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PRIMARY RESEARCH PAPER

Temporal and spatial distribution of macroalgal communities of mountain streams in Valle de Bravo Basin, central Mexico

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Abstract The stream macroalgal community is controlled by heterogeneous physical, chemical, and biological factors related with multiple spatial and temporal scales; however, the mechanisms that explain diversity and distribution are scarcely known. The present investigation was conducted to characterize the macroalgal community structure and spatial and temporal distribution and to recognize biogeographic affinities with mountain streams from other regions. Habitat characteristics, abundance, and diversity were investigated in four mountain streams of Valle de Bravo Basin, central Mexico, during two annual cycles. Sampling of visible benthic growths was collected in the most contrasting parts of the year. Physicochemical parameters were recorded in situ at each site and the main ions and nutriments were evaluated for every collection. Statistical analysis between dates was assessed with one-way analysis of variance (ANOVA) and Canonical Correspondence Analysis (CCA). Observed richness average was four species per site and the high abundance of *Phormidium interruptum*, *Nostoc parmelioides*, *Paralemanea mexicana*, *Batrachospermum gelatinosum*, *Sirodotia suecica*, *Cladophora glomerata*, and *Prasiola mexicana* correlated with cold dry season, high current velocity, and a major size substrate. Valle de Bravo streams can be viewed as a habitat subjected to moderated disturbance, mainly due to the effects of seasonal changes in rainfall contrary to torrents expected of tropical regions. The seasonal patterns of macroalgal communities in Valle de Bravo basin were typically characterized by two distinct periods essentially determined by the rainfall regime and related to temperature, and can be viewed as habitats subjected to moderate disturbance according to intermediate disturbance hypothesis. The distribution species pattern registered suggests a group of temperate species frequently found in mountain regions of the Mexican Volcanic Belt and temperate eastern region of North America and may indicate a possible biogeographic connection with the Neartic region with similar environmental requirements.

Keywords Communities · Ecology · Macroalgae · Mountain streams · Central Mexico

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Introduction

In general, benthic algae are the most important photosynthetic organisms in lotic environments due to their abundance, distribution, and adaptive strategies (Sheath & Hambrook, 1990; Stevenson, 1996; Naicheng et al., 2009). Algal community of mountain streams from tropical latitudes grows in particular conditions: low temperature associated with high altitudes with a characteristic climate regime of the equatorial zone (Martínez & Donato, 2003) where the most contrasting parts of the seasonal cycle are defined by precipitation. These characteristics suggest that environmental factors exert an influence over species richness, abundance, diversity, association, distribution, and successional process of the communities from these regions compared with streams from temperate zones (Whittaker, 1975) where seasons are mainly defined by temperature. There are few studies about the ecological distribution of macroalgal communities in mountain streams, those from temperate zones being the most studied (Ward, 1986; Kawecka & Eloranta, 1987; Pfister, 1993; Sheath et al., 1996; Valvilova & Lewis, 1999).

The majority of these studies refer to the fact that diversity of benthic algae is influenced by environmental factors (discharge, temperature, nutrient concentration, substrate availability, and incident radiation) but few of them refer to the possible mechanisms that explain the diversity and distribution of macroalgae in lotic environments (disturb, environmental heterogeneity, and productivity) (Ács & Keve, 1993; Biggs, 1996; Branco & Necchi, 1996; Bradley et al., 2005; Borges & Necchi, 2008).

In Mexico, floristic studies of mountain streams have begun recently (Ramírez et al., 2001; Ramírez & Cantoral, 2003; Ramírez-Rodríguez & Carmona, 2005; Ramírez-Rodríguez et al., 2007). The present investigation was conducted to characterize the physicochemical composition of the water in two annual cycles, the structure and spatial and temporal distribution of macroalgal communities and recognize biogeographic affinities with mountain streams from other regions.

Materials and methods

Freshwater macroalgal communities from mountain streams (1,890–2,220 m asl) in the Mexican Volcanic Belt (MVB) were investigated through the sampling of four permanent stream sites (Amanalco (S1), Nacimiento González (S2), Carrizal (S3), and Borbollón (S4)) of Valle de Bravo Basin (drainage basin: 546.9 km^2, Olvera-Viascán et al., 1998) from 2006 to 2008 (Fig. 1). The geomorphologic and climatic conditions of the area have led to the formation of coniferous forest, streams with relatively cold to warm

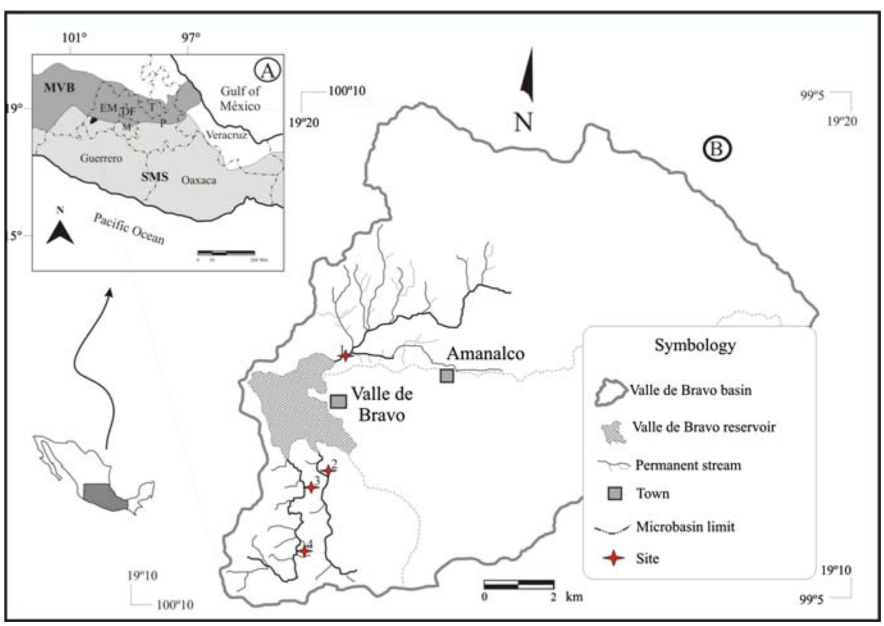


Fig. 1 Location of sampling sites in Valle the Bravo Basin. *Site 1* Amanalco, *Site 2* Nacimiento González, *Site 3* Carrizal, and *Site 4* Borbollón. *Sites number* corresponds to the following Tables and Figures

Table 1 Physical and chemical composition of the study sites in Valle de Bravo Basin

	Site 1 5th order 1890 m asl	Site 2 3rd order 1950 m asl	Site 3 4th order 2000 m asl	Site 4 4th order 2220 m asl
Temperature (°C)	14–19	11–16	10–17	13–19
	16 ± 1	14 ± 1	14 ± 3	15 ± 2
pH	6.6–7.6	6.9–7.6	7–7.8	6.9–7.8
	7.2 ± 0.4	7.3 ± 0.3	7.5 ± 0.2	7.4 ± 0.3
K_{25} (µs cm^{-1})	169–248	60–75	52–119	53–148
	200 ± 30	70 ± 5	92 ± 24	103 ± 33
Q (m^3 s^{-1})	0.01–4	0.02–0.3	0.01–0.6	0.07–0.9
	2 ± 1	0.1 ± 0.1	0.2 ± 0.2	0.3 ± 0.2
Current velocity (cm s^{-1})	18–106	14–83	7–65	11–99
	72 ± 28	43 ± 21	26 ± 18	48 ± 26
Depth (cm)	6–55	5–10	5–14	5–16
	18 ± 15	8 ± 2	8 ± 3	10 ± 3
Dissolved oxygen saturation (%)	72–111	64–111	73–100	64–98
	90 ± 15	85 ± 16	87 ± 8	81 ± 12
Substrate[a] (%)	B = 80, P = 10, S = 10	B = 40, P = 40, G = 10, S = 10	B = 60, P = 20, G = 10, S = 10	P = 50, G = 40, S = 10
Total dissolved solids	143–210	52–107	57–112	47–116
	174 ± 24	82 ± 17	88 ± 15	86 ± 19
Total alkalinity as $CaCO_3$	63–86	36–61	31–58	29–70
	77 ± 8	41 ± 8	47 ± 10	52 ± 16
HCO_3^-	77–105	37–50	38–71	35–86
	95 ± 9	46 ± 4	57 ± 12	62 ± 18
Cl^-	6–116	1–2	1–2	1–7
	20 ± 36	1 ± 0.4	1 ± 0.3	3 ± 2
$SO_4^=$	6–14	0–2	0–3	0–6
	9 ± 3	0.6 ± 0.8	2 ± 1	3 ± 2
Si–SiO_2	27–64	25–40	25–33	14–39
	52 ± 10	35 ± 4	29 ± 3	24 ± 8
Total hardness as $CaCO_3$	65–82	32–58	25–52	28–61
	73 ± 5	48 ± 4	41 ± 10	47 ± 13
Ca hardness as $CaCO_3$	30–39	13–37	12–29	13–45
	34 ± 3	17 ± 8	23 ± 6	28 ± 12
Mg hardness as $CaCO_3$	33–43	18–21	12–23	15–23
	39 ± 3	20 ± 1	18 ± 4	19 ± 3
Ca^{++}	12–16	5–7	5–12	5–18
	14 ± 1	6 ± 0.6	9 ± 3	11 ± 5
Mg^{++}	8–10	4–5	3–6	4–6
	10 ± 0.7	5 ± 0.3	4 ± 0.8	5 ± 0.6
Na^+	11–20	3–4	3–8	3–9
	15 ± 3	4 ± 0.3	6 ± 2	6 ± 2
K^+	3–5	1–3	2–3	1–2
	4 + 0.6	2 ± 0.4	2 ± 0.2	2 ± 0.2

Table 1 continued

	Site 1 5th order 1890 m asl	Site 2 3rd order 1950 m asl	Site 3 4th order 2000 m asl	Site 4 4th order 2220 m asl
SRP	0.2–0.8	0.01–0.07	0.008–0.06	0.01–0.05
	0.6 ± 0.2	0.03 ± 0.02	0.03 ± 0.02	0.03 ± 0.01
$N–NO_3^-$	0.5–5	0.02–0.2	0.009–0.1	0.009–0.3
	2 ± 1	0.08 ± 0.06	0.08 ± 0.04	0.08 ± 0.09
$N–NO_2^-$	0.006–0.07	0.001–0.003	0.001–0.01	0.0006–0.003
	0.02 ± 0.02	0.002 ± 0.0008	0.004 ± 0.003	0.002 ± 0.0009
$N–NH_4^+$	0.006–0.3	0.01–0.08	0.01–0.2	0.01–0.1
	0.2 ± 0.1	0.05 ± 0.02	0.05 ± 0.06	0.06 ± 0.04
DIN	0.02–2	0.002–0.08	0.004–0.08	0.002–0.08
	0.7 ± 1	0.04 ± 0.04	0.04 ± 0.04	0.05 ± 0.04
Total ionic concentration ($meq\ l^{-1}$)	3–5	2	1–3	1–3
	4 ± 0.4	2 ± 0.07	2 ± 0.5	2 ± 0.7
Ionic dominance	$HCO_3^- > Cl^- > SO_4^=$	$HCO_3^- > Cl^- > SO_4^=$	$HCO_3^- > Cl^- > SO_4^=$	$HCO_3^- > SO_4^= \geq Cl^-$
	$Na^+ > Ca^{++} > Mg^{++} > K^+$	$Ca^{++} > Mg^{++} > Na^+ > K^+$	$Ca^{++} > Na^+ > Mg^{++} > K^+$	$Ca^{++} > Na^+ > Mg^{++} > K^+$

Values represent minimum and maximum range, average, and standard deviation ($n = 9$)

Discharge *Q*, soluble reactive phosphorous *SRP*, dissolved inorganic nitrogen *DIN*

[a] *B* boulder, *P* pebbles, *G* gravel, *S* sand

waters, and torrential rainy season in summer (Ferrusquía-Villafranca, 1998; García, 2004). Sampling frequency of visible benthic algae growths was every 3 months during two annual cycles, in the most contrasting parts of the year: warm dry season (D) (March–May, $n = 3$), rainy season (R) (June–November, $n = 2$), and cold dry season (CD) (December–February, $n = 4$).

The following physical and chemical parameters were recorded in situ at each site: water temperature, pH, and specific conductivity (corrected to 25°C, K_{25}) with the conductivity meter Conductronic PC-18, dissolved oxygen with the oxygen meter YSI-85 and oxygen saturation percentage calculated from dissolved oxygen data, considering altitude and water temperature.

Collection and analysis of mayor ions (Na^+, Mg^{++}, K^+, Ca^{++}, HCO_3^-, Cl^-, and $SO_4^=$) and nutrients (Soluble Reactive Phosphorous, SRP; $N–NO_2^-$; $N–NO_3^-$; $N–NH_4$; Dissolved Inorganic Nitrogen, DIN, and $Si–SiO_2$) were performed according to regulations of Greenberg & Clesceri (1985), ASTM (1989), and APHA et al. (1995).

Algal community was characterized by the recording of the recognizable visible algal growths, also known as macroalgae, according with Holmes & Whitton (1981) definition. The macroalgae morphological types were recognized according to Sheath & Cole (1992): free filaments, mats, gelatinous colonies and filaments, and tissue-like forms. Each sampling site consisted of a stream segment of 10 m in length along the riverbed. The segments were divided into five equal parts and contain the main stream microhabitats. Abundance of macroalgae (percent cover) was evaluated with a circular sampling unit of 10-cm radius (area = 157 cm^2) (Necchi, 1995; Ramírez-Rodríguez et al., 2007). Spatial and seasonal differences in physicochemical characteristics were assessed using one-way analysis of variance (ANOVA) followed by Tukey HSD (unequal for seasons) test. Statistics were performed with Statistica program ver 7.0. Data without normal distribution were transformed using $\log_{10}$.

Rarefaction curves were used to compare expected with observed richness from the study area and in each site. Curves were obtained with the incidence-based coverage estimator (ICE), using the EstimateS software (Colwell, 2000). In order to analyze differences in richness and dominance among sites and in each site between seasons dominance–diversity

Table 2 Distribution, seasonality, morphological types (mats *M*, gelatinous colonies *GC*, gelatinous filaments *GF*, tissue-like forms *TF*, free filaments *FF*), and diversity values (H') of macroalgal communities in study sites of Valle de Bravo Basin

Species and morphological forms	Site 1			Site 2			Site 3			Site 4		
	D	CD	R	D	CD	R	D	CD	R	D	CD	R
Cyanophyceae												
1. *Phormidium autumnale* (Agardh) Trevisan ex Gomont (M)						*						
2. *Ph. interruptum* Kützing ex Gomont (M)										*	*	*
3. *Nostoc parmelioides* Kützing ex Bornet et Flahault (GC)							*	*	*			
Rhodophyceae												
4. *Batrachospermum gelatinosum* (Linnaeus) De Candolle (GF)	*	*										
5. *B. helminthosum* Bory (GF)	*	*	*	*	*	*				*	*	*
6. *Sirodotia suecica* Kylin (GF)	*	*	*									
7. *Paralemanea mexicana* (Kützing) Vis et Sheath (TF)	*	*	*				*	*	*			
Chlorophyceae												
8. *Cladophora glomerata* (Linneaeus) Kützing (FF)	*	*	*			*	*	*	*			
9. *Prasiola mexicana* J. Agardh (TF)					*	*						
10. *Spirogyra* sp. (FF)										*		
11. *Oedogonium* sp. (FF)	*											
12. *Mougeotia genuflexa* (Roth) C.A. Agardh (FF)										*		
Xantophyceae												
13. *Vaucheria bursata* (O.F. Müller) C. Agardh (M)	*	*	*									
Bacillariophyceae												
14. *Melosira varians* C.A. Agardh (FF)					*		*					
Seasonal diversity index (H' $\log_{10}$)	0.5	0.5	0.4	0.3	0.2	0.6	0.3	0.5	0.5	0.4	0.11	0.12
Total diversity index (H' $\log_{10}$)		0.4			0.5			0.6			0.3	

Species number corresponds to the following Tables and Figures

curves were obtained based on coverage. Species diversity was assessed using Shannon–Wiener $\log_{10}$ diversity index (H $\log_{10}$) with Primer ver. 6. The relation between spatial and temporal distribution of macroalgae with physicochemistry was assessed using CCA, followed by Montecarlo test (999 permutation, $\alpha = 0.05$) to determinate the significance of the relationship between species distribution and the environmental variables; the statistic was realized with PC-ORD ver.4.

Results

Physicochemistry

In terms of environmental variables, all populations were found in temperate water (14–16°C), neutral pH (7.2–7.5), low mineralization (ionic content, 2–4 meq l^{-1}; total dissolved solids, 82–174 mg l^{-1}; and specific conductance, 70–200 µS cm^{-1}), shallow depth (8–18 cm), and slow to moderate flowing waters (26–72 cm s^{-1}) (Table 1). Stream segments were shaded or partly shaded, with different types of substrata (boulder, pebbles, gravel, and sand) and a high percentage of oxygen saturation (81–90%).

All communities were collected in soft water (41–77 mg l^{-1} of $CaCO_3$) (Sawyer & McCarty, 1967) with a dominance of bicarbonate/calcium. According to the trophic level, all the sites presented mesotrophic–eutrophic conditions (SRP: 0.03–0.6 mg l^{-1}, DIN: 0.04–0.07 mg l^{-1}) (Dodds et al., 1998; Dodds, 2003).

ANOVA showed significant differences between sites ($F = 12.2069$, $P = 0.00$). Tukey test indicated the formation of two groups ($P < 0.05$): the first one formed by S1 with a high ionic and nutriment concentration and the highest wealth, and the second one composed by sites 2, 3, and 4 (Table 1). ANOVA indicated no significant differences ($P > 0.05$) among seasons in any site.

Taxonomic composition

A total of 14 macroalgae species were recorded (Table 2): 36% belonged to Chlorophyceae, 29% Rhodophyceae, 21% Cyanophyceae, 7% Xantophyceae and Bacillariophyceae. *Phormidium interruptum*, *Batrachospermum helminthosum*, *Cladophora glomerata*, and *Paralemanea mexicana* were the most widespread macroalgae. Five species were present in more than one site. In terms of seasonality, six species (43%) occurred throughout the year, four species (28.5%) were present in two seasons, whereas four species (28.5%) were found in only one season. The proportion of macroalgal morphological types were as follows: free filaments (36%), mats and gelatinous filaments (21%), tissue-like forms (15%), and gelatinous colonies (7%). Observed richness in the study area was similar than expected richness except in S2 (Fig. 2) with four to eight species per site (average = 4.5) and a total diversity of H' 0.5.

Species richness, abundance, diversity, evenness, and morphological types change between sites and seasons (Table 2; Fig. 3). In S1 the highest species richness and cover of macroalgal community was recorded, followed by S3, S2, and S4. Dominance–diversity curves showed different dominant species among sites: *Sirodotia suecica* (21%) in S1, *Prasiola mexicana* (7%) in S2, *Cladophora glomerata* (10%) in S3, and *Phormidium interruptum* (9%) in S4. Shannon diversity index showed similar values between sites except in S4 with the lowest diversity. According to the slope of dominance–diversity curves the highest evenness was recorded in S1 and the lowest in S4 (Fig. 3). All sites presented the highest abundance (18–58%) in cold dry season (CD) and the lowest (2–19%) in rainy season (R), except in S2 with the highest abundance (22%) in R. A difference of 40% of coverage between CD and R was recorded. The highest species richness and diversity in S1 was recorded in D and CD, evenness was similar between seasons. A different specific composition between seasons was recorded; however, there is an association formed by six species (*S. suecica*, *Paralemanea mexicana*, *Vaucheria bursata*, *P. interruptum*, *C. glomerata*, and *Batrachospermum helminthosum*) which were registered all the time although their abundance varied among seasons (Fig. 3). The species richness of S2 varied considerably among seasons. The highest number of species, diversity and evenness were recorded in R and the lowest in D. *P. interruptum* and *B. helminthosum* were recorded in all seasons, the former was dominant in the D season and rare in CD; *Prasiola mexicana* was dominant in two seasons (CD and R). Species richness in S3 was similar in all seasons; the lowest diversity and evenness were registered in D. An association formed by four species (*C. glomerata*, *Paralemanea mexicana*, *P. interruptum*, and *Nostoc parmelioides*) were recorded all the time. *Melosira varians* was the abundant species in D, *Paralamanea mexicana* in R, and *C. glomerata* in CD; the latter was rare in R. *Nostoc parmelioides* was abundant in CD and R but rare in D. The highest species richness, diversity and evenness of S4 were recorded in D. *B. helminthosum* and *P. interruptum* were present all the time, the latter being the dominant species.

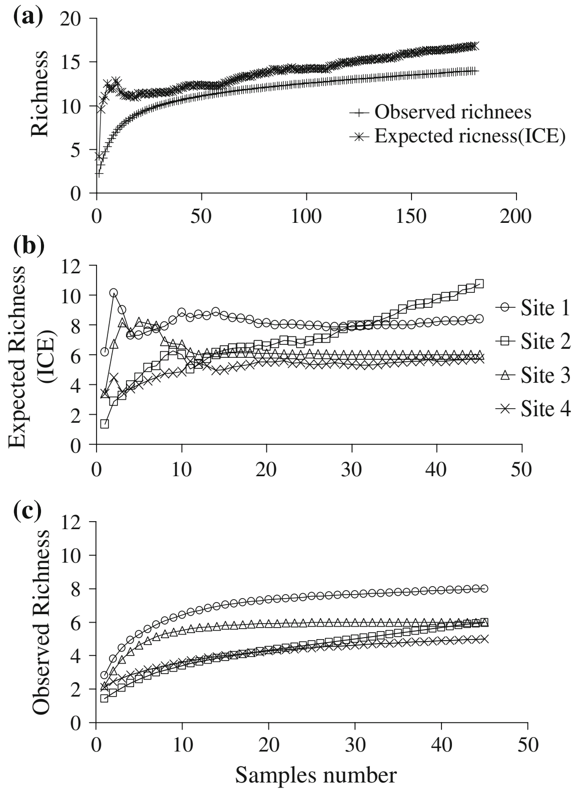
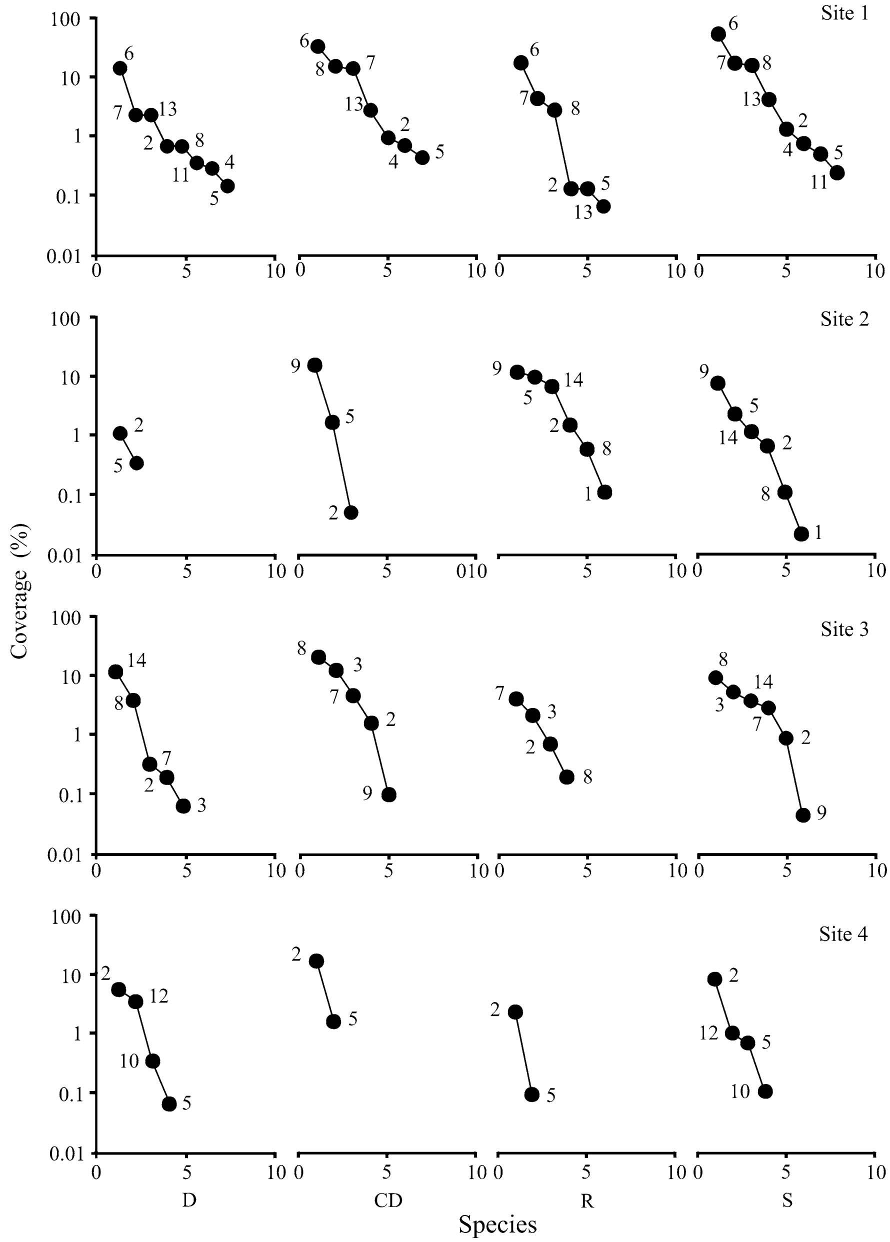


Fig. 2 Macroalgal species richness from the entire collected area in Valle de Bravo Basin, central Mexico (**a**) and the comparison of expected and observed richness between sample sites (**b**, **c**)

Fig. 3 Dominance–diversity curves based on macroalgal percent cover between seasons (dry season *D*, cold dry season *CD*, rainy season *R*) and among sites (Sites *S*). Season abbreviations correspond to the following Tables and Figures



Relationship between spatial and temporal distribution of macroalgae and environmental variables

In CCA (Fig. 4) the first two axes explain 77% of total variation, only the first one being significant ($P = 0.001$). The relation between species and environment was significant to axis one ($P = 0.01$) and showed that discharge, conductivity, total hardness, nutrient concentration, total dissolved solids, SO_4^-, Cl^-, Mg^{++}, Na^+, and K^+ explain spatial distribution of macroalgal species and the grouping of the sites. Species distribution was correlated with the physicochemical characteristics of each site, for that reason two groups were conformed: group one, sites with high nutriments and ionic concentration and group two, sites with lower concentrations. CCA revealed that changes of temperature, discharge and ionic

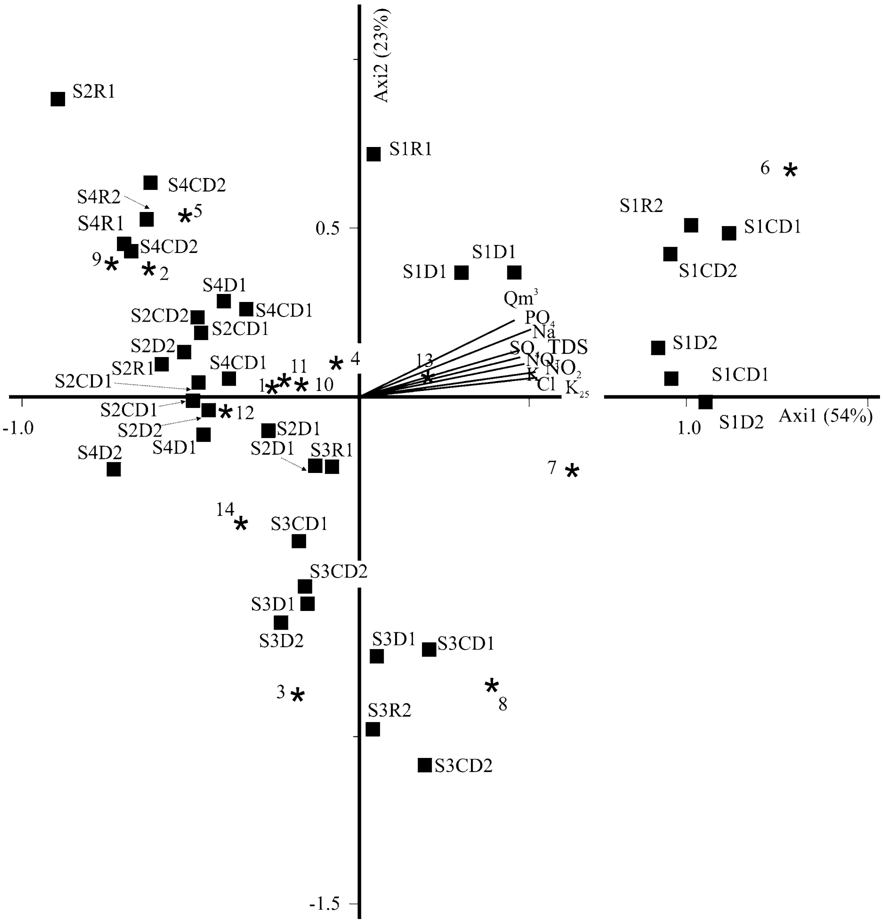


Fig. 4 CCA biplot of the general distribution of sites and macroalgae with regard to physical and chemical data recorded in all the study. *Asterisks* correspond to species. Figure key = site abbreviation, seasonal abbreviation, and date of collection (1. first year of collection and 2. second year of collection)

concentration in all sites, except in S2, had a relation with distribution of macroalgae (Fig. 5). In S1 first two axes were significant ($P = 0.001$) and explain 77% of the total variation. The relation between species and environment was significant for the first two axes ($P = 0.01$). Macroalgae distribution was related with ionic concentration, nutrients, and increment of temperature. The species distribution of S2 (Fig. 5) did not have significant relation with the axes ($P > 0.05$). According to CCA of S3 (Fig. 5) the first two axes explain the 85% of total variation ($P = 0.001$) and the species distribution had a significant relation ($P = 0.001$) with temperature mainly, as well as ionic concentration and nutriments. The first two CCA axis of S4 explain 94% of total variation ($P = 0.02$) and species–environment relation was significant for both axes ($P = 0.01$–0.02). The species distribution was determined mainly by temperature and discharge (Fig. 5).

Discussion

Water temperatures registered in study sites were similar to temperate regions explained by high altitudes; nevertheless, there is not a marked seasonality defined by temperature as streams from temperate latitudes (Blum, 1956). However, there is a variation in temperature that could explain changes in the community showing higher abundances in cold dry season. On the other hand, several species were present only in dry season. A high percentage of species were shared with temperate regions (64%), confirming the hypothesis of affinities with temperate region flora (Ramírez et al., 2001; Kwandrans et al., 2002; Carmona & Vilaclara, 2007; Krupek et al., 2007).

Macroalgal species number per sampling site ranged from 4 to 8 (average = 4.5). Mean species richness per sampling site was relatively high and

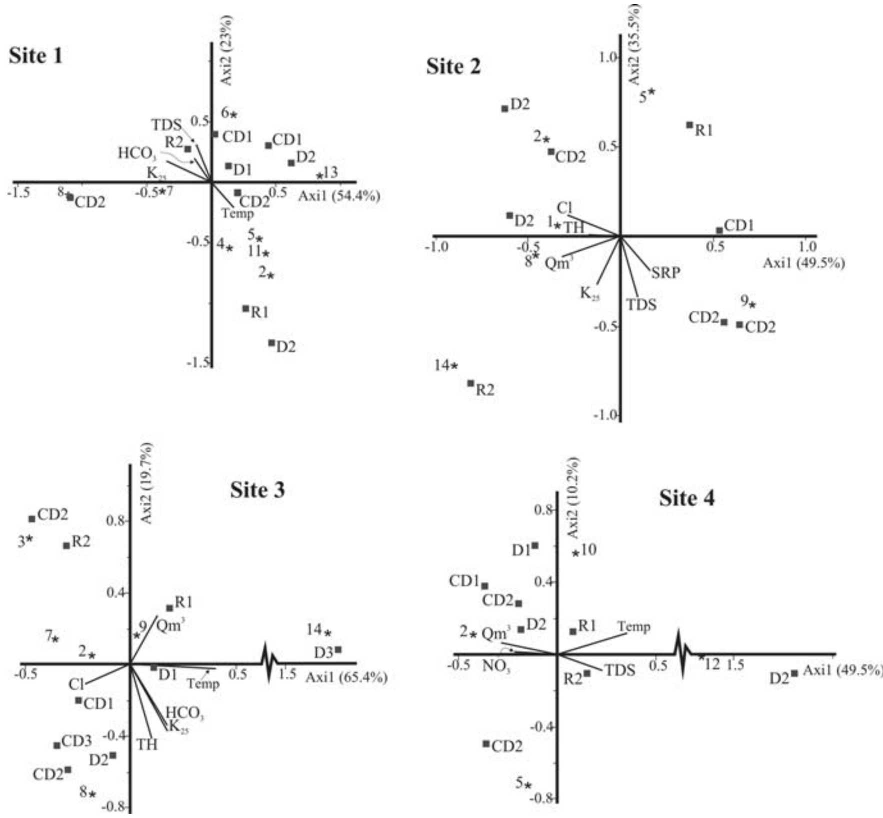


Fig. 5 CCA biplots of the general distribution of macroalgae according to physical and chemical data registered in each site. *Asterisks* correspond to species and the number after seasonal abbreviation is the date of collection (1. first year of collection and 2. second year of collection)

similar to several studies from mountain regions (3.8, Sheath et al., 1986; 4.9, Sheath et al., 1989; 2.7–3.6, Sheath & Cole, 1992). Likewise, the macroalgal species richness found in this study (14 species/four sampling sites) was similar when compared with mountain streams in central Mexico (Ramírez et al., 2001, 12 spp./three sites; Ramírez & Cantoral, 2003, 13 spp./six sites). The *Phormidium interruptum*, *Batrachospermum gelatinosum*, and *Sirodotia suecica* populations appears to be global in its distribution, probably due to its ability to tolerate a wide range of physicochemical characteristics in their stream locations, urban pollution included (Israelson, 1942; Vis & Sheath, 1996, 1998; Kwandrans et al., 2002).

A general finding is that there are no major changes in the composition of macroalgal communities of the same river segment. In terms of dominant species by site, the high abundance of *Nostoc parmelioides*, *P. interruptum*, *B. gelatinosum*, *Paralemaena mexicana*, *S. suecica*, and *C. glomerata*, was positively correlated with cold dry season, high current velocity and a major size substrate. The presence of several morphological types with holdfast rhizoids in these populations (free filaments, gelatinous filaments, and tissue-like filaments) could suggest a strong attachment in major substrates and an adaptation to high current velocities. Similar responses were observed in *Paralemanea mexicana*, *B. gelatinosum* (Carmona & Vilaclara, 2007; Carmona et al., 2009) and *C. glomerata* (Dudley & D′Antonio, 1991) in several streams of temperate waters in South California and central Mexico. In contrast, a higher temperature and ionic concentration registered in dry season were determinant in the absence of dominant species and the occurrence of *Melosira varians* and *Mougeotia genuflexa*, typical species of warm waters in low current streams or lentic habitats (Branco & Necchi, 1996; Novelo et al., 2007).

The seasonal patterns of macroalgal communities in Valle de Bravo basin were typically characterized by two distinct periods, essentially determined by the rainfall regime and related to temperature. The species replacement was low and could be considered as annual. However, any succession events were clearly registered; this could be because successions mechanisms in lotic ecosystems are a deterministic process in short time intervals (McCormick & Stevenson, 1991). The intermediate disturbance hypothesis (IDH) is a useful theoretical concept to explain changes in observed species diversity. The IDH predicts that biotic diversity will be greater in communities subjected to moderate levels of disturbance than those communities exposed to higher or lower disturbances, in terms of intensity and frequency (Connell, 1978; Ward & Stanford, 1983). Valle de Bravo streams can be viewed as habitat subjected to moderated disturbance, mainly due to the effects of seasonal changes of discharge contrary to expected torrential rainfall of tropical regions (Bojorge-García & Cantoral, 2007).

In central Mexico, high altitude streams are restricted to MVB and suggest particular macroalgal communities (in this study and similar works in this region, Ramírez et al., 2001; Ramírez & Cantoral, 2003; Carmona & Vilaclara, 2007) in comparison to other lowland basins in the country (Montejano et al., 2000). The occurrence of *Nostoc parmeloidies*, *B. helminthosum*, *B. gelatinosum*, *Paralemanea mexicana*, *Sirodotia suecica*, *Prasiola mexicana* and *Vaucheria bursata* corresponds to a group of temperate species frequently found in temperate regions of the world (Sheath & Cole, 1992; Sheath et al., 1994; Kwandrans et al., 2002; Kumano, 2002). Affinities of macroalgal communities between Valle de Bravo basin and temperate eastern region of North America indicate a possible biogeographic connection with the neartic region with similar environmental requirements (Sheath & Cole, 1992). *Paralemanea mexicana* is the only endemic species registered in this basin; geographic isolation may be one of the contributing factors to explain the restricted distribution in several hydrological systems in the MVB (Carmona & Necchi, 2002; Carmona & Vilaclara, 2007).

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References

Ács, É. & K. T. Keve, 1993. Effects of the water discharge on periphyton abundance and diversity in a large river (River Danube, Hungary). Hydrobiologia 249: 125–133.

American Public Health Association (APHA), 1995. Standard Methods, 19th ed. American Public Health Association, Washington, DC: 221 pp.

ASTM, 1989. Annual Book at ASTM. Standards Worldwide, USA: 125 pp.

Biggs, B. J. F., 1996. Patterns in periphyton of streams. In Stevenson, R. J., M. L. Bothwell & R. L. Lowe (eds), Algal Ecology: Freshwater Benthic Ecoystems. Academic Press, San Diego, CA: 31–56.

Blum, J. L., 1956. The ecology of river algae. The Botanical Review 22: 291–341.

Bojorge-García, M. & E. Cantoral, 2007. Estructura comunitaria de diatomeas asociadas a talos de *Prasiola mexicana* (Chlorophyta) en el río Magdalena, D.F. Hidrobiológica 17: 11–24.

Borges, F. R. & O. Necchi Jr., 2008. Short-term successional dynamics of a macroalgal community in a stream from Northwestern São Paulo State, Brazil. Acta Botânica Brasileira 22: 453–463.

Bradley, J. C., M. A. Palmer, A. R. Ives & S. S. Brooks, 2005. Diversity–productivity relationships in streams vary as a function of the natural disturbance regime. Ecology 86: 716–726.

Branco, C. C. & O. Necchi Jr., 1996. Distribution of stream macroalgae in the Eastern Atlantic Rainforest of São Paulo State, southeastern Brazil. Hydrobiologia 333: 139–150.

Carmona, J. & O. Necchi Jr., 2002. Taxonomy and distribution of *Paralemanea* (Lemaneaceae Rhodophyta) in Central Mexico. Cryptogamie Algologie 23: 39–49.

Carmona, J. & G. Vilaclara, 2007. Survey and distribution of Batrachospermaceae (Rhodophyta) in tropical high-altitude streams from central Mexico. Cryptogamie Algologie 28: 271–282.

Carmona, J., M. Bojorge-García, Y. Beltrán & R. Ramírez-Rodríguez, 2009. Phenology of *Sirodotia suecica* (Batrachospermaceae, Rhodophyta) in a high-altitude stream in central Mexico. Phycological Research 57: 118–126.

Colwell, R. K., 2000. Estimates Statistical Estimation of Species Richness and Shared Species from Samples. http://viceroy.eeb.uconn.edu/estimates.

Connell, J. H., 1978. Diversity in tropical rain forest and coral reefs. Science 199: 1302–1310.

Dodds, W. K., 2003. Misuse of inorganic N and soluble reactive P concentrations to indicate nutrient status of surface Waters. Journal of North American Benthological Society 22: 171–181.

Dodds, W. K., R. J. Jones & E. B. Welch, 1998. Suggested classification of stream trophic state: distribution of temperate stream types by chlorophyll, total nitrogen and phosphorous. Water Research 32: 1455–1462.

Dudley, T. L. & C. M. D′Antonio, 1991. The effects of substrate texture grazing and disturbance on macroalgal establishment in streams. Ecology 72: 297–309.

Ferrusquía-Villafranca, F., 1998. Geología de México: una sinopsis. In Ramamoorthy, T. P., R. Bye, A. Lot & J. Fa (eds), Diversidad biológica de México. Orígenes y distribución. Instituto de Biología, UNAM, México: 3–108.

García, E., 2004. Modificaciones al sistema de clasificación climática de Köppen. Instituto de Geografía, Mexico: 246 pp.

Greenberg, T. & L. S. Clesceri, 1985. Standard Methods for the Examination of Water and Wastewater, 16th ed. APHA, Washington, DC.

Holmes, N. T. H. & B. A. Whitton, 1981. Phytobenthos to the River Tess and its tributaries. Freshwater Biology 11: 139–163.

Israelson, G., 1942. The freshwater Florideae of Sweden: studies on their taxonomy, ecology and distribution. Symbolae Botanicae Upsaliensis 6: 1–135.

Kawecka, B. & P. Eloranta, 1987. Communities of sessile algae in some small streams of central Finland. Comparison of algae oh the high mountains of Europe and those in northern region. Acta Hydrobiologica 29: 315–403.

Krupek, A. R., C. Z. C. Branco & C. K. Perez, 2007. Distribucao ecológica das comunidades de macroalgas da bacia de dranagem do Rio das Pedras, regiao Centro-Sul do Estado do Paraná Sul do Brasil. Revista Brasiliera Botânica 30: 173–182.

Kumano, S., 2002. Freshwater Red Algae of the World. Biopress Limited, Bristol, England.

Kwandrans, J., P. Eloranta & R. Bengttsson, 2002. Sötvattensensrödalger I Sverigeen översikt och ett nyfynd. Svensk Botanisk Tidskrift 96: 274–280.

Martínez, L. F. & J. Donato, 2003. Efecto del caudal sobre la colonización de algas en un río de montaña tropical (Boyáca, Colombia). Caldasia 25: 337–354.

McCormick, P. V. & R. J. Stevenson, 1991. Mechanisms of benthic algal succession in lotic environments. Ecology 72: 1835–1848.

Montejano, G., E. Carmona-Jiménez & E. Cantoral-Uriza, 2000. Algal communities from calcareous Springs and streams in La Huasteca, central Mexico: a synthesis. In Munawar, M., S. J. Lawrence, I. F. Munawar & D. F. Malley (eds), Aquatic Ecosystems of Mexico. Status & Scope. Backhuys Publishers, The Netherlands: 135–149.

Naicheng, W., T. Tao & T. Q. Xiaodong, 2009. Spatial distribution of benthic algae in the Gangqu River, Shangrila, China. Aquatic Ecology 43: 37–49.

Necchi, O. Jr., & J. C. L. Moreira, 1995. Longitudinal distribution of macroalgae in two tropical lotic ecosystems from southeastern Brazil. Archive für Hydrobiologie 135: 113–128.

Novelo, M. E., S. R. Tavera & C. Ibarra, 2007. Bacillariophyceae from Karstic Wetlands in Mexico. Bibliotheca Diatomologica, Germany: 56 pp.

Olvera-Viascán, V., L. Bravo-Inclán & J. Sánchez-Chávez, 1998. Aquatic Ecology and Management assesment in Valle de Bravo reservoir and its watershed. Aquatic Ecosystem Health and Management 1: 277–290.

Pfister, P., 1993. Seasonality of macroalgal distribution patterns within the reach of a gravel stream (Isar, Tyron, Austria). Archive für Hydrobiologie 129: 89–107.

Ramírez, M. & E. Cantoral, 2003. Flora algal de ríos templados en la zona occidental de la cuenca del Valle de México. Anales del Instituto de Biología, Universidad Nacional Autónoma de México, Serie Botánica 74: 143–194.

Ramírez, V. M., Y. Beltrán, M. Bojorge, J. Carmona, E. Cantoral-Uriza & F. Valadez, 2001. Flora algal del Río La Magdalena, Distrito Federal, México. Boletín de la Sociedad Botánica de México 68: 51–73.

Ramírez-Rodríguez, R. & J. Carmona, 2005. Taxonomy and distribution of freshwater *Prasiola* (Prasiolales, Chlorophyta) in central México. Cryptogamie Algology 26: 1–12.

Ramírez-Rodríguez, R., J. Carmona & C. Martorell, 2007. Microhabitat and morphometric variation in two species of *Prasiola* (Prasiolales, Chlorophyta) from stream in central Mexico. Aquatic Ecology 41: 161–168.

Sawyer, C. N. & P. McCarty, 1967. Chemistry for Sanitary Engineers. McGraw-Hill, New York: 518 pp.

Sheath, R. G. & K. M. Cole, 1992. Biogeography of stream macroalgae in North America. Journal of Phycology 28: 448–460.

Sheath, R. G. & J. A. Hambrook, 1990. Freshwater ecology. In Cole, K. M. & R. G. Sheath (eds), Biology of the Red Algae. Cambridge University Press, Cambridge: 423–453.

Sheath, R. G., M. O. Morison, J. E. Korch, D. Kaczmarczyk & K. M. Cole, 1986. Distribution of stream macroalgae in south-central Alaska. Hydrobiologia 135: 259–269.

Sheath, R. G., P. B. Hamilton, J. A. Hambrook & K. M. Cole, 1989. Stream macroalgae of the eastern boreal forest region of North America. Canadian Journal of Botany 67: 3553–3562.

Sheath, R. G., L. M. Vis & K. M. Cole, 1994. Distribution and systematics of *Batrachospermum* (Batrachospermales, Rhodophyta) in North America. 4. Section Virescentia. Journal of Phycology 30: 108–117.

Sheath, R. G., M. L. Vis, J. A. Hambrook & K. A. Cole, 1996. Tundra stream macroalgae of North American: composition, distribution and physiological adaptations. In Kristiansen, J. (ed.), Biogeography of Freshwater Algae. Kluwer Academic Publishers, Dordrecht: 67–82.

Stevenson, R. J., 1996. An introduction to algal ecology in freshwater benthic habitats. In Stevenson, R. J., M. L. Bothwell & R. L. Lowe (eds), Algal Ecology, Freshwater Benthic Ecosystems. Academic Press, San Diego, CA: 3–30.

Valvilova, V. V. & W. M. Lewis Jr., 1999. Temporal and altitudinal variations in the attached algal of mountain streams in Colorado. Hydrobiologia 390: 99–106.

Vis, M. L. & R. G. Sheath, 1996. Distribution and systematics of *Batrachospermum* (Batrachospermales, Rhodophyta) in North America 9. Section *Batrachospermum*: description of five new species. Phycologia 35: 124–134.

Vis, M. L. & R. G. Sheath, 1998. A molecular and morphological investigation on the relationship between *Batrashospermum spermatoivolucrum* and *B. gelatinosum* (Bratrachospermales, Rhodophyta). European Journal of Phycology 33: 231–239.

Ward, J. V., 1986. Altitudinal zonation in a Rocky Mountain stream. Archive für Hydrobiologie Supplement 74: 133–199.

Ward, J. V. & J. A. Stanford, 1983. The intermediate-disturbance hypothesis: an explanation for biotic diversity patterns in lotic ecosystems. In Fontaine, T. D. & S. M. Bartell (eds), Dynamics of Lotic Ecosystems. Ann Arbor Science, Michigan, USA: 347–356.

Whittaker, R. H., 1975. Communities and Ecosystems. United States of America, Macmillan: 385 pp.