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Moss communities in the irrigation channels of the river Iregua basin (La Rioja, northern Spain)

Javier MARTÍNEZ-ABAIGAR, Encarnación NÚÑEZ-OLIVERA & Nathalie BEAUCOURT*

Universidad de La Rioja, Complejo Científico-Tecnológico, Avda. Madre de Dios 51, 26006 Logroño (La Rioja), Spain

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Abstract – Nineteen bryophytes (all of them mosses), one alga and seven vascular plants were found in 26 irrigation channels of the river Iregua basin (La Rioja, northern Spain), a kind of aquatic environment not previously investigated regarding bryophytes. The species richness, the cover, and the Shannon's diversity (when calculated including bare soil – areas with no bryophyte – as an additional "species") of the communities were correlated negatively with the dryness period in the channels, and positively with the water flow and velocity. Hence, high values of those variables were found in refuge sites, such as the main control-gates through which the river water enters the irrigation channels, whereas low values were typical of frequently dry terminal channels. The diversity values were comparable to those found in the lower course of rivers (which might be systems equally adverse for bryophytes), but only half of those recorded for streams. In the canonical correspondence analysis (CCA), *Cratoneuron filicinum* and *Rynchostegium riparioides* prevailed in channels with a higher water availability, whereas *Amblystegium riparium* was dominant in channels with harder waters and slower currents. A wider spatial sampling, including different channel types and systems, would be needed to analyse the usefulness of bryophytes as bioindicators of the water quality in irrigation channels.

Aquatic bryophytes / species diversity / macrophytes / irrigation channels / CCA analysis

INTRODUCTION

Bryophytes play an important ecological role in flowing water ecosystems, in which they sometimes prevail over algae or vascular plants. In particular, bryophytes are crucial in nutrient cycles and food webs in streams, since they are the most abundant primary producers, support periphyton and provide a refuge, and occasionally food, for macroinvertebrates, amphibia and fish (Bowden *et al.*, 1999). The number of ecological studies analysing both the structure of the bryological communities and the factors controlling bryophyte distribution in flowing waters has considerably increased in the last two decades. Some studies have dealt exclusively with bryophytes (Englund *et al.*, 1997; Glime & Vitt, 1987; Martínez-Abaigar *et al.*, 1991; Muotka & Virtanen, 1995; Papp & Rajczy, 1998; Slack & Glime, 1985; Suren, 1996; Suren & Duncan, 1999; Suren & Ormerod, 1998; Virtanen, 1995; Vitt *et al.*, 1986), while others have also taken into account algae

* Correspondence and reprints: javier.martinez@daa.unirioja.es

and/or vascular plants (Klein *et al.*, 1995; Ormerod *et al.*, 1994; Peñuelas & Catalán, 1983; Peñuelas & Sabater, 1987; Riis *et al.*, 2001; Sheath *et al.*, 1986; Stephenson *et al.*, 1995; Vanderpoorten & Klein, 1999a, 1999b). Altitude, water chemistry, bed stability, substratum granulometry and water level fluctuation seem to be the most important factors influencing the community structure and the species distribution (Muotka & Virtanen, 1995; Suren, 1996; Virtanen *et al.*, 2001).

Most of the studies cited above were conducted in natural systems, and only a minority have been devoted to artificial ones, mainly regulated rivers (Englund *et al.*, 1997; Klein *et al.*, 1995; Vanderpoorten & Klein, 1999b; see also the pioneer work of Empain, 1973). In this context, the bryophyte communities in the irrigation channels have been virtually ignored. This fact contrasts with the recognized ability of aquatic bryophytes to be used as bioindicators of diverse types of water pollution (Glime, 1992), including eutrophication (Carbiener *et al.*, 1990; García-Álvaro *et al.*, 2000; Thiébaut & Muller, 1999; Vanderpoorten & Durwael, 1999; Vanderpoorten & Palm, 1998). Eutrophication might be a common phenomenon in those aquatic systems, such as irrigation channels, that are subjected to agricultural influence.

Irrigation channels may be adverse environments for the establishment and development of plants, due to a particular interaction of stressing factors and disturbance processes: water pollution, great fluctuation of water level (which may cause both prolonged dryness periods and strong floods), periodical elimination of undesirable vegetation, etc. These systems have received relatively little ecological attention, and most studies on the photosynthetic communities inhabiting them have dealt with algae (both macro- and microscopic) and vascular plants (Aboal *et al.*, 1996; Ferreira *et al.*, 1998, 1999; Hussain *et al.*, 1996; Shaltout *et al.*, 1994), but have ignored bryophytes.

The aim of the present study was to investigate the irrigation channels of the river Iregua basin (La Rioja, northern Spain) with respect to: 1) the distribution of bryophytes, macroscopic algae and vascular plants, 2) the structure of the communities formed by those photosynthetic organisms, in terms of cover, richness and diversity, and 3) the physical and chemical factors affecting both the species distribution and the community structure, by means of correlation analysis and canonical correspondence analysis (CCA). This is the first time to our knowledge that the bryophytes inhabiting irrigation channels have been studied. In addition, we tried to determine the usefulness of bryophytes as bioindicators of the water quality in irrigation channels.

MATERIALS AND METHODS

Study area

The study area (Fig. 1) is a triangular alluvial plain located in the lower course of the river Iregua (La Rioja, northern Spain). The area supports almost 10,000 ha of irrigated farmlands spread over nine municipalities. The prevailing crops are fruit trees (pear, peach, apple, cherry), grapevine and vegetables. Water enters the main channels directly from the river Iregua and flows by gravity through the whole system. The main channels and around 50% of the secondary ones are concrete lined and rectangularly shaped, while the rest are earthen chan-

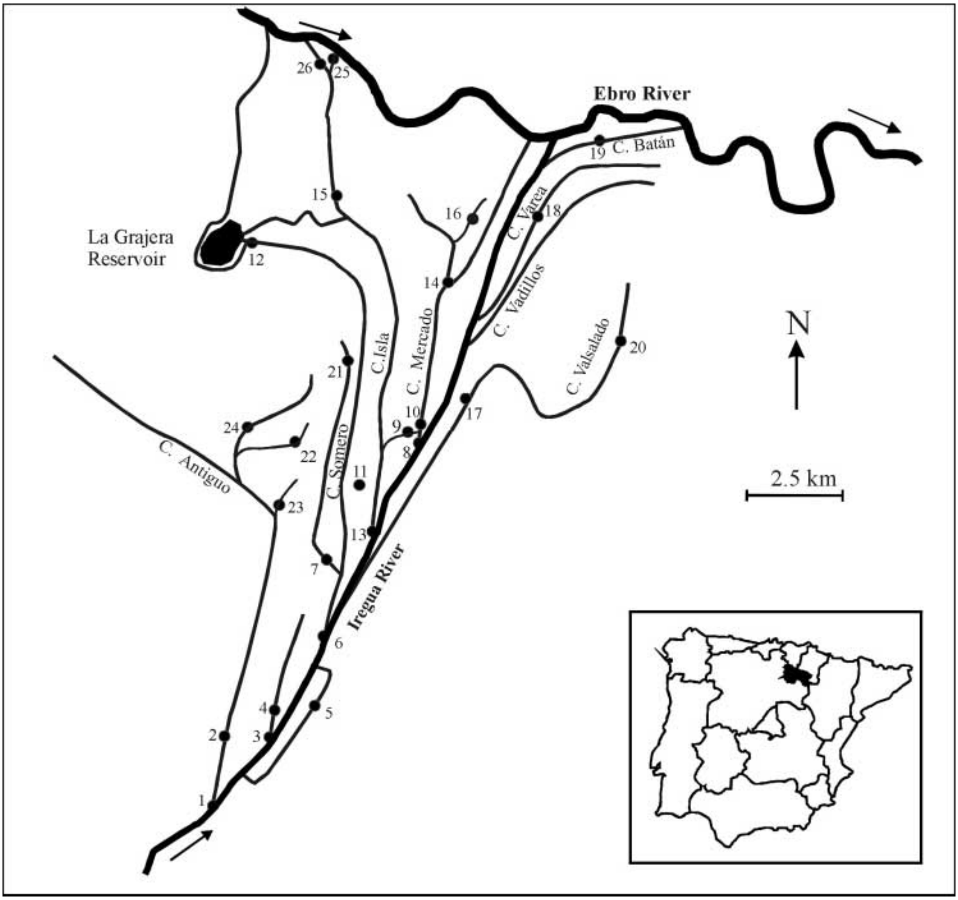

Fig. 1. Principal concrete irrigation channels of the river Iregua basin (province of La Rioja, northern Spain), with the location of the 26 sampling sites. The situation of La Rioja in the Iberian Peninsula (Spain plus Portugal) is also indicated.

nels. The river Iregua is regulated upstream by the reservoirs of Pajares (35 hm^3) and González-Lacasa (33 hm^3), which guarantee the water supply for irrigation.

Morphological and physicochemical characteristics of the channels

The study was carried out in 26 sampling sites belonging to the system of irrigation channels (Fig. 1, Tab. 1). Only channels constructed in concrete were sampled. At each site, the altitude and the channel height and width were recorded. Also, several physicochemical variables were measured monthly over an annual cycle (from May 1995 to April 1996): water depth, water velocity (using a float and a chronometer), water flow (taking into account the water velocity, the water depth and the channel width), pH and temperature (Orion-250A meter), and conductivity (Crison CDTM-523 meter). All these variables were measured *in situ*. Using the interval of time cited above, the annual dryness period of each

Tab. 1. Altitude, dryness period, morphological characteristics, and physicochemical variables (maximum, mean and minimum values of monthly values) of the 26 irrigation channels sampled.

Sites	*Altitude (m)*	*Dryness period (mo/year)*	*Averaged wall heigth (cm)*	*Width (cm)*	*Water depth (cm)*			*Water velocity (m/s)*			*Water flox (m^3/min)*			*pH*			*Temperature (°C)*			*Conductivity (µS/cm)*		
					max.	***mean***	*min.*	*max.*	***mean***	*min.*	*max.*	***mean***	*min.*	*max.*	***mean***	*min.*	*max.*	***mean***	*min.*	*max.*	***mean***	*min.*
1	595	0	75	250	50	**27**	10	2.6	**1.3**	0.4	120.0	**57.7**	8.9	8.7	**7.9**	6.9	16.7	**10.8**	2.5	306	**212**	127
2	595	0	100	200	45	**22**	9	1.6	**0.8**	0.3	86.9	**26.9**	4.7	8.7	**7.9**	6.9	16.7	**10.8**	2.7	306	**214**	133
3	565	0	65	200	20	**10**	5	2.5	**1.0**	0.4	60.0	**14.1**	2.3	8.9	**8.1**	7.0	17.2	**11.5**	2.4	311	**215**	144
4	565	0	45	190	35	**11**	4	0.7	**0.5**	0.3	12.4	**5.8**	1.7	8.9	**8.2**	7.0	17.2	**11.6**	2.4	313	**216**	146
5	570	6	35	120	5	**1**	0	1.1	**0.3**	0	4.0	**0.5**	0	8.5	**7.9**	7.2	18.5	**14.3**	8.6	476	**438**	306
6	510	1	60	150	30	**16**	0	3.4	**1.9**	0	70.5	**31.9**	0	8.9	**8.0**	7.1	18.0	**12.1**	2.4	464	**268**	173
7	500	0	72	120	30	**17**	1	0.9	**0.3**	0	18.6	**4.9**	0	8.8	**8.1**	7.1	18.4	**12.2**	2.6	387	**253**	150
8	470	1	75	200	45	**20**	0	1.0	**0.5**	0	54.0	**16.3**	0	8.6	**8.1**	7.7	18.9	**12.3**	2.5	539	**327**	193
9	470	2	35	32	16	**7**	0	0.5	**0.2**	0	1.0	**0.4**	0	8.7	**8.1**	7.5	18.1	**13.0**	2.7	545	**333**	183
10	470	1	70	150	50	**23**	0	1.1	**0.5**	0	49.9	**15.5**	0	8.7	**8.1**	7.7	19.0	**12.4**	2.4	535	**329**	185
11	465	4	50	65	6	**2**	0	0.8	**0.3**	0	1.9	**0.4**	0	9.0	**8.6**	7.8	20.4	**15.4**	7.9	396	**300**	160
12	455	0	145	140	135	**33**	3	0.8	**0.5**	0.1	39.9	**14.3**	0.6	8.8	**8.2**	7.1	24.5	**14.2**	4.5	421	**275**	186
13	470	1	70	200	25	**11**	0	2.3	**0.9**	0	68.7	**20.3**	0	8.8	**8.1**	7.4	18.0	**12.4**	2.5	522	**315**	148
14	440	4	68	180	30	**12**	0	1.5	**0.7**	0	43.4	**15.0**	0	9.5	**8.6**	7.8	26.0	**14.5**	6.2	393	**288**	220
15	425	2	85	130	35	**15**	0	1.2	**0.3**	0	31.7	**5.4**	0	8.8	**8.3**	7.8	25.0	**14.5**	4.6	388	**300**	207
16	415	11	45	70	30	**3**	0	0.8	**0.1**	0	10.6	**0.9**	0	8.3	**8.3**	8.3	23.0	**23.0**	23.0	234	**234**	234
17	480	3	80	155	50	**13**	0	0.8	**0.3**	0	20.6	**5.8**	0	8.9	**8.3**	7.4	21.0	**14.0**	10.0	407	**264**	162
18	440	0	85	145	55	**23**	10	1.0	**0.3**	0	48.3	**11.2**	0	8.5	**7.9**	7.3	20.3	**11.7**	2.1	546	**377**	177
19	395	0	60	130	25	**20**	14	0.8	**0.5**	0.1	14.8	**8.8**	0.9	8.1	**7.8**	7.2	22.0	**13.3**	3.0	533	**383**	180
20	460	9	70	55	4	**1**	0	1.7	**0.3**	0	2.3	**0.3**	0	8.1	**7.9**	7.6	10.7	**8.8**	5.7	402	**340**	301
21	495	8	60	105	20	**4**	0	0.1	**0.0**	0	1.0	**0.1**	0	8.4	**8.0**	7.6	27.0	**22.0**	18.0	470	**328**	222
22	490	8	40	40	4	**1**	0	0.8	**0.2**	0	0.8	**0.1**	0	8.9	**8.4**	7.7	23.0	**17.3**	4.0	443	**374**	297
23	540	10	50	60	1	**0**	0	0.3	**0.0**	0	0.1	**0.0**	0	7.8	**7.7**	7.5	18.0	**17.0**	16.0	266	**209**	152
24	530	9	70	100	30	**4**	0	0.4	**0.1**	0	7.2	**0.7**	0	9.1	**8.2**	7.6	27.0	**20.0**	16.5	250	**209**	142
25	400	7	50	75	3	**1**	0	1.1	**0.2**	0	1.5	**0.2**	0	9.1	**8.8**	8.2	29.0	**20.0**	13.6	333	**279**	206
26	400	4	65	115	30	**13**	0	0.8	**0.3**	0	14.7	**4.9**	0	9.0	**8.4**	7.6	29.0	**18.1**	6.8	401	**314**	217

channel (in months) was determined. In order to better characterize the water traits, some additional physicochemical variables were seasonally measured (autumn, 4 November 1995; winter, 22 February 1996; spring, 23 April 1996; summer, 1 July 1996) in four critical points of the channel system (Fig. 1): 1 (first inlet gate from the river Iregua), 13 (another inlet gate located 10 km downstream), 12 and 19 (two water outlets from the channel system into the La Grajera reservoir and the river Ebro, respectively). Temperature, pH, conductivity and dissolved oxygen (Syland Simplair M oxygen electrode) were recorded *in situ*. The water was then transported to the laboratory in a portable icebox ever below 5ºC and analysed within 24 h after the collection by conventional methods (Allen *et al.*, 1986; A.P.H.A. *et al.*, 1992). The following variables were analysed: dry residuum (filtration through GF/C Whatman filters – pore size 1.2 µm – and gravimetry); organic matter (volumetric titration with $Na_2S_2O_3.5H_2O$ 0.01M after hot oxidation with $KMnO_4$ 0.002M); alkalinity, CO_3^{2-} and HCO_3^- (volumetric titration with H_2SO_4 0.01M); Cl^-, NH_4^+, NO_3^-, and NO_2^- (selective electrodes connected to an Orion EA940 Expandable Ion Analyzer); SO_4^{2-} and PO_4^{3-} (turbidimetric and ammonium molybdate methods, respectively, measured with a Perkin-Elmer λ3 UV/Vis spectrophotometer); Ca^{2+} and Mg^{2+} (flame atomic absorption spectrophotometer Varian SpectrAA-10; lanthanum chloride was added to the samples to prevent interferences); Na^+ and K^+ (flame emission, Varian SpectrAA-10). All the variables were measured in triplicate.

Irrigation channels may suffer from sediment deposition, waste accumulation and development of plants that obstruct them, and thus they have to be periodically cleaned. The users of the channel system studied here, grouped in a farmers' association ("Comunidad de Regantes"), clean the channels every spring, before the highest irrigation period. This task is made by hand with a shovel. Also, herbicides may be applied in the channel borders to eliminate terrestrial weeds.

Vegetation sampling

In May 1995, 26 channels were sampled with a series of eight line transects at each one. The first transect was placed at random and each consecutive one was separated by 50 cm. This sampling size (a stretch of 3.5 m long for each channel) was previously determined by calculating a diversity spectrum (Núñez-Olivera *et al.*, 1995). Each transect comprised a one-dimensional plot from which cover for each aquatic macrophyte species present (vascular plants, bryophytes and macroscopic algae: Allan, 1995) was recorded, differentiating three areas as a function of sun exposition: shade wall, bed, and sun wall. Using the joint cover measurements of all the transects in each sampling site, the species diversity index was calculated by Shannon's formula (in Magurran, 1989): $H' = - \Sigma p_i \log_2 p_i$, where p_i is the proportion of the cover of the species i with respect to the total cover of the site. Bryophyte species diversity (H'1) was calculated on the basis of lineal cover of bryophytes. Given the importance of bare soil in the vegetation structure, two additional diversity indices were calculated (Martínez Abaigar *et al.*, 1991). H'2 was the bryophyte diversity using "bare soil" (fragments of the transects without bryophytes, either with other types of macrophytes or with no vegetation at all) as an additional variable or "species". H'3 was the macrophyte diversity of the site, considering bryophytes, algae, vascular plants and strictly bare soil (fragments of the transects with no macrophyte cover). The inclusion of bare soil in the calculations made it possible to give a value of bryophyte or macrophyte diversity to those sites in which, respectively, no bryophytes or macrophytes were present. The three diversity indices were obtained for each sun exposition (shade wall, bed and sun wall) and globally for each site. Since all the bryophytes found were mosses, the terms "bryophyte diversity" and "moss diversity" will be interchangeably used throughout the text. The nomenclature of macrophytes follows Corley *et al.* (1981) for mosses, Bourrelly (1985) for algae, and Tutin *et al.* (1964-1993) for vascular plants. Voucher specimens are located in the personal herbarium of J. Martínez-Abaigar.

Data analysis

Monthly morphological and physicochemical data of the channels, and also seasonal physicochemical data, were previously tested for homogeneity of variances and then a two-way analysis of variance (ANOVA), followed by a test of least significant differences (LSD), was applied to each data set to establish whether there were differences between the different channels and the different months (or seasons). The Pearson correlation coefficients (r) were used to assess the relationships between the set of channel variables, the set of community variables, and both sets of variables. SPSS 6.1.2 for Windows was used for these statistical analyses. Canonical correspondence analysis (CCA), described in CANOCO program (Ter Braak, 1987, 1990), was used to relate the cover of the bryophyte species to the characteristics of the irrigation channels. CCA generates a diagram that displays approximate values of the weighted averages of species cover with respect to the environmental variables considered. These are represented by vectors that roughly point in the factor direction of maximum variation, and the length of each vector indicates the relative importance of the respective variable in determining the axis, while the angle between a vector and an axis is an inverse measure of their correlation (Ter Braak, 1987). To conduct the analysis, the channels without bryophytes were eliminated, and the narrow-ranged or strongly intercorrelated channel characteristics were removed as well. Thus, the environmental factors used were: altitude, dryness period, channel height, channel width, water depth, water velocity, water flow, and conductivity.

RESULTS

Physicochemical characteristics of the sampling channels

The morphological and physicochemical variables which were measured monthly in the 26 channels sampled are shown in Tab. 1. Water flowed by gravity from the highest site (number 1, 595 m) to the lowest one (number 19, 395 m), going through channels of varied sizes, between 32 and 250 cm wide and with a 35 - 145 cm high wall. There was no direct relationship between the channel size and its situation within the system, although the width of the main control-gates was generally equal to or higher than 2 m. Water depth, velocity and flow varied significantly ($p<0.01$) according to the channel and the period of the year. The three variables were strongly and positively intercorrelated (r = 0.56-0.79, $p<0.001$). The channel number 1 showed the highest water flow (120.0 $m^3\ min^{-1}$), and other channels near the river course also reached high values, whereas the terminal ones usually had low water flows and were frequently dry (up to 11 months

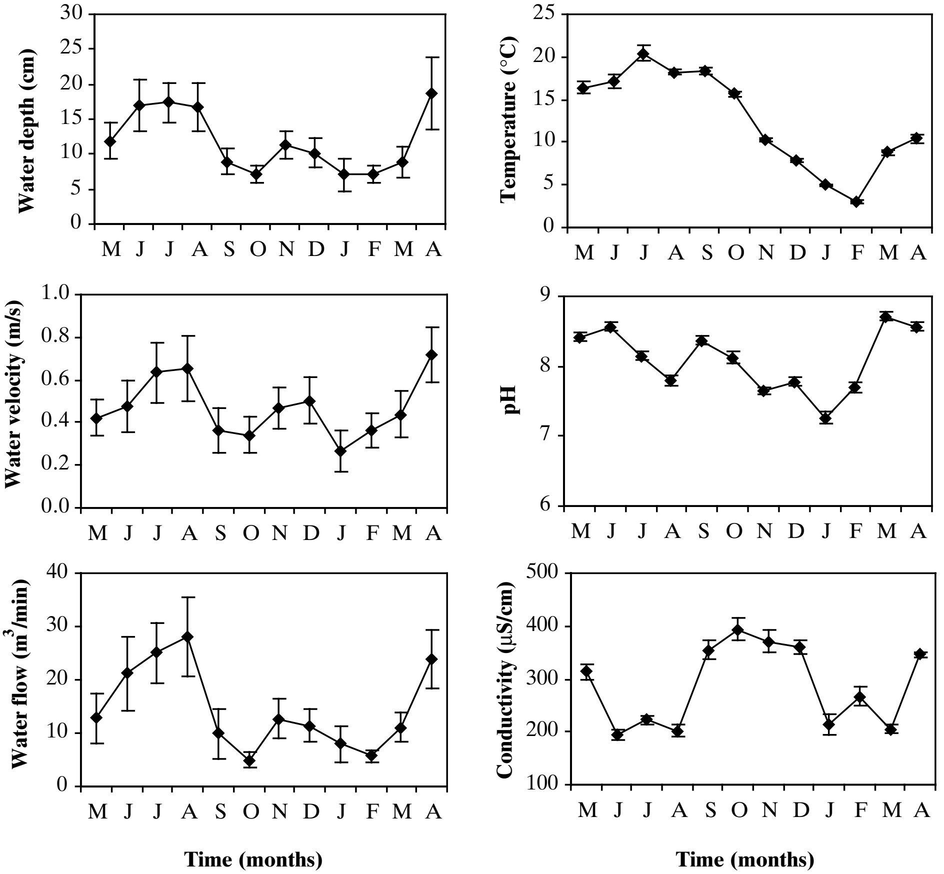

Fig. 2. Monthly variations, during the sampling period (May 1995 - April 1996), of six physicochemical variables in the water flowing through the irrigation channel system. Monthly values of the 26 sampling points are averaged and standard errors are shown.

a year in channel 16). The spatial pattern of water depth and velocity was similar to that of the water flow. The highest velocity was recorded at channel 6 (3.4 m s^{-1}) and low values were shown by those channels with a longer dryness period. The monthly variations of the physicochemical variables are shown in Fig. 2. Again, water depth, velocity and flow varied jointly, with higher values in spring and, especially, in summer, and lower values in autumn and winter.

Temperature, pH and conductivity also varied significantly (p<0.01) depending on the channel and the period of the year. Temperature showed a strong seasonality (29.0°C in July and 2.1°C in February), but there was no clear spatial pattern, although the channels near the river course carried colder waters than those far from it. The pH ranged between 6.9 (channels 1 and 2) and 9.5 (channel 14), and the conductivity between 127 (channel 1) and 546 µS cm^{-1} (channel 18). Both variables showed seasonal patterns, but no spatial patterns (although the channels near the first control-gate, numbers 1-4, had softer waters). The pH was low in winter and high in spring, whereas the conductivity was low in

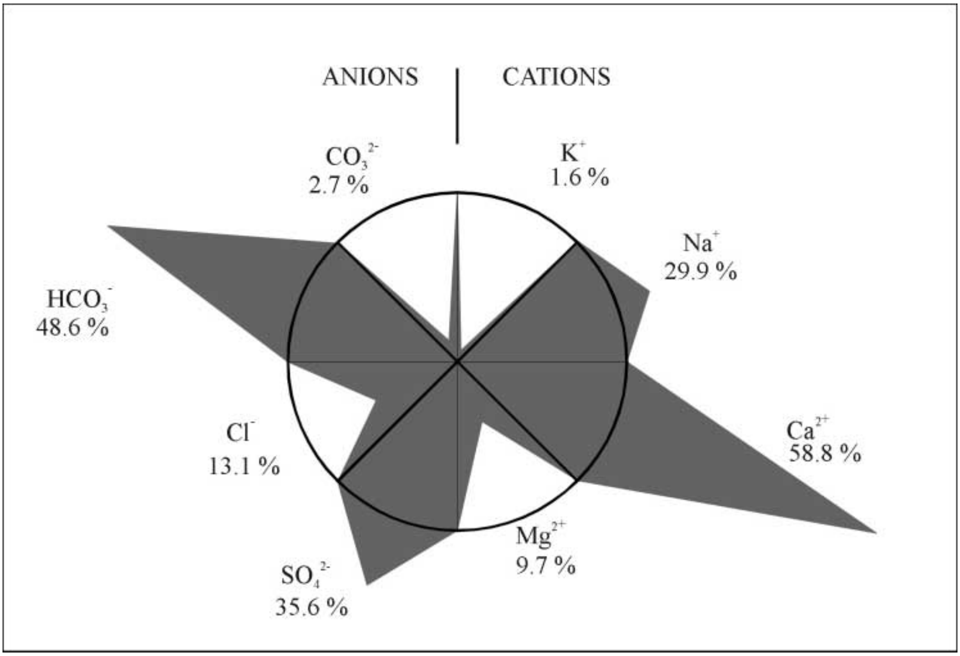

Fig. 3. Averaged annual water ionic composition of the four critical irrigation channels seasonally sampled (localities 1, 12, 13 and 19). The percentages of the four major anions and the four major cations, calculated on the basis of their concentrations in meq l^{-1}, are shown.

winter and summer, and high in autumn (September-December) and spring (April-May).

The averaged seasonal physicochemical data from the four critical sampling channels (1, 12, 13 and 19) are summarized in Tab. 2. The water of the irrigation channels was alkaline, and moderately enriched in ions, nutrients or organic matter. Only the concentrations of Cl^-, SO_4^{2-}, Na^+ and K^+ showed considerably high values in certain seasons or throughout the year. The prevailing anions and cations were, respectively, HCO_3^- and SO_4^{2-}, and Ca^{2+} and Na^+ (Fig. 3). Only the organic matter (higher) and the percentage of dissolved oxygen (lower) were significantly different in channel 12 against the other channels ($p<0.001$). The significantly higher alkalinities and concentrations of HCO_3^- and SO_4^{2-} in autumn ($p<0.01$) were related to the seasonal variation of conductivity.

Vegetation analysis

The cover, richness and diversity of the macrophytes found in the 26 sampling channels, together with the species' frequency, are shown in Tab. 3. Only 27 macrophyte species were found: 19 mosses, one alga and seven vascular plants. The most frequent species was the chlorophyte *Cladophora glomerata* (L.) Kütz., which grew in 69% of the channels. Among the mosses, the most frequent species were the hydrophilous or hygrophilous *Amblystegium riparium* (Hedw.) B., S. & G. (35%), *Cratoneuron filicinum* (Hedw.) Spruce (35%) and *Rhynchostegium*

Tab. 2. Seasonal changes of the physicochemical variables analysed in the four critical sampling points (1, 12, 13 and 19). Maximum, mean and minimum values are shown.

	AUTUMN			***WINTER***			***SPRING***			***SUMMER***		
	max.	***mean***	*min.*	*max.*	***mean***	*min.*	*max.*	***mean***	*min.*	*max.*	***mean***	*min.*
pH	7.8	**7.7**	7.6	7.8	**7.5**	7.2	8.6	**8.5**	8.1	9.5	**8.6**	7.8
Temperature (ºC)	12.7	**10.7**	9.6	4.5	**3.1**	2.5	16.8	**14.9**	13.3	23.0	**21.4**	18.9
Conductivity (µS/cm)	491	**359**	246	421	**280**	212	382	**353**	306	597	**415**	272
Dry residuum (mg/l)	4050	**1019**	7.0	35.8	**12.3**	3.0	50.5	**20.4**	8.7	20.3	**11.3**	5.3
Organic matter (mg/l)	3.64	**2.15**	1.59	3.68	**1.73**	0.92	3.13	**1.82**	1.03	4.11	**2.92**	2.04
O_2 (% saturation)	88.1	**80.5**	69.9	100.0	**91.0**	64.4	100.0	**88.3**	53.3	99.1	**87.1**	52.3
Alkalinity (mg/l)	187.2	**139.5**	96.1	119.9	**101.4**	90.4	137.0	**98.1**	79.1	112.2	**74.1**	47.1
CO_3^{2-} (mg/l)	1.20	**0.96**	0.60	2.60	**1.94**	1.32	5.18	**2.98**	1.00	15.60	**5.71**	0.29
HCO_3^- (mg/l)	186.0	**138.5**	95.5	118.0	**99.3**	89.0	131.6	**95.0**	76.6	107.0	**67.9**	46.8
Cl^- (mg/l)	37.3	**25.2**	12.7	37.3	**16.6**	7.0	18.2	**12.8**	8.0	17.0	**10.4**	5.2
NH_4^+ (mg/l)	0.18	**0.04**	0.00	1.36	**0.36**	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.00
NO_3^- (mg/l)	4.19	**2.62**	1.44	4.03	**1.63**	0.70	1.73	**0.92**	0.50	1.57	**1.00**	0.64
NO_2^- (mg/l)	0.08	**0.04**	0.01	0.17	**0.09**	0.05	0.06	**0.05**	0.03	0.09	**0.08**	0.07
SO_4^{2-} (mg/l)	127.1	**97.6**	81.5	82.6	**59.4**	50.7	42.9	**26.3**	19.7	75.4	**48.1**	33.2
PO_4^{3-} (mg/l)	0.10	**0.07**	0.04	0.12	**0.05**	0.02	0.03	**0.03**	0.02	0.05	**0.04**	0.03
Ca^{2+} (mg/l)	47.5	**33.0**	21.7	144.0	**73.6**	42.6	75.0	**53.9**	42.8	70.2	**44.8**	28.6
Mg^{2+} (mg/l)	5.56	**3.70**	2.65	10.0	**6.35**	4.50	7.20	**5.60**	4.80	7.40	**4.60**	3.40
Na^+ (mg/l)	97.4	**30.0**	6.19	62.0	**37.5**	18.0	30.0	**22.0**	11.4	52.0	**33.3**	18.0
K^+ (mg/l)	11.30	**3.75**	1.11	18.00	**5.67**	1.46	1.99	**1.58**	0.98	1.95	**1.45**	0.90

Tab. 3. Cover (cm of line intercept length in eight line transects across each channel) and frequency following variables are also shown for each channel: total length of the eight line transects, moss species areas with no bryophyte cover – as an additional variable or "species"), total site richness, total site cover plants and strictly bare soil – areas with no macrophyte cover). Values of total moss cover and total site lapping.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Total transect length (cm)	*3200*	*3200*	*2640*	*2240*	*1520*	*2160*	*2112*	*2800*	*816*	*2320*	*1320*	*3440*
Amblystegium riparium	15	-	-	38	10	-	-	-	65	-	-	-
A. serpens	-	-	-	83	-	15	-	-	-	5	-	-
Barbula convoluta	-	-	-	-	-	5	-	-	-	-	-	-
Brachythecium rutabulum	5	-	15	-	-	10	-	20	25	10	-	-
Bryum argenteum	-	-	-	-	25	-	-	-	-	-	-	-
B. barnesii	-	-	-	-	22	-	-	-	-	-	-	160
B. bicolor	-	-	-	5	-	-	-	-	-	-	-	-
B. capillare	-	-	-	-	-	5	-	-	-	-	-	-
Campylium calcareum	-	-	-	-	-	-	-	-	-	5	-	-
Cinclidotus fontinaloides	5	-	-	10	-	-	-	-	-	-	-	-
Cratoneuron filicinum	241	-	220	50	-	50	-	15	70	5	-	-
Didymodon insulanus	-	-	-	-	-	10	-	-	-	-	-	-
D. vinealis	5	-	-	-	-	-	-	5	83	5	-	15
Eurhynchium hians	-	-	-	-	-	-	-	-	-	10	-	-
Fissidens crassipes	10	-	-	-	-	-	-	-	-	-	-	-
Plagiomnium sp.	7	-	-	-	-	-	-	-	-	-	-	-
Pohlia proligera	-	-	-	-	-	-	-	-	-	-	-	-
Rhynchostegium riparioides	280	-	315	91	-	555	-	15	-	-	-	-
Tortula muralis	-	-	-	30	-	-	-	20	10	10	-	-
Moss species richness	8	0	3	7	3	7	0	5	5	7	0	2
Total moss cover (%)	17.8	0	20.3	11.8	3.8	26.4	0	2.7	25.5	1.1	0	5.1
H'1	1.53	-	1.13	2.42	1.49	0.90	-	2.21	2.06	2.72	-	0.42
H'2	0.95	0	0.97	0.89	0.29	1.13	0	0.24	1.43	0.21	0	0.31
Cladophora glomerata	1255	303	110	205	-	75	495	555	-	22	-	55
Cardamine hirsuta	-	-	-	-	-	-	-	-	-	-	5	-
Glyceria fluitans	-	-	-	-	-	-	-	-	-	-	-	-
Nasturtium officinale	-	-	-	-	15	10	-	-	-	-	-	-
Plantago lanceolata	-	-	-	-	-	-	-	-	-	-	25	-
Poa annua	-	-	-	-	-	-	-	-	-	-	5	-
Ranunculus penicillatus	-	187	-	5	-	15	5	-	-	-	-	-
Zannichellia palustris	-	-	-	-	-	-	-	-	-	-	-	-
Total site richness	9	2	4	9	4	10	2	6	5	8	3	3
Total site cover (%)	57.0	14.2	24.4	21.2	4.7	30.6	23.4	22.5	25.5	2.0	2.7	6.7
H'3	1.77	0.76	1.20	1.33	0.37	1.41	0.81	0.95	1.43	0.28	0.20	0.43

values among channels for mosses, macroscopic algae and vascular plants in the 26 sampling channels. The
richness, total moss cover (percentage), moss diversity indices (H'1 and H'2, without or with "bare soil" –
(percentage), and the macrophyte diversity index (H'3) of the site (considering mosses, algae, vascular
cover are usually lower than those calculated as the sum of the individual covers because of species over-

13	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*Frequency (%)*
2720	*2528*	*2400*	*1280*	*2520*	*2520*	*2000*	*1560*	*1800*	*960*	*1280*	*1920*	*1400*	*1960*	-
18	-	-	-	-	19	115	-	-	4	-	-	6	-	35
-	-	-	-	-	-	-	-	-	-	-	-	-	-	12
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	-	-	-	-	-	23
-	-	9	-	-	-	-	-	-	-	-	-	-	-	8
-	-	-	-	-	-	-	-	-	-	18	-	-	2	15
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
31	-	-	-	-	-	-	-	-	9	-	-	-	-	35
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	-	-	-	-	12	23
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	2	-	-	-	-	4
214	-	-	-	-	-	-	-	-	7	-	-	-	2	31
-	-	-	-	-	45	22	-	-	4	-	-	1	4	35
3	0	1	0	0	2	2	0	0	5	1	0	2	4	-
7.9	0	0.4	0	0	2.5	6.9	0	0	2.7	1.4	0	0.5	1.0	-
0.87	-	0	-	-	0.97	0.64	-	-	2.16	0	-	0.59	1.57	-
0.54	0	0.04	0	0	0.19	0.40	0	0	0.24	0.11	0	0.05	0.10	-
1210	845	784	-	223	1127	394	-	20	-	-	-	389	866	69
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	-	-	-	10	-	4
-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
-	-	-	-	10	15	-	-	430	-	-	-	-	-	12
4	1	2	0	2	4	3	0	2	5	1	0	4	5	-
49.4	33.4	33.0	0	9.2	47.3	26.6	0	25.0	2.7	1.4	0	28.3	45.1	-
1.43	0.94	0.94	0	0.47	1.21	1.10	0	0.88	0.24	0.11	0	0.95	1.08	-

Tab. 4. Pearson correlation coefficients (r) between the three diversity indices (H'1, H'2 and H'3), and the cover and richness of both mosses and macrophytes (n = 17 or n = 26). H'2 and H'1 were the moss diversity indices of the sites, calculated, respectively, with and without "bare soil" (areas with no bryophyte cover) as an additional variable or "species". H'3 was the macrophyte diversity index of the site, considering mosses, algae, vascular plants and strictly bare soil (areas with no macrophyte cover). Significance levels: (***), $p<0.001$; (**), $p<0.01$; (*), $p<0.05$.

	H'1	***H'2***	***H'3***	***Moss cover***	***Total cover***	***Moss richness***
H'2	0.28					
H'3	0.04	0.67***				
Moss cover	0.15	0.98***	0.65***			
Total cover	–0.15	0.41*	0.87***	0.41*		
Moss richness	0.76***	0.72***	0.52*	0.65***	0.40*	
Total richness	0.65***	0.68***	0.60***	0.63***	0.46*	0.95***

riparioides (Hedw.) Card. (31%), and also the xerophylous *Tortula muralis* Hedw. (35%). Two other mosses (*Brachythecium rutabulum* (Hedw.) B., S. & G. and *Didymodon vinealis* (Brid.) Zander) had frequencies higher than 20%. The remaining macrophyte species seemed to be occasional and had low frequencies. Most species showed low cover values, except for *Cladophora glomerata* and the mosses *Cratoneuron filicinum* and *Rhynchostegium riparioides*.

The highest macrophyte richness was 10 and the lowest 0, with a mean value of 4. The highest macrophyte cover reached 57%. Both the moss richness and cover were generally the highest in the main control-gates (channels 1, 3, 6, 8 and 13), with maximum values of 8 and 26.4%, respectively. Three channels had no macrophyte and nine had no bryophyte.

The ranges of the diversity indices were 0-2.72 for H'1, 0-1.43 for H'2, and 0-1.77 for H'3. H'3 was higher than H'1 in 10 channels out of 17; in nine sites H'1 had no value since no bryophyte was present. H'1 was higher than H'2 in 14 channels out of 17. All the diversity indices were higher (data not shown) in the shade wall of the channels (0-2.72 for H'1, 0-2.48 for H'2 and 0-2.48 for H'3) than in the sun walls (0-1.20, 0-1.56 and 0-1.69, respectively) and in the beds (0, 0-0.71 and 0-1.19, respectively). Only channels 3 and 6 had bryophytes on their beds (*Rhynchostegium riparioides*).

The correlations between the community parameters (diversity indices, cover and richness) are shown in Tab. 4. Among the diversity indices, only H'2 and H'3 were significantly correlated ($p<0.001$). H'1 was not correlated with any cover, H'2 was strongly ($p<0.001$) correlated with moss cover and weakly ($p<0.05$) with total cover, and H'3 was narrowly correlated with both of them ($p<0.001$). Both the moss richness and the total richness were significantly correlated with H'1 and H'2 ($p<0.001$) and also with H'3 ($p<0.01$). The moss richness and the total richness were correlated with the moss cover ($p<0.001$), but only poorly correlated with the total cover ($p<0.05$). Finally, the moss richness was strongly correlated with the total richness ($p<0.001$). All the significant correlations were positive.

H'1 was not significantly correlated with any of the environmental variables shown in Tab. 1. However, H'2 and H'3, together with both species richnesses and both site covers, were always correlated (absolute values of r between 0.41, $p<0.05$, and 0.68, $p<0.001$) with the dryness period (negatively), water velocity (positively) and water flow (positively). In addition, H'3, total species richness and total site cover were positively correlated with the channel width and water depth (r = 0.38-0.57, $p<0.05$ or $p<0.01$).

The first three ordination axes of the CCA accounted respectively for 41%, 30% and 12% of the variation of species distribution. The eigenvalues for the first three axes were 0.79, 0.59 and 0.24, indicating that the axes 1 and 2 were the most important ones. Axis 1 was significantly correlated ($p<0.05$) with the wall height (0.62) and the water velocity (-0.45), whereas axis 2 was correlated with the water velocity (-0.62), water conductivity (0.61), altitude (-0.51) and channel width (-0.47). The bottom left-hand quarter of the CCA ordination diagram (Fig. 4) was occupied by a group of channels with a great width (150-250 cm), an intermediate wall height (60-75 cm), a rapid water velocity (>0.9 m s^{-1}), a very short or nonexistent dryness period (0-1 month per year), and a relatively low conductivity (< 315 µS cm^{-1}). Three typically aquatic mosses (*Cratoneuron filicinum*, *Rynchostegium riparioides* and *Fissidens crassipes* Wils. ex B., S. & G.) were related to this group of channels, together with some rare non-aquatic ones (*Barbula convoluta* Hedw., *Bryum capillare* Hedw. and *Didymodon insulanus* (De Not.) M. Hill). In the upper right-hand of the CCA ordination diagram, some channels generally located towards the end of the irrigation system were placed; their width was lower than 150 cm, their conductivity generally higher than 315 µS cm^{-1}, and their water velocity lower than 0.5 m s^{-1}. A typical aquatic moss (*Amblystegium riparium*), together with some non-aquatic species, such as *Brachythecium rutabulum*, *Tortula muralis*, *Campylium calcareum* Crundw. & Nyh., *Eurhynchium hians* (Hedw.) Sande Lac. and *Didymodon vinealis*, were related to these channels. Other species (*Bryum argenteum* Hedw., *B. barnesii* Wood ex Schimp. and *Pohlia proligera* (Lindb. ex Breidl.) Lindb. ex H. Arn.) appeared isolated in the diagram.

DISCUSSION

Physicochemical characterization of the irrigation channel system

It could be expected that a system of irrigation channels with such a modest size as the one studied here might be rather homogeneous. However, the morphology of the channels was considerably diverse and some of the physicochemical variables showed important spatial and temporal variations (water flow, water depth, current velocity, conductivity). This diversity is comparable to that found in other irrigation channel systems in the Iberian Peninsula (Ferreira *et al.*, 1998, 1999). The most evident spatial and temporal patterns corresponded to the water flow and its correlated variables (water depth and current velocity), which were higher in the channels near the river course than in the terminal ones; also, higher water flows were recorded in the period of the year with a more intense irrigation demand (summer). The chemical variables of the water hardly showed clear spatial or temporal patterns, except for the conductivity, which was usually higher in periods of low water flow.

The chemical composition of the water entering the irrigation channels, which are located in the lower course of the river Iregua, is directly related to the geological substrata over which it flows in its middle course (limestones, lime-based conglomerates and gypsum), since the upper course is mainly siliceous

(I.G.M.E., 1980). Hence, the water is enriched in HCO_3^-, Ca^{2+}, and SO_4^{2-}. The important presence of Na^+ could be due to the deicing salt frequently added in winter to the mountain roads situated in the upper course. The mineral enrichment found in our study, in terms of conductivity and ionic composition, is only moderate in comparison with that recorded in the irrigation channels of more arid lands, such as south-eastern Spain or Saudi Arabia, which can be 4-10 times higher (Aboal *et al.*, 1996; Hussain *et al.*, 1996).

Bryophytes and other macrophytes present in the irrigation channel system

A total of 19 bryophyte species was found, only five of which were more or less typically aquatic: *Amblystegium riparium*, *Cratoneuron filicinum*, *Rhynchostegium riparioides* (the three most frequent and abundant), *Cinclidotus fontinaloides* (Hedw.) P. Beauv., and *Fissidens crassipes*. Among them, *A. riparium* has been repeatedly found in waters rich in nutrients and/or organic matter (Hussey, 1982; Kelly & Huntley, 1987; Klein *et al.*, 1995; Vanderpoorten & Klein, 1999b). *Cinclidotus fontinaloides* and *F. crassipes* are characterized as bioindicators of eutrophic conditions, whereas *C. filicinum* and *R. riparioides*, according to their higher frequency, have a large ionic amplitude (Klein *et al.*, 1995). The high cover values recorded for the last two species could be based on their creeping prostrate growth form, which allows a firm anchorage to the substratum. According to the data provided, the presence of those five species was to be expected in the irrigation system studied. However, some typical species of the irrigation channels of the river Iregua basin in the past (19th century), such as *Fontinalis antipyretica* Hedw. (Martínez Abaigar & Núñez Olivera, 1996), have vanished nowadays, as a consequence of habitat disturbance or anthropogenic alterations in the water physicochemistry.

Most of the remaining bryophyte species grow typically on soil or are pioneer species colonizing rocks or protosoils. In the channels, they can survive in fissures or in the top parts of the channel walls, which are occasionally water-sprayed or continuously dry, and may accumulate a certain amount of soil. A number of such species (*Brachythecium rutabulum*, *Bryum argenteum*, *B. bicolor* Dicks., *B. capillare*, *Tortula muralis*, *Didymodon vinealis*...) are frequently found on concrete constructions, river banks, or emergent boulders in the lower courses of rivers (Empain, 1973; Klein *et al.*, 1995; Martínez-Abaigar & Ederra, 1992; Vrhovsek *et al.*, 1981).

To our knowledge, there is no previous specific study on bryophytes from irrigation channels which allows us to compare our data. The bryophytes cited in this study represent only 15% of those found in aquatic habitats in the whole course of the river Iregua (Martínez-Abaigar & Ederra, 1992), but these authors collected bryophytes in a much greater diversity of environments. They found 40 liverworts (32% of the total of bryophytes), which contrasts with the absence of liverworts in the irrigation channels. The explanation of this fact needs further research.

The most frequent and abundant macrophyte species found in this study was the chlorophyte *Cladophora glomerata*, which formed a very homogeneous structure of plant vegetation in channels with high and continuous water flow. This alga occurs in other irrigation channel systems as well (Aboal *et al.*, 1996; Ferreira *et al.*, 1998, 1999), due to its rapid growth and vigorous regeneration ability (Aboal *et al.*, 1996). It is also the most widespread alga in flowing waters in Spain, especially in mesotrophic alkaline waters (Cambra & Aboal, 1992) as those studied here. Rooted vascular plants were represented only by seven species, among which only *Ranunculus penicillatus* (Dumort.) Bab. and *Zannichellia palustris* L. are worth citing. This contrasts with the high number of them cited in other studies (43-55: Ferreira *et al.*, 1998; Shaltout *et al.*, 1994), but both the sampling and the irrigation channels were different in each study. *Ranunculus penicillatus* is very common in the main course of the river Iregua and could easily reach the irrigation channels by means of vegetative propagation (rooted plant fragments). The presence of rooted vascular plants in concrete channels could be favoured by the damage in the walls and/or by the sediment deposits in the bottom (Ferreira *et al.*, 1999), since both processes could promote root anchorage. In most of the channels studied, both phenomena are rare and this could explain their scarcity. Also, the periodical cleaning of the channels might more easily eliminate the rooted vascular plants than the bryophytes, because of the larger size and visual impact of the former.

Vegetation structure and its dependence on environmental factors

The variations in both the morphology of the channels and the physicochemical characteristics of the water caused important changes in the vegetation structure of the different sampling sites. All the community variables (species richness, cover and diversity indices), except for H'1 (the bryophyte diversity calculated without considering the bare soil), were intercorrelated. This may imply that the diversity indices calculated including bare soil are more in line with the real structure of the communities and the site physiognomy, as derived from the data of cover and species richness. This also occurs in other vegetation types we have studied, such as bryophytes from flowing waters (Martínez Abaigar *et al.*, 1991) and shrublands (Núñez-Olivera *et al.*, 1995). In addition, this kind of diversity indices are better related to environmental factors (Martínez Abaigar *et al.*, 1991; Núñez-Olivera *et al.*, 1995; this study). However, the diversity indices calculated ignoring the bare soil are not correlated with cover and species richness in the studies previously carried out regarding bryophytes (Glime *et al.*, 1981; Slack & Glime, 1985). Thus, it would be advisable to further consider the bare soil in future studies on species diversity.

The differences found between the three diversity indices (H'1, H'2, and H'3) are rather clear. H'2 and H'1 are the moss diversity indices of the sites, calculated, respectively, with or without "bare soil" (areas with no bryophyte cover) as an additional variable or "species". H'3 is the macrophyte diversity index of the site, considering all the present macrophytes and also bare soil (strictly, areas with no macrophyte cover). H'3 is usually the highest diversity index, since it introduces new macrophyte species and bare soil, which had not been previously recorded in H'1 or H'2. However, H'1 is higher than H'3 in those sites where *Cladophora glomerata* or the bare soil act as highly dominant species, since the Shannon's diversity depends on both the number of species and the proportions of each one. H'1 is in most of the cases higher than H'2, since the latter introduces a dominant "species" (soil without bryophytes) in communities as open as those studied here. Thus, there is an inverse relationship between the values of the Shannon's diversity and the manifestation of dominance.

No comparative value of bryophyte diversity in irrigation channels exists in the literature, but, globally, the values found here are half of those recorded for streams (Glime & Vitt, 1987; Martínez Abaigar & Núñez Olivera, 1991; Slack & Glime, 1985). This was to be expected, since the streams are frequently bryophytedominated and the communities are more complex. However, the different sampling methods and sizes used in the cited works limit the reliability of the data comparison. Diversity values in irrigation channels seem to be comparable to those found in the lower course of rivers (Martínez Abaigar & Núñez Olivera, 1991), which might be systems ecologically more similar.

Our values of total species richness are much lower than those obtained in irrigation channels when microscopic algae are taken into account (Aboal *et al.*, 1996; Ferreira *et al.*, 1999), but more or less similar if they are ignored (1-13: Aboal *et al.*, 1996; Ferreira *et al.*, 1998; Shaltout *et al.*, 1994). Also, the site cover values are similar (5-100%: Ferreira *et al.*, 1998). Nevertheless, the comparison of the different data may be, again, controversial, since the sampling size and the characteristics of each particular system of irrigation channels are quite diverse. Also, none of these works considered bryophytes.

The higher diversity values found in the shade wall of the channels, with respect to those in the sun wall and the bed, were to be expected, since water loss is lowered and this benefits bryophyte growth. Also, all bryophytes show some shade-plant characteristics in their physiology (Proctor, 2000). Channel beds are rarely colonized by macrophytes, and only *Cladophora glomerata* grows frequently there (Aboal *et al.*, 1996; this study). However, plenty of microscopic algae may be common on bed deposits if the water flow is low (Aboal *et al.*, 1996; Ferreira *et al.*, 1999). The scarcity of macrophytes, especially of bryophytes and vascular plants, on the channel beds may be caused by the difficulties for establishment derived from the combination of substratum hardness, lack of fissures and stronger water flow and abrasion. Also, the shovels used for the periodical cleaning of the channels may scrape the vegetation more easily in the beds than in the walls.

The dependence of the vegetation structure and the species distribution on the environmental factors was tested by means of Pearson correlations and CCA. All the community variables (species richness, cover and diversity indices), except for H'1, were correlated with some environmental factors: negatively with the dryness period and positively with the water flow and velocity. High values of species richness, cover and diversity indices were found in the control-gates through which the river water enters the irrigation channels, and in the main channels nearby the river course. In these sites, the dryness period is virtually non-existent and the water flow and velocity are high. By contrast, low values of richness, cover and diversity (including bryophyte absence) are typical of those channels which are dry during most of the year. This emphasizes the crucial importance of water availability in the development of vegetation in the irrigation channels, either considering the bryophytes alone or all the macrophytes. In terrestrial environments, a gradient in cover and diversity has also been identified depending on the water availability (Núñez-Olivera *et al.*, 1995).

Other factors that may affect macrophytes in general, but not particularly bryophytes, are the channel width and the water depth. This could be related to the fact that *Cladophora glomerata*, the most frequent and abundant macrophyte species, has always been found completely submerged.

The CCA ordination diagram (Fig. 4) shows the relationships among the 19 mosses found, the 17 channels in which they grow and the eight selected environmental variables used in the analysis. The CCA rather confirms the factors emphasized by Pearson correlations. A higher water availability, which was found in the wide channels with rapid waters, a negligible dryness period and a relatively low water conductivity (the four main control-gates located at higher altitudes), promoted the development of some typically aquatic mosses (*Cratoneuron fil-*

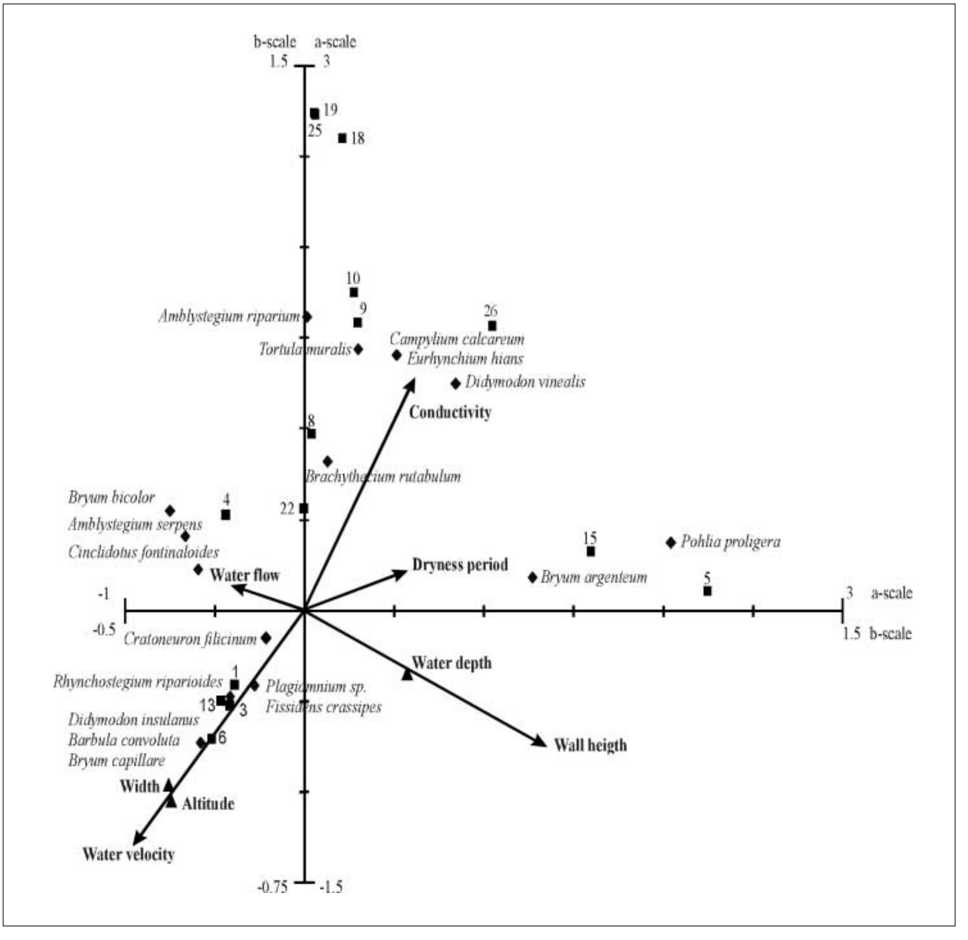

Fig. 4. Species-environment biplots for axes 1 (horizontal) and 2 (vertical) of the canonical correspondence analysis (CCA) for mosses. Moss cover was used in the analysis. The most significant environmental variables are shown as vectors, the associated ones as black triangles, sampling points (see Tab. 1) as black squares and moss species as black diamonds. The a-scale applies to the environmental vectors and the b-scale to the species and sampling points. One rare species (*Bryum barnesii*) and two sampling points (12 and 23) are not shown since they lie outside the range of this diagram.

icinum, *Rynchostegium riparioides* and *Fissidens crassipes*). In waters with higher conductivity and slower current velocity, which may be found in small terminal channels, *Amblystegium riparium* is important. Several non-aquatic species that grow typically on soil or stone may appear nearby the aquatic ones in the CCA diagram, since they benefit from particular microenvironments not directly related to irrigation channels. Thus, the location of non-aquatic species within the CCA diagram must be taken cautiously, since it may be influenced by factors not considered in this study.

The main differences between the CCA and the analysis of Pearson correlations have to do with the different importance paid to two environmental factors: 1) the dryness period, which is a relevant factor determining the vegetation structure in the analysis of Pearson correlations but not in the CCA; however, dryness period is indicative of water availability, which in turn is emphasized in the CCA by other variables, such as water velocity; and 2) the water conductivity, which is important in the CCA but not in the analysis of Pearson correlations; it seems to be a factor of a secondary importance in our study, although it is decisive in the determination of vegetation structure when a wider gradient than ours is found, either in streams (Martínez Abaigar & Núñez Olivera, 1991) or in other systems of irrigation channels (Ferreira *et al.*, 1998). Other environmental variables, such as pH and temperature, which are crucial in the abundance and distribution of the aquatic bryophytes in streams (Martínez Abaigar & Núñez Olivera, 1991; Slack & Glime, 1985; Stephenson *et al.*, 1995), are negligible in irrigation channel systems, probably due to their relative homogeneity (Ferreira *et al.*, 1999; this study).

Finally, our sampling campaign does not allow us to properly evaluate the effect of the periodical cleaning of the channels on the vegetation structure, since no comparison of the communities before and after cleaning the channels was done. We suppose that cleaning might have no dramatic effect on bryophytes, since their tight attachment to the substratum might allow them not to be scraped, but this point needs further investigation.

CONCLUSION

Irrigation channels may be harsh environments for the development of bryophytes and, perhaps, of most macrophytes. Some adverse factors are the periodic fluctuations in the water level, the complete dryness which some channels may exhibit, the water pollution by minerals or organic matter, and the vegetation cleaning carried out by farmers. Hence, the bryophyte assemblages in irrigation channels have relatively low values of species richness, cover and diversity as compared with those inhabiting more favourable habitats for aquatic bryophytes, such as mountain streams. In addition, most bryophytes have low frequencies and this scarcity may condition the interpretation of the ordination analyses, since their ecological behaviour in the channels is difficult to relate to the environmental factors considered. Only some aquatic or semi-aquatic species can tolerate the adverse factors cited above and may survive especially in refuge sites, such as the main entrances of water from the river course, in which water is more abundant, more continuously supplied and less polluted. These species are *Amblystegium riparium* (which can also tolerate harder and more polluted waters), *Cratoneuron filicinum* and *Rhynchostegium riparioides*. Although the bryophytes are the macrophyte group which shows the highest number of species (19) in the irrigation channel system studied, their importance is secondary outside those refuge sites. The unique alga found (*Cladophora glomerata*) is certainly the most characteristic macrophyte, since it is the most frequent and abundant one, whereas vascular plants are less relevant than bryophytes.

Irrigation channels are ecosystems poorly known from an ecological point of view, especially regarding bryophytes. Each system of channels may have unique environmental conditions (morphology, physicochemistry, supply of water, cleaning programme) that affect vegetation in a particular manner. Also, within each system, the environmental conditions in the different channels and throughout the year may not produce gradients enough to significantly affect the vegetation structure and the species distribution. A much wider spatial sampling would be needed, including different channel types and systems, to analyse the ecological requirements of the different species and communities. Until then, the role of bryophytes as bioindicators of the water quality in irrigation channels is largely guesswork, apart from the recognized preferences of certain species for waters enriched in minerals, nutrients or organic matter.

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