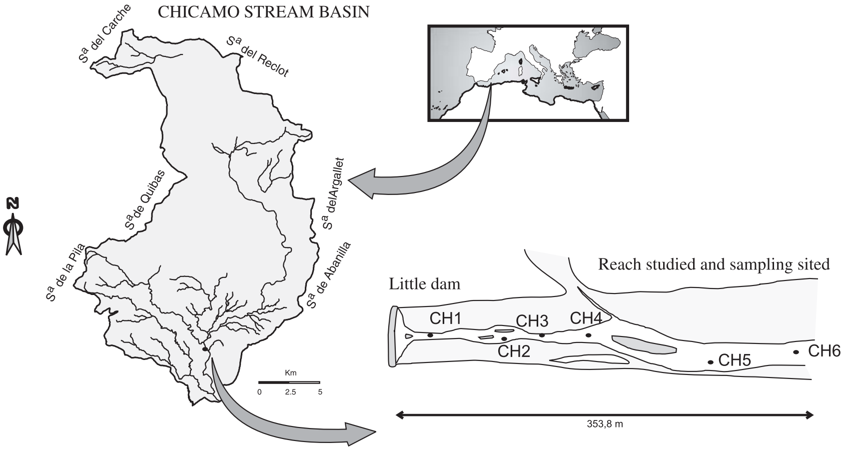

Figure 1. Map of the study area with sampling site locations.

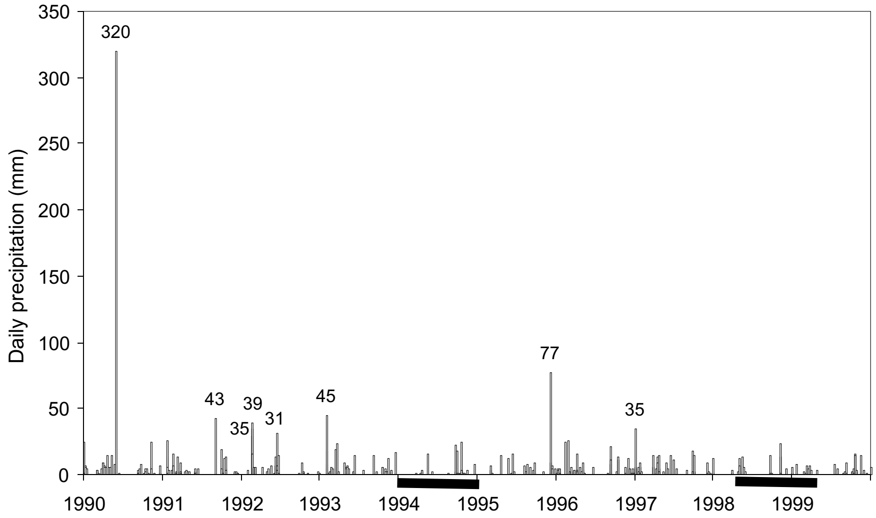

Figure 2. Daily rainfall from 1990 to 1999. Solid bar = study periods.

The study period (January–December 1994 and May 1998–May 1999) was dry (total rainfall 1994 = 150.5 mm; 1998 = 177.1 mm; 1999 = 124 mm). Both study years were preceded by significant flash-floods (Fig. 2). We considered that values >30 mm precipitation/24 h can generate floods (Segura, 1987).

The natural vegetation of the watershed is open Mediterranean scrub, although about 50% has been cleared for agriculture (Pardo, 1994).

The study was carried out in a temporal, braided and shallow reach 353.8 m long, in the middle section of the Chicamo stream (Fig. 1). The upstream limit of the study site was a small irrigation

Table 1. Mean, range, standard deviation (SD), and coefficient of variation (CV,%) of physical, chemical and biological parameters measured in the Chicamo stream during the 2 years studied

	n	Average	Maximum	Minimum	SD	CV
Stream width (m)	89	5.55	22.50	0.00	5.72	103.1
Depth (cm)	89	5.24	32.00	0.00	7.83	149.43
Current velocity (m s^{-1})	89	0.02	0.16	0.00	0.03	150
Discharge (l s^{-1})	89	5.41	73.00	0.00	10.55	195.0
Temperature of water (°C)	89	19.69	29.50	7.00	5.54	33.2
Dissolved O_2 (mg l^{-1})	89	10.42	17.49	4.39	2.61	25.04
Salinity (g l^{-1})	89	8.49	12.20	4.80	1.78	21
Conductivity 25 °C (mS cm^{-1})	89	13.21	19.20	7.69	2.15	16.3
pH	87	7.89	8.64	7.00	0.33	4.18
Alkalinity (mg l^{-1})	73	97.83	300.80	3.20	113.69	116.21
Suspended solids (g l^{-1})	85	8.86	760.63	0.00	82.02	925.7
P-PO_4 (μg l^{-1})	85	9.30	255.26	0.02	27.74	298.3
NO_3-N (mg l^{-1})	89	2.59	31.17	0.04	3.38	130.5
NO_2-N (μg l^{-1})	89	25.71	206.37	0.97	32.50	284
NH_4-N (μg l^{-1})	89	207.32	2450.84	0.00	408.98	197.3
$N_{inorganic}$/P	85	4388.05	202381.84	3.35	21727.04	495.15
Periphyton (g AFDW m^{-2})	60	122.79	317.47	61.22	54.78	44.61

dam about 2 m in height and totally silted-up. Although water was always present throughout the study period due to subsurface water seepages, stream water did not flows during the summer. The average wetted width of the channel ranged from 0 to 22.5 m ($n = 89$) although total width of the channel was 53.5 m. During the study period, water depth ranged from 0 to 32 cm ($n = 89$). Mean annual discharge was 5.41 l s^{-1} ($n = 89$) with a range from 73 l s^{-1} down to 0 l s^{-1} in summer. The mean water temperature was 19.7 °C (range of 7–29.5 °C; $n = 89$) while salinity ranged from 4.8 to 12.2 g l^{-1} ($n = 89$). The principal physical and chemical parameters for the study period are shown in Table 1 and additional information on the physico-chemical characteristics of the stream can be found in Vidal-Abarca et al. (2000).

Sediments consist of gravel and sand over consolidated marls in the erosional zones of runs and silts in pools and depositional zones. Because of unpredictable floods, riparian vegetation is sparse. There are no trees and *Phragmites australis*, *Tamarix canariensis* and some species of reeds are present. Periphyton (diatoms and Cyanobacteria) covered almost the entire study area. Patches of filamentous green algae (primarily *Cladophora glomerata*) and *Chara vulgaris* occurred in pools and depositional zones.

Methods

Sampling procedures

The study was carried out from January to December, 1994 and between May, 1998 and May, 1999. During 1994, samples were taken monthly in four sampling sites (CH1, CH2, CH5 and CH6) whereas in 1998–1999, they were taken each two weeks during base flow and each two days over two weeks after rain, in three sampling sites (CH1, CH3 and CH4) (Fig. 1). CH1, CH3, CH4 and CH6 are runs with very low flow (mean current velocity = 0.03 m s^{-1}; mean depth = 2.5 cm), while CH2 and CH5 are little pools (mean current velocity = 0.02 m s^{-1}; mean depth = 12.9 cm) that were silted in 1998–99. CH6 was not sampled in 1998–1999 because was dry during several months.

Three sediment samples were collected at each site using a 33.183 cm^2 PVC core, which was introduced to 2 cm depth in sediments. The samples were pumped from a manual pump and preserved at −15 °C until laboratory analysis. In addition, 156 samples of periphyton were collected using a 11.45 cm^2 PVC core during 1998–1999.

In the laboratory, benthic macroinvertebrates were sorted from sediment samples under a dissecting microscope. Detrital components were divided into coarse (CBOM, >1 mm), fine (FBOM, 56 μm–1 mm) and ultrafine (UBOM, 0.7–56 μm) fractions (Raikow, et al., 1995). The periphyton samples were filtered (Whatman GF/C glass fiber filters) and the filters were halved. One half and the fractions of benthic organic matter were dried (60 °C, 24 h), weighed, ashed (550 °C, 4 h) and reweighed to determine the ash free dry weight. Data were recorded as g AFDW m^{-2}. The other half of the filters were frozen for 96 h before being extracted in methanol for determination of chlorophyll *a* (Aloi, 1990). These data were recorded as mg chlorophyll *a* m^{-2}.

Data analyses

To examine temporal variations (between years, months and dates) in benthic organic matter, analyses of variance (One way-ANOVA) were used on log−(x + 1) transformed data. Pearson correlation analyses were computed between the total and fractions of BOM, and between these and some physical, chemical and biological parameters measured at the sampling sites.

Principal Component Analysis (PCA) was performed on a matrix of 86 cases by 9 log−(x + 1) transformed variables (TBOM, CBOM, FBOM, UBOM, discharge, temperature, conductivity at 25 °C, nitrite, $N_{inorganic}/P$ ratio) using the *XL*STAT program (Fahmy, 1999). To visualise the PCA groups more easily, a cluster analysis was performed on a matrix of the scores of the three first axes of the PCA, using Ward's clustering technique with the *XL*STAT program.

Results

Storage of BOM was dominated by the fine fraction (479.4 g m^{-2}, 66%) followed by UBOM

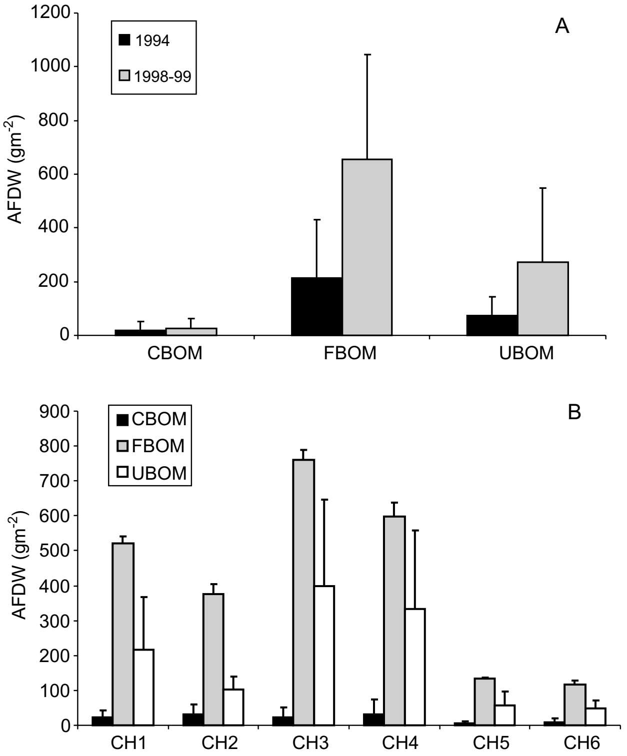

Figure 3. (A) Standing stocks (g AFDW m^{-2}) of coarse, fine and ultrafine BOM (mean ± SD) for the two study periods. (B) Standing stocks (g AFDW m^{-2}) of coarse, fine and ultrafine BOM (mean ± SD) in each sampling site.

(225 g m^{-2}, 31%) and CBOM (22.1 g m^{-2}, 3%). Amounts of benthic organic matter fractions measured during 1998–99 were significantly higher than in 1994 (Fig. 3A; Table 2). In general, CH3 and CH4 had the highest standing stocks of TBOM for all the samples (Fig. 3B).

The TBOM from all six sampling sites was dominated by FBOM (68.57% of TBOM for CH1; 73.93% for CH2, 64.38% for CH3; 62.12% for CH4; 67.45% for CH5 and 66.91% for CH6). TBOM and its fractions differed among years and among, months, dates and sites (Table 2). These results suggest that there are many different sources of variance in benthic organic matter in this stream. Moreover, the physical and chemical parameters measured during study period were very variables, with some parameters showing a high degree of variability as seen from the coefficient of variation (Table 1). Nitrate-N was the major form of inorganic nitrogen and their con-

Table 2. Results of variance analysis (One way-ANOVA) for total BOM and its fractions among years, sites, months and dates

	Annual variation		Spatial variation				Temporal variation			
			dates		month		dates		month	
	F	*p*-Value	F	*p*-Value	F	*p*-Value	F	*p*-Value	F	*p*-Value
CBOM	23.8215	1.751×10^{-6}	16.048	4.072×10^{-13}	14.133	5.448×10^{-12}	3.815	4.709×10^{-9}	3.815	3.721×10^{-7}
FBOM	160.852	1.39×10^{-29}	54.810	0	53.677	0	12.016	1.96×10^{-30}	18.760	0
UBOM	243.427	0	70.722	0	70.277	0	16.813	0	24.509	0
TBOM	203.656	0	65.447	0	63.925	0	13.703	0	20.802	0

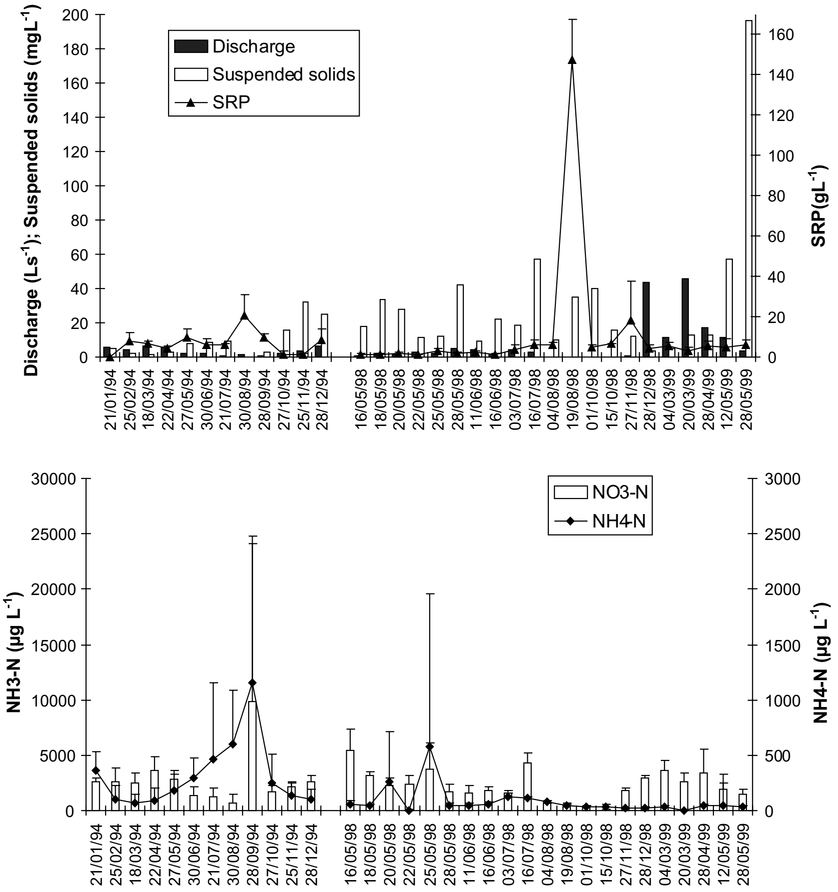

Figure 4. Temporal changes in nutrients (NO_3-N, NH_4-N and SRP; $n = 4$ for 1994; $n = 6$ for 1998–1999) and discharge and suspended solids (mean ± SD) measured in the Chicamo stream.

centrations were highly variable (CV = 130.5%). SRP was more variable than the different nitrogen forms (CV = 293.4%). However, suspended solids was parameter showed highest variability (CV = 925.7%) (Fig. 4).

Seasonal variability in the size of TBOM fractions did not exhibit a common trend across the two study periods (Fig. 5). Although the fine and ultrafine fractions peaked in autumn and winter for both study periods, the maximum value occurred on April 24, 1999 associated with local heavy rain the previous day that was not registered by the meteorological station (Fig. 2). The lowest amounts of BOM were found on June 30, 1994.

The relationships between the fractions of BOM were also examined for each sampling site (Table 3). Predictably, in all the sites, FBOM was correlated with UBOM and total BOM and with TBOM in all sampling sites except CH2. There were no significant correlations of CBOM with total and the other fractions of benthic organic matter.

A positive and significant correlation was found for CBOM with water depth and for FBOM and TBOM with discharge (Table 4). Temporal patterns of discharge differed between 1994 and 1998–1999 (Fig. 5), but although there was no significant correlations between discharge with any BOM fractions in 1994, there was a positive and significant correlation for FBOM and discharge during 1998–1999 ($r = 0.346$; $p < 0.05$). Negative correlations were found between FBOM and temperature. FBOM, UBOM and total BOM were negatively correlated with nitrate, ammonium and relation $N_{inorganic}/P$ and positively correlated with

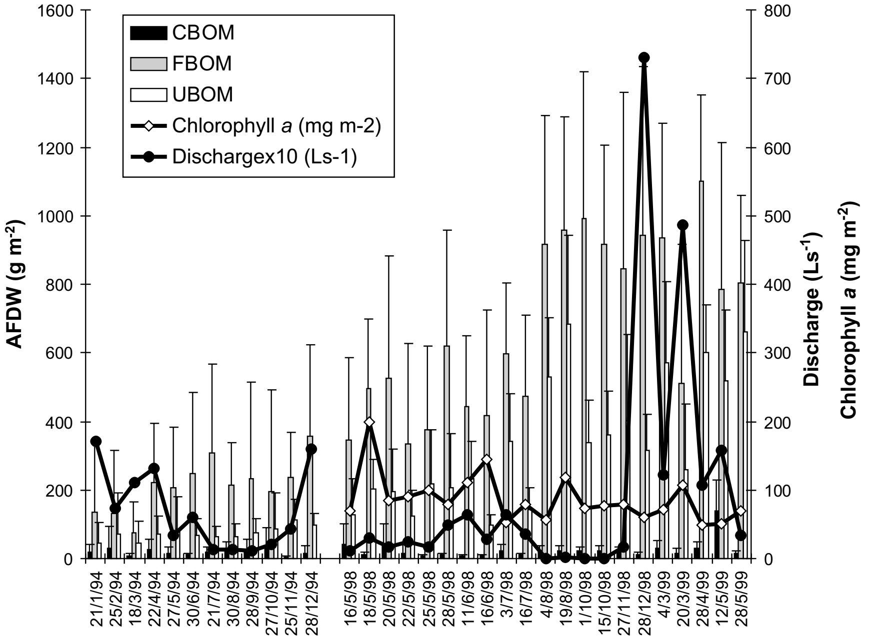

Figure 5. Temporal changes in storage of CBOM, FBOM and UBOM (mean ± SD), discharge and periphyton biomass measured in the Chicamo stream.

periphyton (Table 4). Finally, positive correlations existed between CBOM and alkalinity and nitrite concentration.

The first three axes of PCA explain 67.2% of the total variance (Table 5). The first axis is related positively with TBOM and the fine and ultrafine fractions and negatively with dissolved oxygen. The second axis is positively related to water temperature and negatively to discharge which may relate to seasonal variability of flow (Fig. 5).

Cluster analysis was used to define discrete groups of samples more clearly. We removed two outliers (75 and 76) separated by PCA (Fig. 6) with the highest values of discharge during the two studied years. Cluster analysis generated five groups (Fig. 7). The first group includes samples with highest values of TBOM, FBOM and UBOM, independently of season (Fig. 8 and 9). The second group comprises samples taken during summer with high water temperatures whereas samples with the lowest values of TBOM, FBOM and UBOM during winter occurred in the third group. The fourth group includes the rest of the samples with intermediate values for all parameters, and finally the fifth group had only two samples taken after a large storm.

Discussion

The storage of BOM at 31 sites located in 18 streams of United States and southern Canada varied from 20 g AFDW m^{-2} in Monument Creek, Alaska to 35 000 g AFDW m^{-2} in an Oregon headwater stream. Across these sites, the coarse and fine fractions of BOM contribute about 24 and 14% of benthic detritus, respectively (Jones, 1997). Streams in the southeastern United States had BOM stores ranging from 600 to 10 500 g AFDW m^{-2}. In contrast, in the drier western and midwestern United States, BOM was less than 600 g AFDW m^{-2} (Jones, 1997). In the Chicamo stream, the average storage of total BOM was 726 g AFDW m^{-2} which is similar to values found in arid and semiarid regions of north America, but almost half that found by Molla (1994) in a Mediterranean stream in central Spain (1375.5 g AFDW m^{-2}). In contrast, FBOM contributed 66% of total whereas CBOM was only 3% of the total (Table 7).

FBOM results from the breakdown of large particles, and considerable amounts of FPOM (fine particulate organic matter) may consist of the faeces of grazing and detritivorous aquatic macro-

Table 3. Pearson correlation coefficients between TBOM, CBOM, FBOM and UBOM for each sampling site.

	CBOM	FBOM	UBOM
CH1; $n = 33$			
FBOM	0.2258		
UBOM	0.1988	0.8462*	
TBOM	0.2661	0.9847*	0.9234*
CH2; $n = 12$			
FBOM	−0.1453		
UBOM	−0.0137	0.3160	
TBOM	0.0273	0.9651*	0.5001
CH3; $n = 21$			
FBOM	0.2654		
UBOM	0.4153	0.8080*	
TBOM	0.3861	0.9631*	0.9345*
CH4; $n = 21$			
FBOM	0.2832		
UBOM	0.3377	0.7175*	
TBOM	0.3042	0.9263*	0.8873*
CH5; $n = 12$			
FBOM	0.5364		
UBOM	0.1201	0.8097**	
TBOM	0.4663	0.9892*	0.8861*
CH6; $n = 12$			
FBOM	0.1172		
UBOM	−0.0829	0.5654***	
TBOM	0.1851	0.9820*	0.6866***

Significance levels of correlations: *$p < 0.001$; **$p < 0.01$; ***$p < 0.05$.

Table 5. Cumulative variance and eigenvalues of BOM and its fractions and physical and chemical parameters for the first three axis of PCA. The eigenvalues less than 0.25 have been omited

	Axis 1	Axis 2	Axis 3
Variability	0.367	0.180	0.125
Cumulative (%)	36.70	54.70	67.20
LnCBOM	0.574		−0.411
LnFBOM	0.945		
LnUBOM	0.909		
LnTBOM	0.964		
LnDischarge(l s^{-1})		−0.763	
LnTemperature (°C)		0.799	
LnO_2 dissolved (mg l^{-1})	−0.590	−0.276	−0.512
LnCond 25 °C (mS cm^{-1})			0.839
Ln NO_2-N (μg l^{-1})	−0.285	0.494	
Ln N/P	−0.416	−0.417	0.315

invertebrates (Wallace et al., 1982; Power et al., 1985). We have no data about faecal production of grazers and detritivores in the Chicamo stream, but Guerrero (2002) showed that macroinvertebrate production during summer of 1999 in the study reach of Chicamo stream did not exceed 13.04 g AFDW m^{-2} day^{-1} whereas the periphyton production was 1174.25 g AFDW m^{-2} day^{-1} and total BOM production was 7207.63 g AFDW m^{-2} day^{-1}. Usually benthic accumulation of FBOM is lower than that of other fractions of benthic organic matter (Webster et al., 1999), however in arid streams, it may

Table 4. Pearson correlation coefficients between total BOM and its fractions and several physical, chemical and biological variables measured in the reach of Chicamo stream studied

	n	CBOM	FBOM	UBOM	TBOM
Depth (cm)	91	0.4364*	0.2012	0.2203	0.2620**
Discharge (l s^{-1})	91	0.0268	0.3993*	0.1327	0.3199***
Temperature (°C)	91	−0.0227	−0.3621*	−0.0483	−0.2583
Alkalinity (mg l^{-1})	75	0.5477*	0.1925	0.2826***	0.2926***
P-PO_4 (μg l^{-1})	87	0.0321	0.2234	0.2638**	0.2637**
NO_3-N (μg l^{-1})	91	0.0232	−0.3042***	−0.2730**	−0.3159***
NO_2-N (μg l^{-1})	91	0.4915*	−0.0562	0.1469	0.0669
NH_4-N (μg l^{-1})	91	0.0096	−0.3042***	−0.2193	−0.2934***
$N_{inorganic}$/P	87	0.0177	−0.5189*	−0.5830*	−0.5922*
Periphyton (g AFDW m^{-2})	41	0.0989	0.3618*	0.4776*	0.4530*

Significance levels of correlations: $^{*}p < 0.001$; $^{**}p < 0.01$; $^{***}p < 0.005$.

exceed other fractions of benthic detritus (Jones, 1997) as found in the Chicamo stream. Although we have no data for periphyton biomass for 1994, the high values of FBOM during 1998–1999 did not seem be due to increasing periphyton production because it is constant along the year (Fig. 5). Chicamo stream acts as a sink for detritus which only is mobilized by large or frequent floods. 1994 was preceded by several flash-floods that presumably washed out stored organic matter storage. This did not occur before 1998–1999, although flood intensities were higher (>50 mm). This paradox may be due to rainfall data registered in meteorological station that do not reflect localized heavy rainfall in the catchment.

The positive significant correlations between periphyton biomass and the total and fine and ultrafine fractions of OM indicate an authochthonous origin of BOM in the Chicamo stream. Fisher

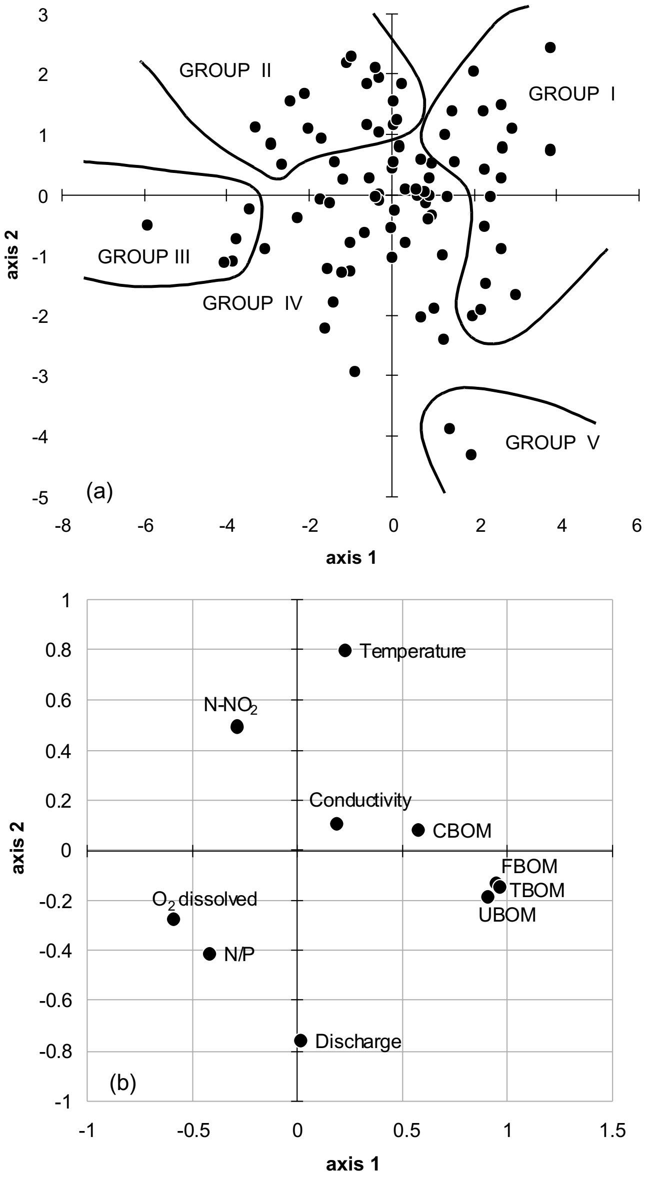

Figure 6. Plots of samples (a) and variables (b) on the first two components of a PCA.

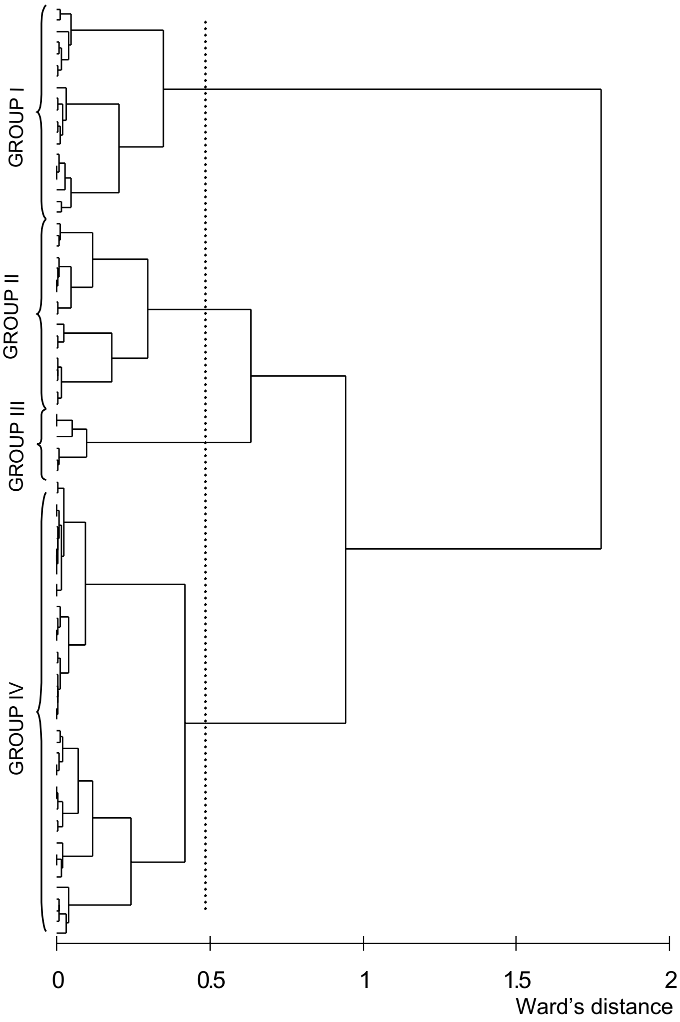

Figure 7. Dendrogram from classification of scores of three first components of a PCA.

(1995) suggested that in open streams of arid regions, the dynamics of organic matter is dominated by living plants. Examples include Rock Creek, Idaho dominated by macrophytes and algae (Brock, 1980), Rattlesnake Spring, Washington by watercress and algae (Cushing & Wolf, 1984), and Sycamore Creek, Arizona, by *Cladophora glomerata* and its epiphytes (Busch & Fisher, 1981). In the Chicamo stream periphyton is the dominant aquatic community (Velasco et al., 2003) and its annual growth cycle may underpin benthic organic matter annual dynamics.

The positive significant correlations between discharge and TBOM and FBOM in the Chicamo stream are not easy to explain. Webster et al. (1983) and Hill et al. (1992b) comment that during non-storm periods, the storage of benthic organic matter depends on structure (presence of pools) and microrelief of the streambed and the presence of retention structures as large woody debris. Martí et al. (1997) shown that transient storage zones increase water residence time allowing surface water to interact more with sediments and consistently could be very efficient processing organic matter. However, in the Chicamo stream there are not such transient storage zones, only small pools which fill with BOM derived from both the biomass of periphyton and of fine organic matter mobilised from catchment during rainfall.

We have not found a temporal model to explain variations of benthic organic matter in the

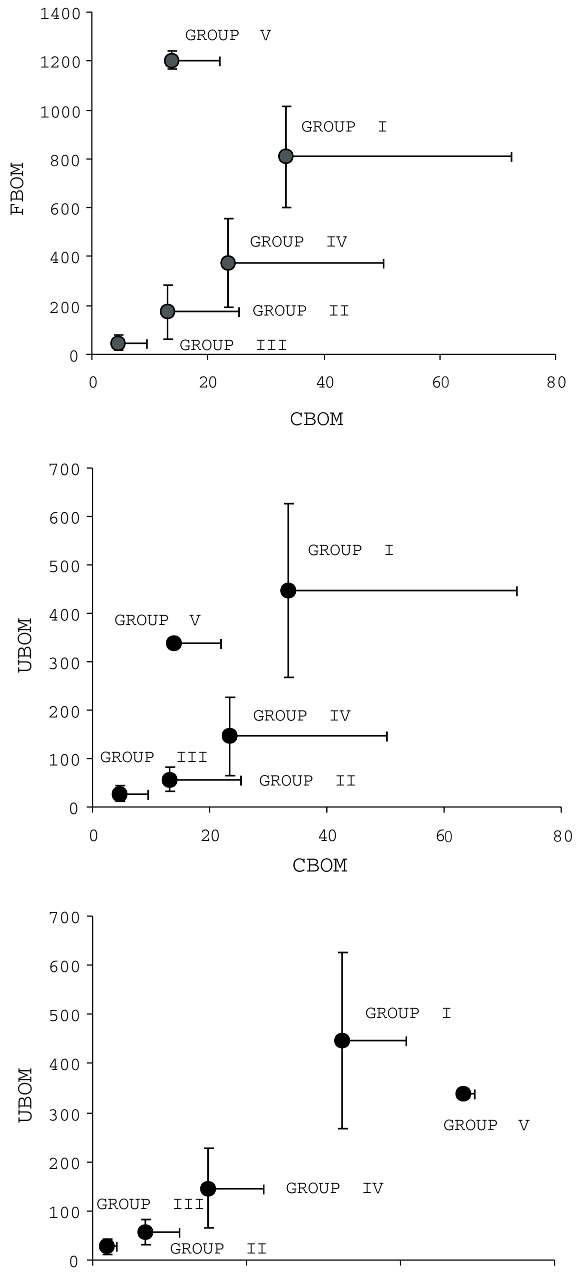

Figure 8. Average values (±SD) of each group obtained by PCA and classification for fractions of BOM.

Chicamo stream. Hill et al. (1992a) studying Texas prairie streams, found that in summer, values for benthic organic matter were significantly higher than in the other seasons. Similar results were found by Molla (1994) in a Mediterranean stream where TBOM increased five-fold from May to July. These patterns differ from those in the Chicamo stream where we detected highest values for the fine and ultrafine fractions in autumn and winter. As the annual production of periphyton is constant during the year, BOM and its fractions probably depend more on discharge after rainfall than seasonal variation.

In the Chicamo stream, there is high variability in total BOM and its fractions among sites, and among two years, months, and dates. Variability in the storage of BOM is usual in streams. Cummins et al. (1983) concluded that this compartment is often variable across years, and Hill et al. (1992a) comment that what is unusual about prairie streams is the year-to-year constancy in POM storage. Variability in BOM is especially true in intermittent, temporary and arid streams where variability of flow is very high (Fisher, 1995). Such high variability can be due to factors such as forest clear cutting (Golladay et al., 1989), catchment activities such as clearance for agriculture, grazing, urbanization, etc which occur in the Chicamo stream, and disturbance by flooding as suggested by Grimm (1987) and Jones et al. (1995).

However, this variability does not extend to the percentage of contribution by the fractions of benthic organic matter to the total BOM among years. In the Chicamo stream, the contribution of fractions of BOM among the two years studied was relatively constant overall (% CBOM = 5.8 and 2.9 for 1994 and 1998–1999 respectively; % FBOM = 69.82 and 78.86; % UBOM = 24.36 and 33.03) and within sampling sites CH1 (% CBOM = 7.3 and 2.0 for 1994 and 1998–1999 respectively; % FBOM = 66.61 and 68.95; % UBOM = 26.08 and 29.0).

Based on a combination of PCA and cluster analysis, we can define five different groups that can be interpreted based on their ecological or functional properties. The first group included samples with high values of TBOM and FBOM (1289 g AFDW m^{-2} and 808 g AFDW m^{-2}, respectively) and peak UBOM weights (447 g AFDW m^{-2}). Moreover, high P-PO$_4$ (21.88 μg l^{-1}) concentrations and periphyton biomass (150 g AFDW m^{-2}) and low N/P ratios were measured. This group included samples taken across the years so the high values of BOM can be

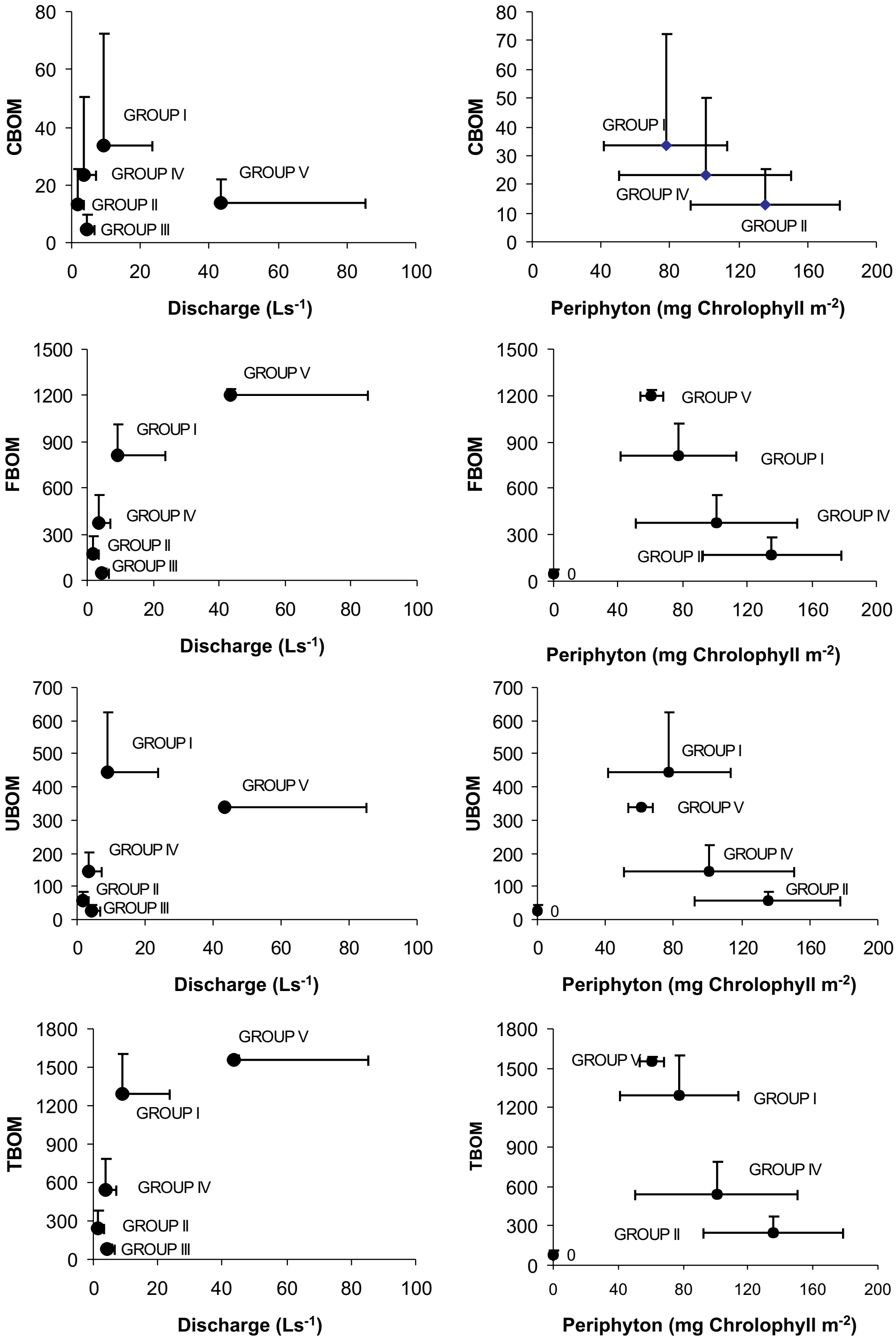

Figure 9. Average values (±SD) of each group obtained by PCA and classification for total and fractions of BOM and discharge and periphyton biomass.

Table 6. Average, range and standard deviation (SD) of TBOM and its fractions, and physical, chemical and biological parameters for five groups defined by PCA and classification analysis

	GROUP I (n = 19)			GROUP II (n = 16)				GROUP III (n = 6)				GROUP IV (n = 43)				GROUP V (n = 2)	
	Average	Max.	Min.	SD	Average	Max.	Min.	SD	Average	Max.	Min.	SD	Average	Max.	Min.	SD	Average
CBOM (g AFDW m^{-2})	33.49	164.12	5.69	38.92	13.09	49.39	3.41	12.30	4.55	14.39	1.20	5.06	23.44	103.03	1.08	26.80	13.84
FBOM (g AFDW m^{-2})	808.29	1142.12	372.69	208.05	173.57	384.99	53.29	109.95	47.00	100.58	7.20	32.09	375.32	843.76	93.41	180.05	1202.72
UBOM (g AFDW m^{-2})	446.80	880.12	158.81	179.41	57.10	122.71	23.44	24.84	27.45	52.19	9.38	15.56	145.95	364.93	54.50	80.59	338.73
TBOM (g AFDW m^{-2})	1288.59	1670.63	543.35	312.39	243.76	512.66	88.91	131.50	79.00	121.83	18.19	34.98	544.71	1189.97	172.39	238.26	1555.30
Stream width (m)	2.01	3.80	0.00	0.93	5.31	22.50	2.25	5.08	4.10	5.80	3.10	1.12	7.21	21.00	0.75	6.71	3.02
Depth (cm)	2.81	6.50	0.00	1.50	7,13	25.00	0.70	9.54	13.95	27.00	1.73	13.21	4.15	32.00	1.05	6.99	3.60
Current velocity (m s^{-1})	0.03	0.10	0.00	0.03	0,02	0.07	0.00	0.02	0.05	0.10	0.03	0.03	0.02	0.16	0.00	0.03	0.07
Discharge (l s^{-1})	9.09	48.55	0.00	14.56	1,57	6,10	0.00	1.79	4.41	8.40	2.25	2.32	3.60	15.90	0.33	3.64	43.40
Temperature water (°C)	21.34	29.00	13.50	4.73	23.56	29.50	18.00	3.38	14.00	16.00	11.00	1.79	19.83	29.50	8.00	4.78	8.25
Dissolved O_2 (mg l^{-1})	7.93	12.30	4.39	2.18	9.81	12.20	6.47	1.81	13.11	15.48	11.90	1.42	11.17	17.49	6.42	2.33	10.51
Sat. oxygen (%)	90.60	143.39	53.15	26.25	115.48	150.38	78.27	20.03	127.48	153.51	110.64	16.92	121.60	180.96	72.97	24.01	90.75
Salinity (g l^{-1})	10.44	12.20	7.00	1.41	8.47	11.20	7.00	1.51	7.28	9.00	5.20	1.39	8.01	11.00	4.80	1.37	8.50
Conductivity 25 °C (mS cm^{-1})	14.48	18.81	9.77	1.95	13.81	19.20	7.95	3.18	12.41	14.63	10.89	1.61	12.67	16.02	7.69	1.56	14.13
pH	7.93	8.43	7.24	0.31	7.86	8.25	7.46	0.19	7.40	7.94	700	0.40	7.94	8.64	7.05	0.33	8.20
Alkalinity (mg l^{-1})	5.19	7.52	3.20	1.14	152.01	270.72	4.88	99.48	215.26	261.32	169.20	42.22	107.17	300.80	4.32	118.54	5.00
P-PO_4 (μg l^{-1})	21.88	255.26	1.83	57.44	10.44	34.47	1.44	8.26	3.68	6.46	0.02	2.78	4.43	14.14	0.41	3.77	4.02
NO_3-N (mg l^{-1})	1.73	5.55	0.04	1.71	4.00	3.12	0.04	7.54	2.66	4.12	1.18	1.17	2.43	5.95	0.56	1.14	2.89
NO_2-N (μg l^{-1})	32.93	206.37	0.97	54.72	53.20	125.59	8.78	32.46	19.51	22.78	16.38	2.71	16.29	58.38	5.26	10.21	4.96
NH_4-N (μg l^{-1})	39.67	85.59	0.00	24.96	655.98	2450.84	58.19	759.84	269.52	521.83	98.86	162.15	102.30	1151.63	0.00	194.50	26.85
$N_{inorganic}$/P	849.36	3071.28	3.35	902.57	1473.32	7091.57	87.27	1825.00	36137.48	202381.84	1062.64	81486.62	2658.30	12823.25	217.77	2704.01	2012.94
Periphyton (g AFDW m^{-2})	149.78	27162	70.57	57.82	78.81	86.70	70.92	11.16					96.66	140.73	61.22	23.18	185.02

Table 7. Organic matter storage in streams of semi-arid and arid regions (units are g AFDW m^{-2})

Stream	Type	Wood (>1 mm)	CBOM	FBOM	UBOM	TBOM	Reference
Rattlesnake Springs, WA, USA	Cool desert spring stream		242				Cushing (1997)
King Creek, KA, USA	Prairie stream	91	38*				Gray (1997)
King Creek, KA, USA	Gallery forest stream	329	238*				Gray (1997)
Sycamore Creek, AR, USA	Hot desert stream	Very low	5.2*	>50		104**	Schade (1995); Grimm (1987); Fisher et al. (1982)
Streams of the Trinity Rivers basin, TX, USA	Intermittent prairie streams	Low	17.75	5.74	2.83	26.5	Hill et al. (1992a)
Streams of the Trinity Rivers basin, TX, USA	Perenial prairie streams	Low	4.3	2.45	1.16	7.9	Hill et al. (1992a)
Arroyo Montesina, Spain	Mediterranean forest stream		330.5	1045		1375.5	Mollá (1994)
Chicamo stream, Spain	Semiarid, Mediterranean stream	Very low	17.7	213.2	74.4	305.4	Martínez et al. (1998)
Chicamo stream, Spain	Semiarid, Mediterranean stream	Very low	22.1	479.4	225	726.4	This study

* CBOM (not including wood); ** (not including leaves and wood).

due to either inputs after rainfall (discharge is high = 9.1 l s^{-1}) or by high primary production.

The second group included samples with medium amounts of BOM. This group included the samples with lowest flow values (1.6 l s^{-1}) and periphyton biomass (79 g AFDW m^{-2}), and highest water temperatures (23.6 °C) and nitrogen concentrations (NO_3-N = 4004.8 μg l^{-1}; NO_2-N = 53.2 μg l^{-1}; NH_4-N = 656 μg l^{-1}). Most of these samples were taken during summers when production is high because of high temperatures but this drier phase has high rates of authochthonous matter decomposition.

The third group can be defined by the lowest values of total and all fractions of BOM (TBOM = 80 g AFDW m^{-2}; CBOM = 4.6 g AFDW m^{-2}; FBOM = 47 g AFDW m^{-2}; and UBOM = 27.5 g AFDW m^{-2}) and of water temperature (14 °C), salinity (7.3 g l^{-1}) and P-PO_4 (3.7 μg l^{-1}). In this group were the highest values of dissolved oxygen (13 mg l^{-1}) and of the relation N/P. This unproductive phase includes some samples taken during winter.

The fourth group included samples with intermediate values for almost all parameters measured. This group included many samples taken across the two sets of years. Finally, the fifth group included only two samples collected after a storm. This group had the highest values of total (1555.3 g AFDW m^{-2}) and fine fraction (1202.7 g AFDW m^{-2}) of BOM, but not coarse and ultrafine fractions. This indicates that both inputs of allochthonous and downstream transport can be important after floods or heavy rainfall. In arid streams without riparian vegetation, strong rainfall can export CBOM accumulated in the stream, especially the ultrafine material. In this group were measured the highest values for current velocity (0.07 m s^{-1}) and discharge (43.4 l s^{-1}). This situation occurs also in temporary streams such as the Australian streams studied by Boulton & Lake (1992).

This pattern described above leads to a model of the complex dynamics of benthic organic matter. However, we do not know how streams, especially the arid and semiarid streams, process organic matter. Webster & Meyer (1997) found that streams are inefficient processors of organic matter, especially those dominated by allochthonous inputs, exporting considerably more material than is metabolized. Our data suggests that in summer when flow stops, the decomposition process is more active than in winter. During floods after large storms, the organic matter transport downstream is very high and may generate an equilibrium between inputs from the catchment and in-stream vs. output downstream. Probably, BOM dynamics partly depends on annual and seasonal patterns of discharge including the frequency and intensity of flash-floods and other aspects of different flow phases during the year.

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