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Do environmental stream classifications support flow assessments in Mediterranean basins?

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Abstract

Natural flow regimes are of primary interest in designing environmental flows and therefore essential for water management and planning. The present study discriminated natural hydrologic variation using two different environmental classifications (REC-Segura and WFD-ecotypes) and tested their agreement with an *a posteriori* (hydrologic) classification in a Spanish Mediterranean basin (the Segura River, SE Spain). The REC-Segura was developed as a two-level hierarchical classification based on environmental variables that influence hydrology (climate and source-of-flow). The WFD-ecotypes were developed by the Spanish Ministry for the Environment to implement the Water Framework Directive (WFD) using hierarchical hydrologic, morphologic and physicochemical variables. The climate level in the REC-Segura broadly described the hydrologic pattern observed along the NW-SE aridity gradient of the basin. However, source-of-flow (defined by karstic geology) was only able to discriminate variation in flow regimes within one climatic category. The WFD-ecotypes, despite incorporating hydrologic variables, did not fully discriminate hydrologic variation in the basin. Ecotypes in tributary streams located in dry or semiarid climates embrace different flow regimes (both perennial and intermittent). There was little agreement between environmental and hydrologic classifications. Therefore, the authors advise against the use of environmental classifications for the assessment of environmental flows without first testing their ability to discriminate hydrologic patterns.

Keywords: *Mediterranean rivers; stream classification; environmental flows; Water Framework Directive; ecotypes*

1 Introduction

Characterising stream flows is of prime interest for water resource planning and management as well as for ecohydrologic studies. Many authors have emphasised the need to classify flow regimes at the regional scale to provide typologies that can support the assessment of environmental flows (Arthington et al. 2006; Poff et al. 2006). Hydrologic classification constitutes the first step of a new holistic framework intended to develop regional environmental flow criteria called the “Ecological Limits of Hydrologic Alteration (ELOHA)” (Poff et al. 2006), where the unaltered hydrology of rivers and streams constitutes the basis for assessing the effects of flow alteration and estimating environmental flows. However, the utility of different river classification systems is still being evaluated (Leathwick et al. 2011; Olden et al. 2011).

There are two basic approaches used to classify rivers according to their natural regimes (Olden et al. 2011): (1) inductive, or *a posteriori,* and (2) deductive, or *a priori*. The *a posteriori* (hydrologic) approach involves analysing at least 15 (Kennard et al. 2010) or

20 (Richter et al. 1997) years of hydrologic records. Flow series may be obtained from gauging stations or inferred from precipitation-runoff models (Poff et al. 2010; Olden et al. 2011) in order to calculate hydrologic metrics, such as the "Indicators of Hydrologic Alteration" (Mathews and Richter 2007; Richter et al. 1996), that allow clustering rivers and streams according to their similarity in flow regime. This procedure has been applied at different resolutions, from catchments in Mediterranean areas (Alcazar and Palau 2010; Baeza and Garcia de Jalon 2005; Bejarano et al. 2010; Belmar et al. 2011) to countries such as the USA (Mcnamay et al. 2011; Poff 1996), France (Snelder et al. 2009) and Australia (Kennard et al. 2010).

The *a priori* approach describes and quantifies spatial variation in flow regime attributes across broad spatial scales where the availability of measured (gauged) or modelled hydrologic data is scarce or absent. It embraces three different methodologies (Olden el al. 2011): environmental regionalisation, hydrologic regionalisation and environmental classification. For environmental regionalisation, specific regions are considered homogeneous with respect to certain environmental and hydrologic characteristics at a particular scale (Bryce and Clarke, 1996; Loveland and Merchant, 2004). However, hydrologic regionalisation delineates geographic areas with similar streamflow patterns, uses regression to relate environmental catchment characteristics to hydrologic metrics and assesses model reliability (for an example of a methodological proposal, see Tsakiris et al. 2011). Finally, environmental classification defines classes on the basis of physical and climatic attributes that are assumed to broadly produce similar hydrologic responses in stream systems, often geographically independent and depicted by a spatial mosaic of hydrologic types across the landscape (Detenbeck et al. 2000).

The River Environment Classification (REC; Snelder and Biggs 2002) has been a landmark for stream environmental classifications. Originally applied in New Zealand, it has also been applied in Chile (Peredo-Parada et al. 2011). Moreover, its ability to detect variations in hydrologic characteristics (Snelder et al. 2005), invertebrate assemblages (Snelder et al. 2004a) and nutrient concentrations (Snelder et al. 2004b) has been demonstrated. The REC is based on a hierarchical scheme of controlling factors (or classification levels) that are assumed to be the dominant causes of variation in the physical and biological characteristics of rivers at a variety of spatial scales. Therefore, different classification solutions are possible using the same schema of controlling factors, with the choice of level depending upon the objective. In particular, the first and second levels, “climate” and “source-of-flow” respectively, were those used to discriminate rivers according to their differences in flow regime (Snelder et al. 2005).

The Water Framework Directive (WFD) proposed two river classification systems (A and B, Annex II) to provide a basis for managing aquatic ecosystems. In Spain, water legislation (ORDER *ARM/2656/2008*, Ministry for the Environment) includes an environmental classification (WFD-ecotypes) based on the system B, which was developed for river segments considered as management units (i.e those where the definition of environmental flow regimes is mandatory). This hierarchical classification uses seven environmental variables: two hydrologic (annual specific runoff and discharge), three morphologic (mean slope and altitude of the watershed, and stream order) and two physicochemical (mean annual temperature and estimated water conductivity); however, it has not been hydrologically evaluated for use in assessing environmental flows.

In this study, the ability to discriminate the natural hydrologic variation of the rivers and streams in a Spanish Mediterranean basin (the Segura River) by two environmental classifications (REC-Segura, based on the REC, and WFD-ecotypes) and their agreement with an *a posteriori* (hydrologic) classification were tested. This study will provide researchers and water managers with useful information regarding if (1) environmental classifications can be used as surrogates of hydrologic methodologies to discriminate distinct natural flow regimes and (2) WFD-ecotypes are management units suitable for defining environmental flows.

2 Methods

2.1 Study area

Located in south eastern Spain, the management area of the Segura River basin (which includes coastal watercourses draining to the Mediterranean Sea) presents a great heterogeneity of flow regimes (Belmar et al. 2011). Despite its small size (18 870 km^2), there is a strong climatic and altitudinal gradient from NW to SE. The climate ranges from wet (>1000 mm mean annual precipitation) and cold in the mountains (>1000 masl) of the NW to semiarid (<350 mm mean annual precipitation) in the SE lowlands

(200 mm precipitation near the coast). Mean annual temperatures range between 10 and 18 ºC (CHS 2007). The lithology of the plains is characterised by limestone and marls with some volcanic areas, whereas calcites and dolomites dominate the mountain headwaters.

Seven out of the thirty-two WFD-ecotypes defined in Spain are present in the Segura Basin (Fig. 1): mineralised Mediterranean lowland streams (ecotype 7), mineralised Mediterranean low mountain streams (ecotype 9), Mediterranean limestone mountain streams (ecotype 12), highly mineralised Mediterranean streams (ecotype 13), low altitude Mediterranean mainstems (ecotype 14), mineralised Mediterranean-continental mainstems (ecotype 16) and large Mediterranean mainstems (ecotype 17).

An *a posteriori* classification based on hydrologic metrics (Belmar et al. 2011) defined distinct natural flow regime classes in the Segura Basin along the stated aridity gradient. The southeast was characterised by intermittent or ephemeral flow regimes with zero-flows for more than 20% and 50% of the year, respectively, and high peaks in autumn associated with typical torrential rains. At the opposite extreme, in the northwest, larger and more stable flows with a soft decrease in summer were found. Rivers in intermediate areas presented bimodal hydrographs, due to seasonal spring and autumn rains, and medium intra- and inter-annual flow variability.

2.2 Hydrologic basis

The hydrologic network defined in Belmar et al. (2011) (in which all streams have a minimum drainage area of 10 km^2) and its associated hydrologic information were used as a baseline to characterise the hydrologic properties of the rivers and streams in the Segura Basin. A summary of the hydrologic methodologies used by the authors is presented below (for further details, see Belmar et al. 2011).

First, due to the lack of suitable gauged flow data, natural monthly flows were generated for the period 1980/81-2005/06 using the ‘‘Integrated System for Rainfall–Runoff Modelling” (SIMPA), developed by the Centre for Hydrographical Studies (Ministry for the Environment, Spain). Second, 73 monthly and annual hydrologic indices were calculated. These metrics, based on the “Indicators of Hydrologic Alteration” (Mathews and Richter 2007; Richter et al. 1996) among others (Monk et al. 2006; Monk et al.

2007; Olden and Poff 2003), included measures of flow magnitude (central tendency and dispersion) and drought duration. Third, a Principal Component Analysis (PCA) performed using the PC-ORD software (v 4.41; McCune and Mefford 1999) summarised this hydrological information. The PCA scores of the first three axes, which explained 85% of variance, were weighed by the proportion of variance explained by each and selected as a set of new synthetic, non-intercorrelated hydrologic variables. Finally, a flexible-β clustering technique (Legendre and Legendre 1998; McCune and Grace 2002) grouped streams according to their similarity of natural flow regime using Euclidean distances.

In the present study, this hydrologic classification (Belmar et al. 2011) was pruned to obtain versions with the same number of classes as each environmental classification, which allowed their agreement to be tested.

2.3 REC-Segura classification

The present study's environmental classification (REC-Segura) was built using an approach similar to that applied in New Zealand for the River Environment Classification (Snelder et al. 2005; Snelder and Biggs 2002): two hierarchical levels to discriminate rivers according to their differences in flow regime. Categories were assessed for each stream by spatial integration of variables across its watershed using a Geographic Information System (GIS).

The first level (climate) comprised categories based on the magnitude and seasonality of precipitation, which has already showed behaviour analogous to that of streamflows in close Mediterranean basins (Nalbantis and Tsakiris 2009). Temperature was discarded due to its strong correlation (Spearman Rank Correlation: -0.86, $p = 0.000$) with precipitation. Mean monthly watershed precipitation was estimated for all nodes from a 1 km grid map created by the Spanish Ministry for the Environment by means of an interpolation using data from the Spanish weather station network. Precipitation categories were based on those in Rivas-Martinez (1983): semiarid, dry and subwet (Table 1). Seasonality was estimated using the Precipitation Concentration Index (PCI; Oliver 1980) calculated for October, as recommended by Pascual et al. (2001), assuming that most precipitation occurs during this month in streams belonging to torrential basins. Three categories were defined: moderately seasonal, seasonal and strongly seasonal (Table 1), based on critical values used by Michiels and Gabriels (1996). Within each climate class, flow regimes were expected to have a pattern similar to the precipitation regime, with maximum mean monthly flows in rainy seasons (autumn, winter or spring) and minimum mean monthly flows in summer.

The second level (source-of-flow) was based on karstic geology due to its effect on ground water storage capacity and transmissivity, and therefore, its major influence on base flow (Snelder and Biggs 2002). Gárfias-Soliz et al. (2010) pointed out the necessity of taking into account the degree of karstification in *a priori* classifications. In this context, karstic areas were expected to discriminate subtle differences related to the magnitude of flows and their seasonal variation. Using Spain's Map of Karst 1:1.000.000 developed by the *Instituto Geológico Minero de España* (IGME), two subclasses based on the dominancy of karstic geology in the watershed, ≥50% surface and <50% respectively, were defined for each climate class (Table 1).

2.4 Hydrologic discrimination by environmental classifications

The discrimination of hydrologic variation by the REC-Segura, both at climate and source-of-flow levels, as well as by the WFD-ecotypes was tested by means of a non-parametric Multiple Analysis of Variances (PERMANOVA), using the three new synthetic, non-intercorrelated hydrologic variables from the PCA (Belmar et al. 2011). PERMANOVA analyses were performed using PRIMER (v. 6.1.12; Clarke and Gorley 2006).

2.5 Agreement between environmental and hydrologic classifications

The environmental classifications were compared with hydrologic classifications with the same number of classes through the adjusted Rand index (ARI; Hubert and Arabie 1985). This index, a measure of cluster agreement (Steinley 2004), is based on the relationship of each pair of objects and whether they differ between two cluster solutions. It ranges between 0 (indicating that agreement between two clustering solutions is no better than chance) and 1 (indicating perfect agreement). ARI was calculated with the mclust (v. 3.4.8.) package for R (Fraley and Raftery 2010).

3 Results

3.1 REC-Segura classification

At the first level (climate), the REC-Segura split up the streams and rivers in the Segura Basin into all of the defined classes (Table 1). As expected, there was a match between the geographical distribution of these classes (Fig. 2a) and the increasing aridity gradient from NW to SE reflected by the modelled flows. Moderately seasonal subwet streams (class 1) were composed of upper river segments of the Segura and Mundo rivers which never cease flowing (Fig. 3). Moderately seasonal dry streams (class 2) presented the highest average mean annual flow and also the widest range of values, as they include both the bottom half of the Segura River and some of its tributaries, located mainly on the right bank. Seasonal dry (class 3), moderately seasonal semiarid (class 4), seasonal semiarid (class 5), and strongly seasonal semiarid (class 6) streams represent a gradient of increasing temporality as zero-flow duration increases. These classes were composed of tributaries with inter- and intra-annual coefficients of variation greater than those of classes 1 and 2 and bimodal hydrographs with strong flow peaks in winter and spring. Only class 6 showed a different hydrograph, with flows mainly associated to storm events.

The second classification level (source-of-flow) defined 11 subclasses (Fig. 2b) out of the 12 possible, because there were no karstic geologic materials in seasonal dry areas.

3.2 Discrimination of flow regimes by the REC-Segura

PERMANOVA pair-wise comparisons showed significant hydrologic differences ($p<0.05$) among most REC-Segura climate classes (Table 2a). However, moderately seasonal semiarid streams (class 4) were not different from moderately seasonal subwet (class 1), moderately seasonal dry (class 2) and strongly seasonal semiarid (class 6) streams. In addition, seasonal dry (class 3) and seasonal semiarid (class 5) streams were not different from each other.

Only the moderately seasonal dry streams (class 2) presented hydrologic differences in karstic areas (Table 2b), showing a softer seasonality (Fig. 4).

3.3 Discrimination of flow regimes by the WFD-ecotypes

PERMANOVA pair-wise comparisons indicated significant hydrologic differences ($p \leq 0.006$) among Mediterranean limestone mountain streams (ecotype 12), low altitude Mediterranean mainstems (ecotype 14), mineralised Mediterranean-continental mainstems (ecotype 16) and large Mediterranean mainstems (ecotype 17) (Table 3). However, there were not significant differences among mineralised Mediterranean lowland streams (ecotype 7), mineralised Mediterranean low mountain streams (ecotype 9) and highly mineralised Mediterranean streams (ecotype 13).

Mediterranean limestone mountain streams (ecotype 12) include highly karstic headwaters located in the upper sector of the Segura Basin characterised by low average mean annual flow and moderate peak flows in winter (Fig. 5). Low altitude Mediterranean mainstems (ecotype 14), mineralised Mediterranean-continental mainstems (ecotype 16) and large Mediterranean mainstems (ecotype 17) comprise perennial sections of the Segura River that differ in flow magnitude, and increases downstream. These ecotypes are characterised by large flows in the winter-spring period and moderate intra- and inter-annual coefficients of variation (Fig. 5). However, mineralised Mediterranean lowland streams (ecotype 7), mineralised Mediterranean low mountain streams (ecotype 9) and highly mineralised Mediterranean streams (ecotype 13), all located in the medium and low (dry and semiarid) sectors of the Segura Basin, presented greater zero-flow duration and inter-annual variation as well as bimodal hydrographs with peak flows in autumn and spring.

3.4 Agreement among classifications

Little agreement was found between environmental and hydrologic classifications. The adjusted Rand Index (ARI) was 0.09 and 0.1, respectively, for the 1st (climate) and 2nd (source-of-flow) levels of the REC-Segura, whereas the WFD-ecotypes presented a value of 0.1.

4 Discussion

The ability to infer hydrologic variation for river sections where unimpaired flow data are not available is an important issue for water management and planning in Mediterranean rivers, in general, and for developing environmental flow rules, in particular. If environmental classifications were able to discriminate the key attributes of the natural flow regime, they could define regional management units (*sensu* Arthington et al. 2006). These classifications would then be useful for extrapolating hydrologic information from streams in the same class (i.e. from gauged to ungauged streams) and designing environmental flows (Snelder et al. 2005). However, their hydrologic performance in our study area, as well as that of another *a priori* approach such as the environmental regionalisation in other temperate areas (Deckers et al. 2010), was not enough.

The agreement between the REC-Segura and the hydrologic classification was very low. Although the first level (climate) broadly matched the NW-SE pattern of hydrologic variation in the Segura Basin, seasonal dry (class 3), moderately seasonal semiarid (class 4), and seasonal semiarid (class 5) streams did not discriminate hydrologic variation, because dry and semiarid areas presented both perennial and intermittent flow regimes. The second level (source-of-flow) only increased performance slightly. The poor discrimination of karstic geology could be due to the homogeneity of the materials (calcites and dolomites in the subwet sector and marls in the semiarid sector) or the resolution of the information available. Therefore, further improvements in our ability to explain and predict hydrologic variation may also be achieved by undertaking these analyses at finer spatial scales (Sanborn and Bledsoe 2006; Stein et al. 2008), as well as considering other factors. Winter (2001) stated that flow regime varies geographically in response to climate (precipitation and temperature), topography, geology, land cover and stream order. All of these factors are present in the REC (Snelder and Biggs 2002), but those factors not considered in this study (land cover and stream order) occupy low hierarchical levels (the forth and fifth, respectively) and were not described as “hydrology drivers” by the author (Snelder et al. 2005; Snelder & Biggs 2002). However, Peredo-Parada et al. (2011) found that the use of stream order in the REC for Chilean rivers improved results. These different outcomes prove that environmental variables do not necessarily reflect only hydrologic variation, which is in accordance with our results, because they usually encompass more general principles concerning the causes of physical variation in streams and rivers (Carlisle et al. 2010; Snelder et al. 2005), instead of direct hydrologic measures, and exclude significant local (e. g. reach-scale) factors. In any case, the use of land cover, in recognition of the importance of vegetation controlling evapotranspiration and infiltration (Peel et al. 2001), was not possible in the study area due to the impossibility of accessing this information under natural conditions.

Even considering two hydrologic variables (the annual runoff coefficient and mean annual discharge), the WFD-ecotypes did not fully discriminate the variability of flow regimes in the basin. Hydrologic differences were found in four out of the seven analysed ecotypes. Therefore, attributing the same hydrologic reference to ecotypes in dry or semiarid areas (mineralised Mediterranean lowland streams, mineralised Mediterranean low mountain streams and highly mineralised Mediterranean streams; ecotypes 7, 9 and 13, respectively), where perennial and temporary regimes coexist, could lead to the definition of erroneous environmental flow regimes. The low performance of the WFD-ecotypes was not surprising, as this classification does not take into account the variability of flows or the extent of droughts, giving more importance to the altitude and degree of mineralisation.

In conclusion, although the REC-Segura classes and the WFD-ecotypes were able to detect statistically significant differences in hydrologic regimes, they showed limited discrimination of hydrologic variability and little agreement with the hydrologic classification. Therefore, caution is recommended in the use of environmental classifications for assessing environmental flows in the Segura Basin, as well as in other Mediterranean basins with similar hydrologic characteristics. More systematic methods are needed to validate and improve these classifications (Loveland and Merchant 2004), as they still present uncertainty in the choice of hydrologic drivers. In this context, the use of new emergent techniques, such as generalised dissimilarity modelling (GDM), may optimise the ability to discriminate patterns using parallel sets of data (for a biological example, see Leathwick et al. 2011).

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Table 1. Levels, classes and criteria used to construct the REC-Segura

Classification level	Classes	Mapping characteristics	Category Assignment Criteria
1. Climate	1. Moderately Seasonal Subwet	Mean annual precipitation and Precipitation Concentration Index (PCI) for October	Subwet: Mean annual precipitation ≥ 600 mm
	2. Moderately Seasonal Dry		Dry: Mean annual precipitation = 350 - 600 mm
	3. Seasonal Dry		Semiarid: Mean annual precipitation = 200 - 350 mm
	4. Moderately Seasonal Semiarid		Strongly Seasonal: Precipitation Concentration Index for October ≥ 20
	5. Seasonal Semiarid		Seasonal: Precipitation Concentration Index for October = 15 -19
	6. Strongly Seasonal Semiarid		Moderately Seasonal: Precipitation Concentration Index for October = 10 -14
2. Source-of-flow	1. Non karstic	Percentage of karstic surface in the basin	Non karstic: Percentage of karstic surface ≤ 50 %
(geology)	2. Karstic		Karstic: Percentage of karstic surface > 50 %

Table 2. PERMANOVA results (bold text when $p < 0.05$) showing hydrologic differences among pairs of REC-Segura classes at the first (a) and second (b) hierarchical level of classification. Classes are numbered as shown in Table 1. Note that, for the second level, two digits show the class both for the first (climate) and the second (source-of-flow) levels, respectively.

a) Classes	t	P
1, 3	**5.962**	**0.001**
1, 5	**6.717**	**0.001**
1, 6	**4.378**	**0.001**
2, 1	**3.238**	**0.001**
2, 3	**4.562**	**0.001**
2, 5	**5.263**	**0.001**
2, 6	**2.792**	**0.001**
3, 6	**3.198**	**0.002**
4, 1	1.596	0.076
4, 2	1.098	0.293
4, 3	**2.582**	**0.007**
4, 5	**1.915**	**0.037**
4, 6	1.355	0.152
5, 3	0.599	0.640
5, 6	**2.755**	**0.005**

b) Classes	t	P
11, 12	1.391	0.141
21, 22	**2.505**	**0.003**
31, 32	1.119	0.227
41, 42	-	-
51, 52	0.967	0.357
61, 62	0.721	0.530

Table 3. PERMANOVA results showing hydrologic differences among pairs of ecotypes (bold text when $p<0.05$). Ecotypes have been labelled following the numeration established by the Ministry for the Environment: 7, mineralised Mediterranean lowland streams; 9, mineralised Mediterranean low mountain streams; 12, Mediterranean limestone mountain streams; 13, highly mineralised Mediterranean streams; 14, low altitude Mediterranean mainstems; 16, mineralised Mediterranean-continental mainstems; 17, large Mediterranean mainstems

Ecotypes	t	P
9, 7	1.007	0.297
9, 13	0.973	0.388
9, 14	**5.340**	**0.001**
9, 16	**5.132**	**0.001**
9, 17	**3.220**	**0.006**
12, 7	**2.866**	**0.001**
12, 9	**2.834**	**0.001**
12, 13	**3.015**	**0.003**
12, 14	**7.972**	**0.001**
12, 16	**7.871**	**0.001**
12, 17	**4.779**	**0.001**
13, 7	1.435	0.123
13, 14	**12.432**	**0.001**
13, 16	**11.785**	**0.001**
13, 17	**7.376**	**0.001**
14, 7	**11.792**	**0.001**
14, 17	**5.020**	**0.003**
16, 7	**10.527**	**0.001**
16, 14	**5.944**	**0.001**
16, 17	**4.416**	**0.001**
17, 7	**6.875**	**0.006**

Figure legends

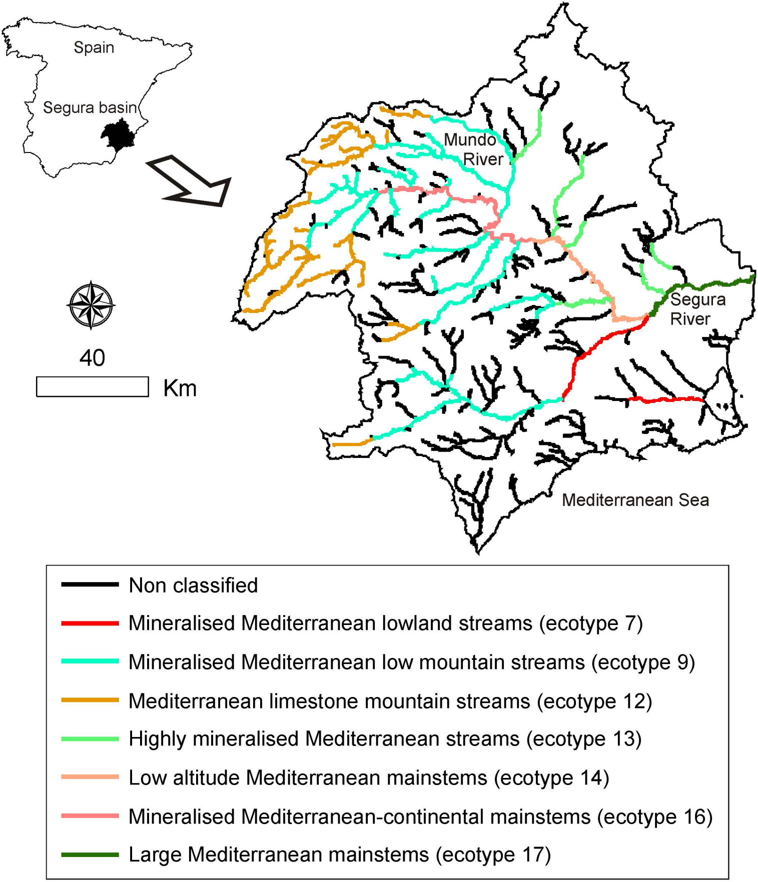
Fig. 1 Location of the Segura Basin and Mediterranean ecotypes present

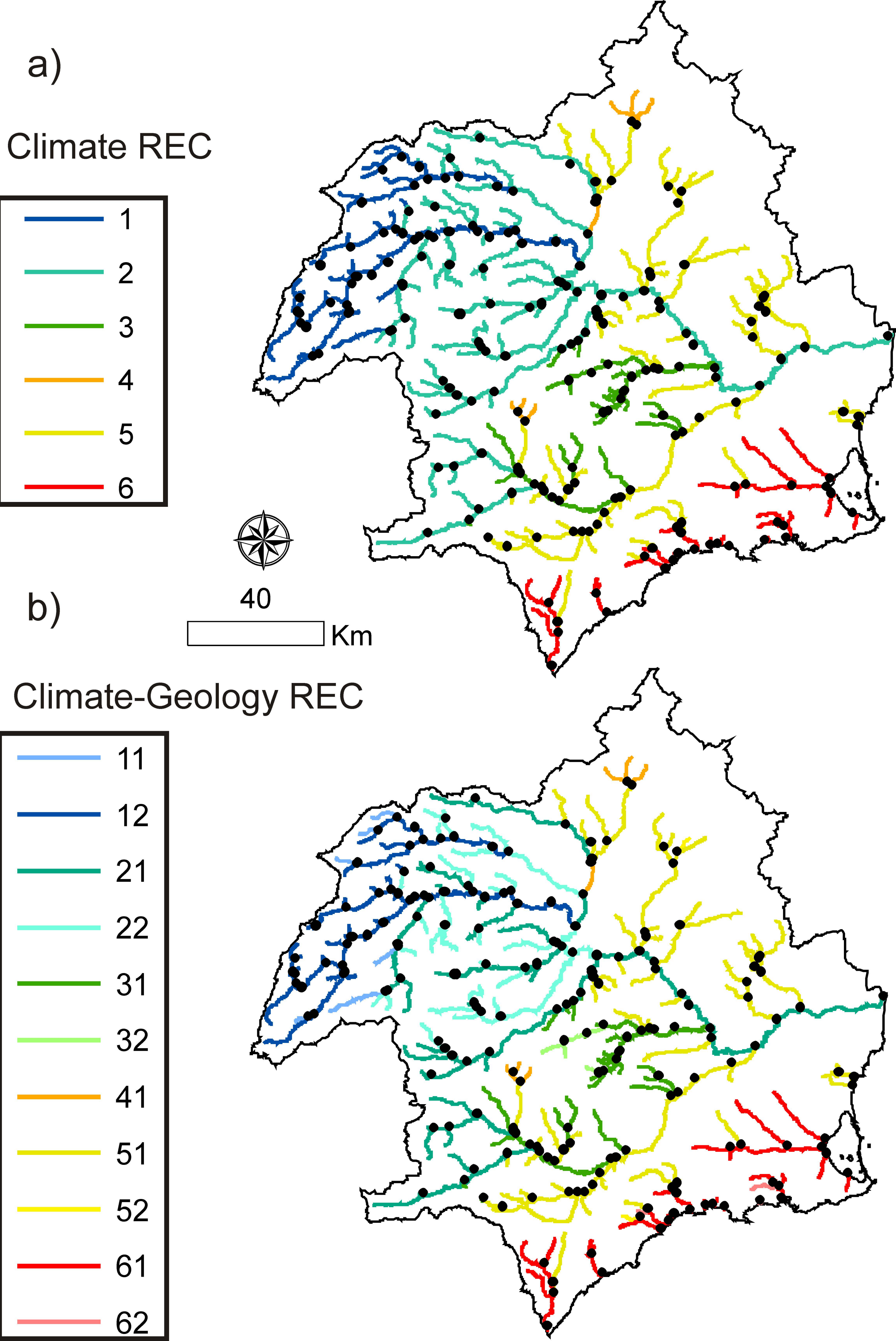
Fig. 2 REC-Segura classification at the first (a) and second (b) hierarchical level. Classes are numbered as shown in Table 1. Note that, for the second level, two digits show the class both for the first (climate) and second (source of flow) levels, respectively

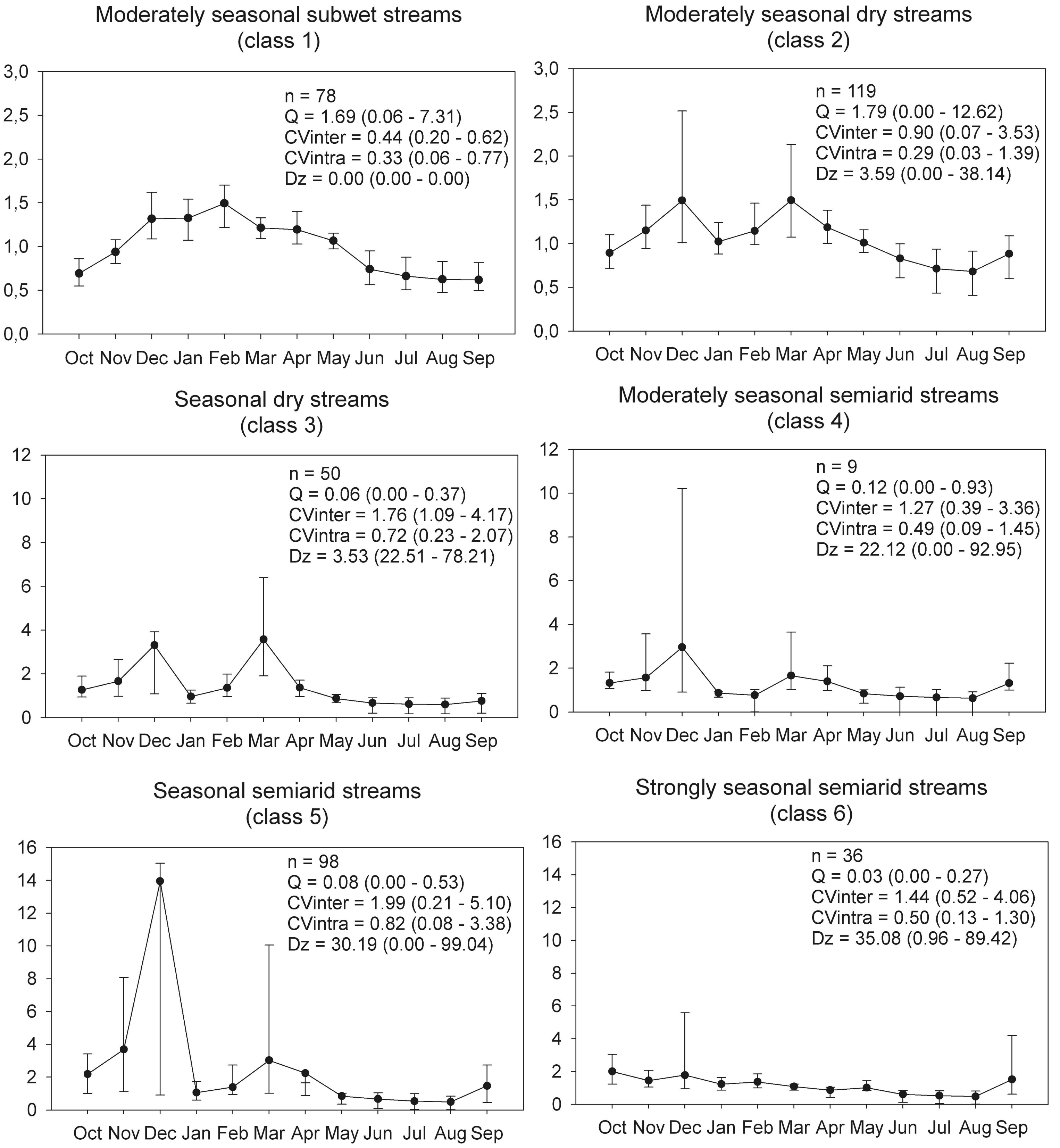
Fig. 3 Mean monthly flows divided by the median annual flows for the REC-Segura classes at the first hierarchical level (climate). The numeric values correspond to the average (out of the parentheses), minimum and maximum of the following variables: mean annual flow in $m^3 \cdot s^{-1}$ (Q), inter-annual coefficient of variation (CVinter), intra-annual coefficient of variation (CVintra) and duration of zero-flows in % (Dz)

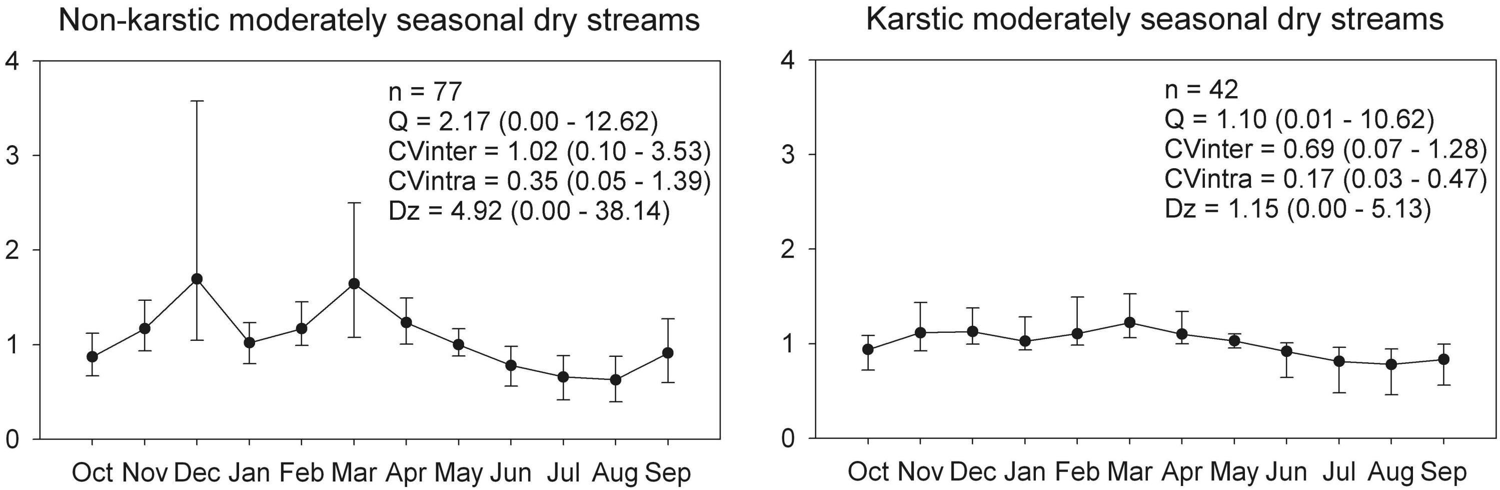
Fig. 4 Mean monthly flows divided by the median annual flows for non-karstic and karstic moderately seasonal dry streams. The numeric values correspond to the average (out of the parentheses), minimum and maximum of the following variables: mean annual flow in $m^3 \cdot s^{-1}$ (Q), inter-annual coefficient of variation (CVinter), intra-annual coefficient of variation (CVintra) and duration of zero-flows in % (Dz)

Fig. 5 Mean monthly flows divided by the median annual flows for the WFD-ecotypes. The numeric values correspond to the average (out of the parentheses), minimum and maximum of the following variables: mean annual flow in $m^3 \cdot s^{-1}$ (Q), inter-annual coefficient of variation (CVinter), intra-annual coefficient of variation (CVintra) and duration of zero-flows in % (Dz)


Spain
Segura basin
40
Km
Mundo River
Segura River
Mediterranean Sea
Non classified
Mineralised Mediterranean lowland streams (ecotype 7)
Mineralised Mediterranean low mountain streams (ecotype 9)
Mediterranean limestone mountain streams (ecotype 12)
Highly mineralised Mediterranean streams (ecotype 13)
Low altitude Mediterranean mainstems (ecotype 14)
Mineralised Mediterranean-continental mainstems (ecotype 16)
Large Mediterranean mainstems (ecotype 17)


a)
Climate REC
1
2
3
4
5
6
40
Km
b)
Climate-Geology REC
11
12
21
22
31
32
41
51
52
61
62

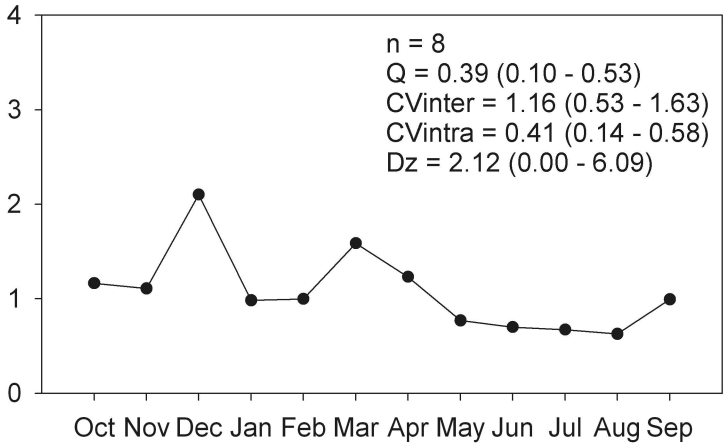

Moderately seasonal subwet streams
(class 1)
n = 78
Q = 1.69 (0.06 - 7.31)
CVinter = 0.44 (0.20 - 0.62)
CVintra = 0.33 (0.06 - 0.77)
Dz = 0.00 (0.00 - 0.00)
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
Moderately seasonal dry streams
(class 2)
n = 119
Q = 1.79 (0.00 - 12.62)
CVinter = 0.90 (0.07 - 3.53)
CVintra = 0.29 (0.03 - 1.39)
Dz = 3.59 (0.00 - 38.14)
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
Seasonal dry streams
(class 3)
n = 50
Q = 0.06 (0.00 - 0.37)
CVinter = 1.76 (1.09 - 4.17)
CVintra = 0.72 (0.23 - 2.07)
Dz = 3.53 (22.51 - 78.21)
12
10
8
6
4
2
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
Moderately seasonal semiarid streams
(class 4)
n = 9
Q = 0.12 (0.00 - 0.93)
CVinter = 1.27 (0.39 - 3.36)
CVintra = 0.49 (0.09 - 1.45)
Dz = 22.12 (0.00 - 92.95)
12
10
8
6
4
2
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
Seasonal semiarid streams
(class 5)
n = 98
Q = 0.08 (0.00 - 0.53)
CVinter = 1.99 (0.21 - 5.10)
CVintra = 0.82 (0.08 - 3.38)
Dz = 30.19 (0.00 - 99.04)
16
14
12
10
8
6
4
2
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
Strongly seasonal semiarid streams
(class 6)
n = 36
Q = 0.03 (0.00 - 0.27)
CVinter = 1.44 (0.52 - 4.06)
CVintra = 0.50 (0.13 - 1.30)
Dz = 35.08 (0.96 - 89.42)
16
14
12
10
8
6
4
2
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep



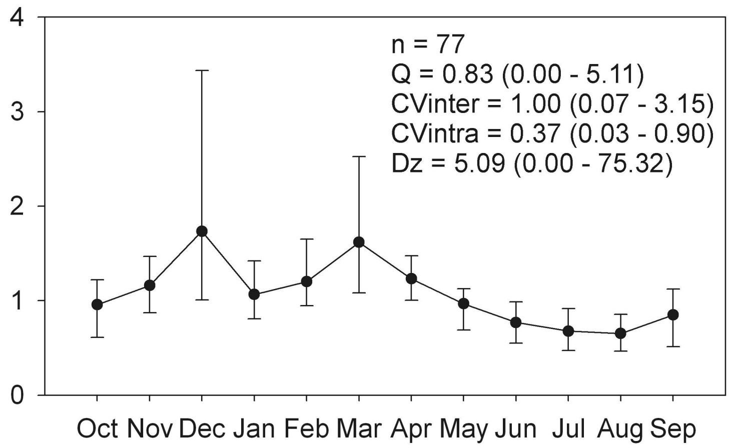
Non-karstic moderately seasonal dry streams

Karstic moderately seasonal dry streams

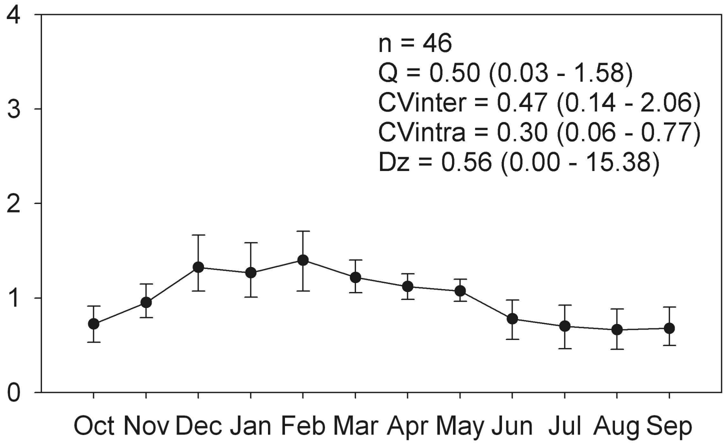
Mineralised Mediterranean lowland streams
(ecotype 7)



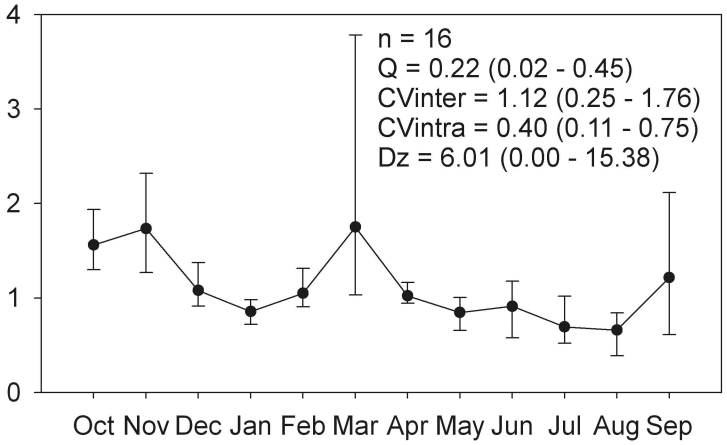
Mineralised Mediterranean low mountain streams
(ecotype 9)



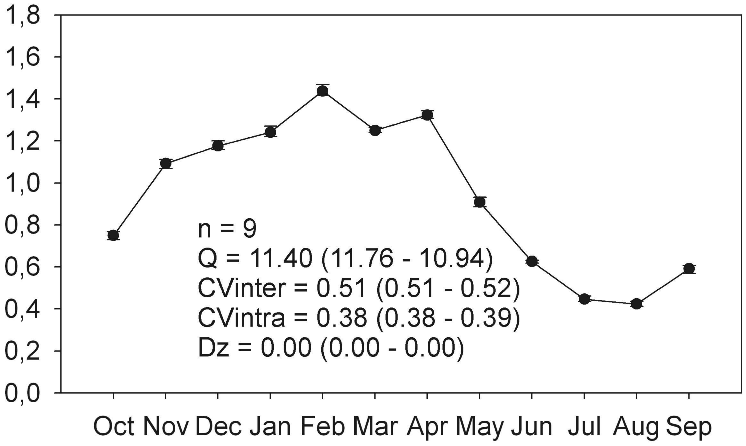
Mediterranean limestone mountain streams
(ecotype 12)



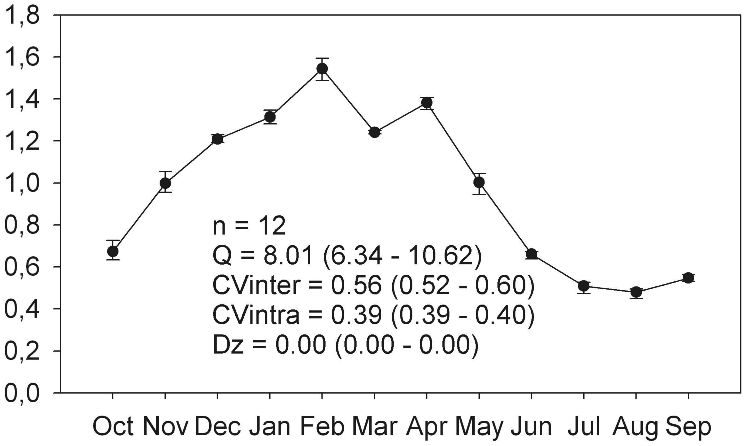
Highly mineralised Mediterranean streams
(ecotype 13)



Low altitude Mediterranean mainstems
(ecotype 14)



Mineralised Mediterranean-continental mainstems
(ecotype 16)



Large Mediterranean mainstems
(ecotype 17)