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Diel variations in physical and chemical parameters in a semi-arid stream in Spain (Chicamo Stream)

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Introduction

Rivers and streams fluctuate both spatially and temporally. Diel, seasonal and annual variations are well documented for temperate forest rivers (e.g. CHESTERIKOFF et al. 1991, REBSDORF et al. 1991), for desert streams and pools (e.g. SCHOLNICK 1994, JONES et al. 1995) and prairie streams (e.g. ZALE et al. 1989) but few data exist on diel variations in arid and semi-arid streams in the Mediterranean region (e.g. MARTÍ et al. 1994, GUASCH et al. 1998). However, these fluctuations are important for the aquatic community (e.g. JACKSON 1988) and may influence their life cycle.

This study focused on diel variations in some physical and chemical parameters in a Mediterranean stream, as part of a major project, the principal objective of which was to examine some aspects of the metabolism of the Chicamo Stream, a semi-arid Mediterranean stream located in south-east Spain. The objectives of this study could be summarized as: (1) the analysis of diel variations of seven physico–chemical parameters in six sampling sites of the Chicamo Stream, during winter, spring, summer and autumn, and (2) a comparison of the seasonal and diel fluctuations with the variations obtained during an annual cycle.

Study area

The Chicamo Stream is located in south-east Spain. It is a fourth-order stream, with a gradient of 0.15 (m/m), draining a watershed of 502 km^2 with a bedrock of highly impermeable materials (sedimentary marls). It has a maximum length of 59.4 km but only 22 km flow permanently. Annual rainfall is less than 270 mm with maxima in autumn and spring. The mean annual temperature is 18 °C. The highest average flows may occur during spring and autumn, when storms can produce flash flooding. The natural cover of the watershed is open Mediterranean scrub, although much is dedicated to agriculture.

Six sites (two runs: CH1 and CH6, two pools: CH2 and CH5, one lateral pond: CH3 and one located in the end of one small tributary: CH4; see Table 1) were selected in a 345-m section of the middle reach of the stream, where the flow is continuous throughout the year. During the period studied (1994–1995), discharge ranged from 31 to 0.0 L s^{-1} and current velocity from 0.37 to 0.0 m s^{-1}. The maximum width of the channel was 53.5 m, although the wetted stream ranged from 2 to 20.8 m. Water depth ranged from 14 to 22 cm in pools and ponds and from 2 to 3 cm in runs.

The water in Chicamo Stream is hyposaline, with high concentrations of nitrate and ammonium-N (2566.44 µg L^{-1} and 655.65 µg L^{-1}, respectively), but low soluble reactive phosphorus concentrations (6.39–8.46 µg L^{-1}) (VIDAL-ABARCA et al. 2000).

The riparian vegetation is sparse because of frequent floods. Trees are absent and shrubs such as

Table 1. Habitat variables of the sampling sites of the Chicamo Stream.

Sampling site	Habitat	Hydrology	Substrate	Aquatic vegetation
CH1	Run	Permanent	Compacted marls	Macrophytes + periphyton
CH2	Pool	Permanent	Organic sediment	Macrophytes + periphyton
CH3	Lateral pond	Temporary	Organic sediment	–
CH4	Little affluent	Temporary	Organic sediment	Periphyton + helophytes
CH5	Pool	Permanent	Organic sediment	Periphyton
CH6	Run	Permanent	Marls + gravel	Periphyton

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Phragmites australis, Tamarix canariensis and some species of reeds are present. Periphyton, dominated by diatoms and cyanobacteria, covers almost the entire wetted stream. Some patches of filamentous green algae (*Cladophora glomerata*) and *Enteromorpha intestinalis* grow in runs while *Chara vulgaris* grows in pools. Habitat variables in each sampling site of the Chicamo Stream are shown in Table 1.

Methods

Dissolved oxygen concentration, the saturation of dissolved oxygen, water temperature, pH, alkalinity, salinity and conductivity were measured at each sampling site on four dates (27–28 July and 18–19 November, 1994 and 24–25 June and 7–8 February, 1995) every 2 h during a 24-h period. Triplicate water samples were collected to measure nitrate, nitrite and ammonia concentrations and soluble reactive phosphorus (SRP) at two sampling sites (CH1 and CH6) during the same period, but at 4-h intervals.

The concentration of oxygen was measured by the Winkler method; pH was measured with a Crison pH meter and salinity and conductivity with a YSI-33 conductivity meter, the latter corrected to 25 °C. Alkalinity was determined in situ, as described by MACKERETH et al. (1978). Nutrient concentrations were determined following the standards of APHA (1985).

Results and discussion

A description of the diel cycles studied and the mean, range and standard deviation of the physico–chemical parameters measured in the Chicamo Stream are presented in Table 2. Water temperature and dissolved oxygen showed the same diurnal patterns. The values were lower during the night than during daytime, reaching their highest value at midday (Fig. 1). June showed the widest range of diurnal variation, while February presented the narrowest range. Both parameters showed significant positive correlation (Table 3), indicating the close relationship between these variables throughout the year. These results contrast with those obtained by GUASCH et al. (1998) for La Solana, a Mediterranean stream located in north-east Spain, where re-aeration was high. The high temperature measured through the year does not limit the growth of periphyton and some macrophytes; the metabolism in the Chicamo Stream is influenced by both physical processes (temperature, diffusion, etc.) and biotic exchange processes.

Significant correlations between pH and dissolved oxygen were obtained in spring and

Table 2. Water properties in the Chicamo Stream. Mean and standard deviation (in parentheses) and maximum and minimum values (below).

	July 1994	November 1994	February 1995	June 1995
Sunrise	4.5 h	4.5 h	6.5 h	5 h
Sunset	19.5 h	14 h	14 h	19 h
Day length	15 h	10.5 h	7.5 h	14 h
Water temperature (°C)	24.78 (5.2) (34–18)	14.67 (3.16) (21–9.6)	15.14 (3.14) (22.4–11.6)	21.1 (5.06) (32–14)
Dissolved oxygen (mg L^{-1})	7.22 (2.65) (14.0–1.6)	9.75 (1.88) (14.8–5.5)	10.54 (4.36) (20–4.3)	6.52 (3,4) (20–3)
Saturation oxygen (%)	89.31 (39.26) (194.9–17.25)	96.61 (23.2) (159.55–49.88)	107.31 (52.29) (222.12–40.35)	76,02 (45.09) (224.34–31.04)
pH	7.7 (0.29) (8.48–7.12)	8.29 (0.18) (8.7–7.91)	8.1 (0.31) (9.17–6.48)	7.74 (0.29) (8.48–7.13)
Salinity (g L^{-1})	9.12 (2.47) (16–5.7)	7.54 (1.1) (12–5)	8.47 (2.4) (18.3–4)	7.95 (1.36) (12–5.7)
Conductivity 25°C (µS cm^{-1})	15183.8 (3544.7) (24087–9660)	12755.4 (1767.5) (18150–4887)	14055.6 (3684.6) (29155–6350)	13383 (2059.07) (17640–9660)
Alkalinity (meq L^{-1})	–	6.29 (2.2) (12.26–2.56)	5.46 (2.23) (10.53–2.11)	–

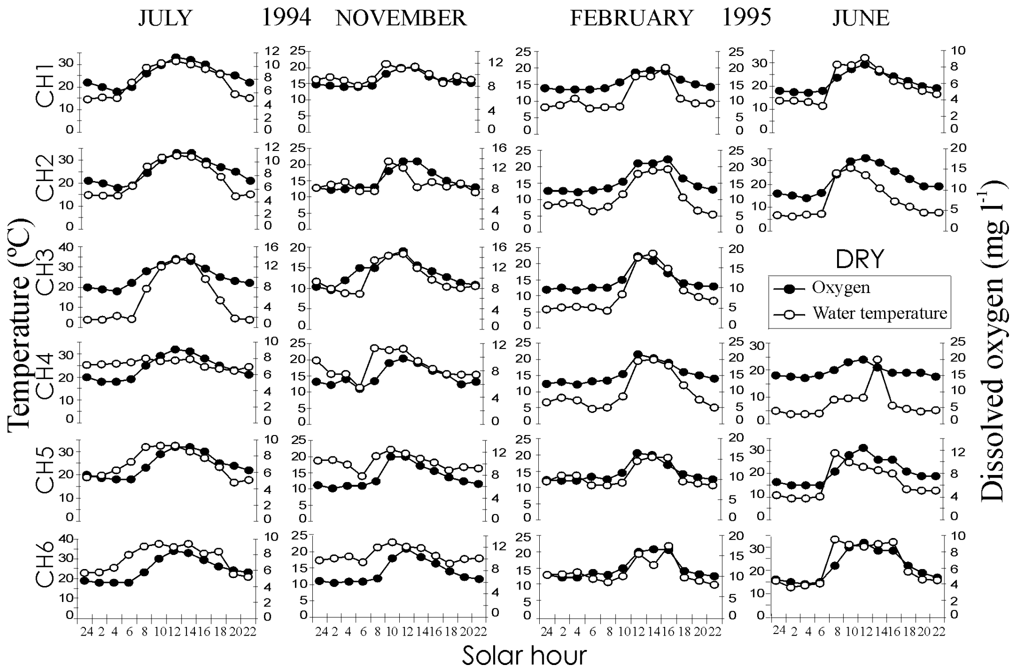

Fig. 1. Diel variation of dissolved oxygen and water temperature for six sampling sites and for four dates in the Chicamo Stream.

summer (Table 3), when the highest values of gross primary production (between 10.07 and 1.39 g O_2 m^{-2} day^{-1}; SUÁREZ & VIDAL-ABARCA (2000)) were observed. The variation of both parameters suggests that, at least during spring and summer, the metabolism of the aquatic community in the Chicamo Stream is more important than physical processes, as occurs in shallow aquatic ecosystems (DUARTE et al. 1990).

Diel variation of alkalinity showed a similar pattern for November and February (Fig. 2). Alkalinity increased during the night and decreased during the day, with a minimum at sunset, suggesting a high degree of $CaCO_3$ precipitation during the day when photosynthetic activity was high. Negative correlations between alkalinity and water temperature, dissolved oxygen and pH (Table 3) suggest that the diel variations of inorganic carbon are also governed by the metabolic activity of primary producers (GUASCH et al. 1998).

Table 3. Pearson correlations between physical and chemical parameters measured in the Chicamo Stream (***P < 0.001, **P < 0.01, *P < 0.05).

	Water temp.	Oxygen	pH	Salinity
July 1994				
Oxygen	0.699***			
pH	0.614***	0.613***		
Salinity		–0.291	–0.272	
Alkalinity				
February 1995				
Oxygen	0.876***			
pH				
Salinity				
Alkalinity	–0.215*	–0.349**	–0.321**	0.485**
November 1994				
Oxygen	0.591**			
pH				
Salinity	0.371**	0.294*	0.352*	
Alkalinity	–0.447**	–0.265*		–0.291*
June 1995				
Oxygen	0.705***			
pH	0.623***	0.613***		
Salinity		–0.291*	–0.272*	
Alkalinity				

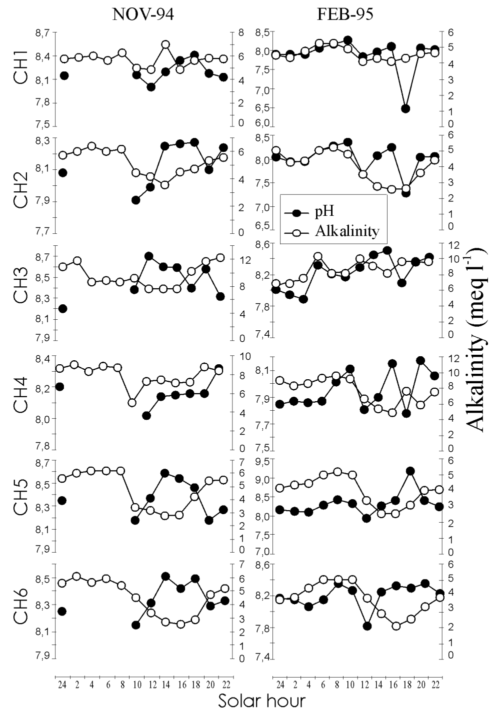

Fig. 2. Diel variation of alkalinity and pH for six sampling sites and for two dates in the Chicamo Stream.

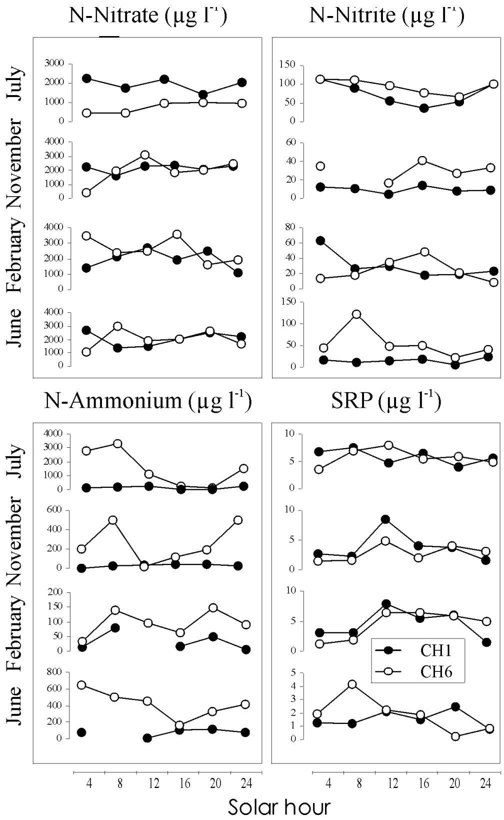

Fig. 3. Diel variation of nitrate, nitrite, ammonium and SRP for two sampling sites and for four dates in the Chicamo Stream.

Nutrients did not follow any diel pattern (Fig. 3). Only the ammonium measured in sampling site CH6 showed a similar pattern at all sampling dates, with the concentration increasing during the night and decreasing during the day. Several investigations have suggested that ammonium rather than nitrate is taken up preferentially by primary producers, because energetically it is a less costly form of nitrogen (e.g. HOWARD-WILLIAMS et al. 1989). Moreover, ammonium is the principal form of nitrogen released during organic matter decomposition and is used by microorganisms during assimilation or nitrification (HILL & WARWICK 1987). In the Chicamo Stream organic matter decomposition is a very active process throughout the year (MARTINEZ et al. 1998) and the periphyton community (including microorganisms) probably used ammonium preferentially.

The diel variations for many parameters measured in the Chicamo Stream were sometimes greater than those found for the annual cycle (Table 4). For example, water temperature, dissolved oxygen, oxygen saturation and pH showed a wider diel range, while salinity, alkalinity and nutrients remained within the annual variation values. This suggests that biological activity is more important than the physical and chemical processes that occur in water and sediments in aquatic ecosystems (KAENEL et al. 2000).

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Table 4. Mean, maximum, minimum and standard deviation (SD) for variables measured. Annual refers to data obtained from sampling each month over a year, and diurnal cycles refers to four dates and six sampling sites in the Chicamo Stream.

	Diurnal cycles					Annual				
	n	Mean	Max.	Min.	SD	n	Mean	Max.	Min.	SD
Water temperature (°C)	276	18.8	34.0	9.6	6.0	118	19.1	30.5	7.0	5.7
Dissolved oxygen (mg L^{-1})	276	8.59	20.00	1.60	3.59	118	10.38	20.07	2.70	3.09
Saturation oxygen (%)	276	93.0	224.3	17.2	42.4	118	110.7	187.1	33.3	30.0
pH	248	7.93	9.17	6.48	0.37	113	7.90	8.64	7.00	0.33
Salinity (g L^{-1})	276	8.28	18.30	4.00	2.03	115	8.32	13.50	2.00	1.93
Conductivity 25 °C (µS cm^{-1})	276	13865	29155	4887	3050	115	13183	21684	2964	2594
Alkalinity (meq L^{-1})	132	5.87	12.26	2.11	2.24	93	5.09	10.95	0.83	1.87
N-nitrate (µg L)	48	1959.1	3599.3	422.3	710.6	119	3286.4	31170.3	30.8	4344.8
N-nitrite (µg L^{-1})	47	41.9	122.5	4.5	34.1	119	31.4	479.9	0.9	55.8
N-Ammonium (µg L^{-1})	45	329.4	3317.2	0.0	657.7	119	1269.3	29171.8	0.0	4046.2
SRP (µg L^{-1})	48	3.83	8.47	0.22	2.25	110	9.77	255.26	0.02	24.84

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