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The influence of natural flow regimes on macroinvertebrate assemblages in a semiarid Mediterranean basin

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<http://dx.doi.org/10.1002/eco.1274>

PUBLISHER

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VERSION

AM (Accepted Manuscript)

PUBLISHER STATEMENT

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REPOSITORY RECORD

Belmar, O., J. Velasco, C. Gutierrez-Canovas, A. Mellado-Diaz, A. Millan, and Paul J. Wood. 2019. "The Influence of Natural Flow Regimes on Macroinvertebrate Assemblages in a Semiarid Mediterranean Basin". figshare. <https://hdl.handle.net/2134/17358>.

Ecohydrology

The influence of natural flow regimes on macroinvertebrate assemblages in a semiarid Mediterranean basin.

Journal:	<i>Ecohydrology</i>
Manuscript ID:	ECO-11-0181.R1
Wiley - Manuscript type:	Research Article
Date Submitted by the Author:	10-Apr-2012
Complete List of Authors:	Belmar, Oscar; University of Murcia, Ecology and Hydrology Velasco, Josefa; University of Murcia, Ecology and Hydrology Gutierrez-Canovas, Cayetano; University of Murcia, Ecology and Hydrology Mellado, Andres; Centro de Estudios Hidrograficos CEDEX, Wood, Paul; Loughborough University, Geography;
Keywords:	natural flow regime, flow stability, minimum flows, macroinvertebrate composition, richness, Segura River Basin, semiarid Mediterranean streams

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The influence of natural flow regimes on macroinvertebrate assemblages in a semiarid Mediterranean basin.

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Abstract

The investigation of flow-ecology relationships constitutes the basis for the development of environmental flow criteria. The need to understand hydrology-ecology linkages in natural systems has increased due to the prospect of climate change and flow regime management, especially in water-scarce areas such as Mediterranean basins. Our research quantified the macroinvertebrate community response at family, genus and species level to natural flow regime dynamics in freshwater streams of a Mediterranean semiarid basin (Segura River, SE Spain), and identified the flow components that influence the composition and richness of biotic assemblages. Flow stability and minimum flows were the principal hydrological drivers of macroinvertebrate assemblages, whereas the magnitude of average and maximum flows had a limited effect. Perennial stable streams were characterised by flow sensitive lotic taxa (Ephemeroptera, Plecoptera, Tricoptera) and intermittent streams by predominately lentic taxa (Odonata, Coleoptera, Heteroptera and Diptera). Relatively minor biological changes were recorded for intermediate flow regime classes along a gradient of flow stability. Seasonal variation and minimum flows are key hydrological components that need to be considered for river management and environmental flows in the Segura River Basin and other Mediterranean basins. The anthropogenic modification of these parameters, due to both human activities and climate change, would probably lead to significant changes in the structure and composition of communities in perennial stable streams. This would be characterised by a reduction of flow sensitive EPT taxa and an increase in more resilient OCHD taxa.

Key words: natural flow regime, flow stability, minimum flows, macroinvertebrate composition, richness, Segura River Basin, semiarid Mediterranean streams

Introduction

The search for links between instream ecology and hydrology has become one of the fundamental issues in contemporary river science (Vaughan *et al.*, 2009). Empirical investigation of regional flow-ecology relationships constitutes the basis for the development of environmental flow (e-flow) criteria (Arthington *et al.*, 2006; Poff *et al.*, 2010). In addition, the need to understand ecology-hydrology linkages in natural systems has been highlighted by the need to define reference conditions against which

1 modified dynamics can be compared (Tockner *et al.*, 2003). These needs are
2 particularly pressing in the light of predicted climate change (European Environment
3 Agency, 2008) and anthropogenic modification of natural flow regimes, especially in
4 water-scarce areas such as Mediterranean basins.

5
6 Instream hydrological variability, encapsulating elements of the entire flow regime such
7 as the daily, seasonal and annual patterns of discharge, the frequency, timing,
8 predictability and duration of extreme flows (high and low), rates of change in
9 discharge, and the magnitude of flows, are widely recognised as key ecological
10 organizers in fluvial ecosystems (Richter *et al.*, 1996; Poff *et al.*, 1997; Hart and Finelli,
11 1999; Bunn and Arthington, 2002). Spatial variation of these characteristics is
12 determined by variations in climate and mediated by basin geology, topography and
13 vegetation (Winter, 2001). These hydrological and environmental factors influence the
14 physical habitat for aquatic and riparian biota determining the conditions for
15 reproduction and recruitment and affecting the availability of trophic resources, refuges
16 during adverse situations and opportunities for dispersal (Naiman *et al.*, 2008).
17 Consequently, flow variability has strong ecological implications which shape the
18 structure and function of riverine ecosystems from the local to regional scales, and from
19 days (ecological effects) to millennia (evolutionary effects) (Lytle and Poff, 2004). It
20 has been hypothesised that sites with similar hydrological characteristics should share
21 similar faunal community composition, traits and ecosystem functioning (Poff and
22 Ward, 1989). Therefore, as Arthington *et al.* (2006) and Poff *et al.* (2010) suggested,
23 ecological responses of flow regimes to a given anthropogenic change should be
24 broadly similar in rivers with similar natural flow regimes.

25
26 This hypothesis provides a powerful foundation to predict ecological responses to future
27 flow regime changes, constituting the key element of a new holistic framework for
28 developing scientifically-credible regional environmental flows: the ‘Ecological Limits
29 of Hydrologic Alteration’ (ELOHA) (Arthington *et al.*, 2006; Kennard *et al.*, 2010;
30 Poff *et al.*, 2010). Therefore, identifying and quantifying specific relationships between
31 flow regimes and biological communities in undisturbed river ecosystems are essential
32 steps to ensure sustainable river management (Arthington *et al.*, 2006; Jowett and
33 Biggs, 2009). Such relationships have been studied in general at the regional scale,
34 using macroinvertebrates (e.g. Monk *et al.*, 2006; Konrad *et al.*, 2008; Kennen *et al.*,

2010, Armanini *et al.*, 2011), fisheries (e.g Poff and Allan, 1995; Pegg and Pierce, 2002; Kennard *et al.*, 2007; Snelder *et al.*, 2009) or multiple taxonomic groups (e. g. Jowett and Duncan, 1990; Clausen and Biggs, 1997). However, the strength and nature of relationships between the flow regime and the biological assemblage vary depending on the geographical region, the floral or faunal group considered and the taxonomic resolution analysed.

In some areas, such as Mediterranean-climate regions, organisms have to withstand high intra and interannual hydrological variability, together with frequent natural flow extremes (floods and droughts) (Gasith and Resh, 1999). Species may respond over evolutionary time scales by developing morphological, physiological and/or life-history traits to bear such stresses (Poff *et al.*, 1997; Bonada *et al.*, 2007a; Bonada *et al.*, 2007b). Previous studies of Mediterranean streams (e. g. Bonada *et al.*, 2002; Jáimez-Cuéllar *et al.*, 2002; Vivas *et al.*, 2002; Bonada *et al.*, 2004; Mellado, 2005; Sanchez-Montoya *et al.*, 2007; Argyroudi *et al.*, 2009) as well as other semiarid areas (e. g. Boulton and Lake, 2008) have highlighted the importance of flow permanence on the composition and structure of macroinvertebrate communities. A progressive replacement of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa by Odonata, Coleoptera and Heteroptera (OCH) taxa has been reported as flow permanence decreases (Sánchez-Montoya *et al.*, 2007; Argyroudi *et al.*, 2009) or hydrological connectivity is reduced (Bonada *et al.*, 2006); although Diptera have also been associated with river sections with low or no flows and dominate lentic habitats in Southeast Spain (Vivas *et al.* 2002). Consequently, flow stability and hydrological extremes (especially low flows) are expected to be the most important components of Mediterranean flow regimes shaping instream assemblages, although its relative importance is still unclear.

The aim of this study was to quantify the effect of different flow regimes on macroinvertebrate communities. We utilised a dataset containing stream macroinvertebrate records at family, genus and species level across a semiarid Mediterranean region that encompasses a wide gradient of hydrological regimes (Belmar et al 2011) to test these predictions: (1) Flow stability and minimum flows should be the principal hydrological drivers of macroinvertebrate assemblage composition and richness; (2) an increase in the explanatory power of hydrology should

1 occur as taxonomic resolution increases; and (3) a replacement of taxa should take place
2 along a hydrological gradient from permanent streams with stable discharges to streams
3 with high flow intermittence and flow variability. In general, a decrease in the
4 percentage of flow sensitive Ephemeroptera, Plecoptera and Trichoptera families should
5 occur as an increase in the percentage of more resilient Odonata, Coleoptera,
6 Heteroptera and Diptera families takes place.

7
8 **Methods**

9 *Study area*

10 Located in the Southeast of Spain, the Segura River Basin drainage network, including
11 coastal watercourses draining to the Mediterranean Sea, was selected as the study area.
12 The management area of the Segura River Basin, one of the most arid zones of the
13 Mediterranean region, includes watercourses with highly heterogeneous flow regimes.
14 These water-bodies range from perennial rivers, with low seasonal and interannual flow
15 variability, to highly seasonal ephemeral streams (Belmar *et al.*, 2011). This variability
16 is due to a strong climatic and altitudinal gradient from NW to SE, despite its relatively
17 small size (18 870 km²). Climate ranges from wet (>1 000 mm mean annual
18 precipitation) and cold in the high elevation mountains of the NW (>1 000 m.a.s.l.) to
19 semiarid and hot in the SE lowlands (< 350 mm mean annual precipitation). Mean
20 annual temperatures range between 10 and 18 °C (CHS, 2007). The lithology of the
21 plains is characterised by limestone (karst) and Miocene and Triassic marls, with some
22 small influences of volcanic strata. In contrast, calcites and dolomites dominate the
23 mountainous headwaters. The vegetation is varied and ranges from Mediterranean
24 conifer forests in the NW mountains to arid and semi-arid shrublands in the SE
25 lowlands. This gradient in altitude and climate is coupled with an anthropogenic
26 population density gradient. The river network has low population densities in the
27 forested headwaters, intermediate densities in the agricultural midlands (with major
28 flow regulation) and highly populated cities in the lowlands (Mellado, 2005).
29 Agricultural (52.1%), forest and semi natural (45.2%), and artificial (2.1%) are the
30 dominant landuses in the Segura basin (estimated from Corine Land Cover 2000),
31 making the Segura River Basin one of the most regulated in Europe (Ministerio de
32 Medio Ambiente MMA, 2004). Water resource demands exceed 224% of that available
33 and only 4% of runoff reaches the mouth of the river (Zimmer, 2010). This has resulted
34 in over exploitation of the surface waters, an inter-basin transfer from the Tagus River

(a mean of $325 \text{ hm}^3 \text{ yr}^{-1}$), a mean groundwater extraction of around $478 \text{ hm}^3/\text{year}$ (over 80% of natural recharge) and a high regulatory capacity of 770 hm^3 (over 90% of the natural input) due to 24 dams over 10 m in height (Grindlay *et al.*, 2009; Grindlay *et al.*, 2011).

Hydrological data

A drainage network was derived from a 25 m digital elevation model (DEM) developed by the *Instituto Geológico Nacional* (IGN) and layers available from the website of the Spanish Ministry of Environment, using the ArcGIS software (v 9.2) and the ArcHydro extension (v 1.2) (ESRI, Redlands, California, U.S.A.). The network comprises sections that link each network junction or node, and each node was associated with its corresponding watershed (derived from the DEM). The minimum watershed area to define a river section was 10 km^2 , resulting a hydrological network with 390 river sections.

The hydrological classification developed for the Segura River Basin in Belmar *et al.* (2011) was used to define distinct natural hydrological regimes. This classification was developed using 73 indices based on the “Indicators of Hydrologic Alteration” (IHA) (Mathews and Richter, 2007). These flow indices represent a wide range of ecologically-relevant flow statistics (Richter *et al.*, 1996; Olden and Poff, 2003; Monk *et al.*, 2006; Mathews and Richter, 2007; Monk *et al.*, 2007) and comprise monthly and annual flow statistics including measures of duration of droughts as well as the central tendency and dispersion of flow magnitude (average, low and high flow conditions). Indices related to the frequency, duration and rate of change of high flow events were not used by Belmar *et al.* (2011) due to the absence of daily flow data. Natural flows were derived from a monthly rainfall-runoff model developed by the Centre for Hydrographic Studies (CEDEX, Ministry of Environment and Public Works, Spain), for the period 1980/81 – 2005/06. The classification of the flow regimes recorded comprised eight flow-regime classes (names are provided throughout to aid interpretation) principally characterised by the magnitude of mean annual flow, the duration of droughts and the interannual variation of flow (Table I). The resulting flow regimes can be placed into four broad hydrological groups: (1) mainstem rivers, with perennial flow thorough the year, low interannual variation and an average annual discharge greater than $10 \text{ m}^3/\text{s}$ (class 1, *large rivers*) or between 2 and $10 \text{ m}^3/\text{s}$ (class 2,

1 *medium rivers*); (2) perennial stable streams, which only difference respect to mainstem
2 rivers is their reduced average discharge, between 0.3 and 2 m³/s (class 3, *creeks*) or
3 lower than 0.3 m³/s (class 4, *headwater streams*); (3) perennial seasonal streams, which
4 eventually cease flowing (although perennial surface water persists) and with peak
5 discharges in winter (class 5, *winter peak flow seasonal streams*) or spring (class 6,
6 *spring peak flow seasonal streams*); and (4) temporary streams, including *intermittent*
7 *streams* (class 7), which do not flow for between 20% and 50% of the time, and
8 *ephemeral streams*, that do not experience flow for more than 50% of the time (class 8).
9 Indices and classes were assigned to their corresponding river section.

10
11 *Macroinvertebrate data*

12 Macroinvertebrate abundance data at family, genus and species level were compiled
13 from the *Biodiversidad* database (*Ecología Acuática* research group, Department of
14 Ecology and Hydrology, University of Murcia, Spain). Species data were available for
15 beetles (Coleoptera), which have been recorded in all kinds of water bodies in the
16 region and have been shown to be good indicators of aquatic biodiversity (Bilton *et al.*,
17 2006; Sanchez-Fernandez *et al.*, 2006). Samples had been taken along 100 m stream
18 transects using a kick-net (500 – 1000 µm) and following the multi-habitat protocol
19 (Jáimez-Cuéllar *et al.*, 2002). Baseline macroinvertebrate samples were collected
20 between 1980 and 2006.

21
22 A minimum of 5 samples per hydrological class were selected, ensuring that they had
23 been collected in freshwater streams (conductivity < 5 000 µS cm⁻¹), above water
24 regulation infrastructures (e.g., dams or weirs) and abstraction areas and in absence of
25 significant evidences of anthropogenic alteration. However, using the criteria above two
26 classes did not have any biological data: *large rivers* (class 1), due to the absence of
27 reference conditions, and *ephemeral streams* (class 8), where no sampling had been
28 undertaken due to their frequent dry status.

29
30 Every sample was collected during the spring or early summer from a different
31 sampling site (Figure 1). This time-period is considered the most representative of the
32 annual macroinvertebrate community composition in Mediterranean streams (Bonada *et al.*,
33 2009). Each site was paired with the closest downstream node in the drainage
34 network. In order to avoid pseudoreplication, when there was more than one site (and

sample) available for the same node, only the closest to the hydrological node was selected. The final dataset consisted of 35 samples associated with 83 macroinvertebrate families, and 133 genera, and 43 samples associated with 110 Coleoptera species (Appendix A).

Environmental data

Climatic, topographic and geologic variables that were assumed to control hydrological processes (Snelder *et al.*, 2005) were derived from different GIS layers available for the watershed. Average annual precipitation and air temperature were derived from 1 km grid maps created by the Spanish Ministry of Environment by means of interpolation using data from the Spanish weather stations network (Estrela *et al.*, 1999). Drainage area, mean altitude and slope were calculated using the IGN's digital elevation model (DEM). Geology was characterised by the percentage of karst area in each watershed and derived from the "Spain's Map of Karst" 1:1 000 000 developed by the *Instituto Geológico y Minero de España* (IGME) and, indirectly, through water conductivity (recorded for every biological sample). We hypothesised that the karstic surface would control groundwater storage and baseflow (Snelder and Biggs, 2002) and that higher conductivities would reflect the predominance of sedimentary marls that result in flashy hydrographs that reflect precipitation patterns (Bracken *et al.*, 2008).

Data analysis

A Principal Component Factor Analysis (PCFA) (i.e. a Principal Components Analysis (PCA) combined with a Varimax rotation) was used to examine dominant patterns of intercorrelation among the hydrological indices (Belmar *et al.* 2011) and to identify subsets of indices that describe the major sources of variation while minimizing redundancy (i.e. multicollinearity). The Varimax rotation allows obtaining a clearer pattern of loadings (indices clearly marked by high loadings for some axes and low loadings for others) and, therefore, a better interpretation of the meaning of each axis. The hydrological characteristics of each stream in the network were defined through the corresponding PCFA scores (hydrological components) and hydrological class.

Rare taxa (those collected at fewer than 5% of sampling sites) were removed for multivariate analyses. Abundance data were transformed by means of the Beals smoothing function (Beals, 1984; McCune, 1994) to reduce noise by enhancing the

1 pattern of joint occurrences. This function is appropriate in the current investigation
2 because the data consist of a large number of small sample units (Peck *et al.*, 1995) and
3 fulfill the requirements established by De Cáceres and Legendre (2008).

4
5 For each taxonomic level analysed, we performed a non-metric multidimensional
6 scaling (NMDS) ordination based on Bray-Curtis distances among the sampling sites.
7 The strength of the correlation between the NMDS axes and the environmental
8 variables, as well as the hydrological components, was plotted as vectors. In addition,
9 the individual variables and components were analyzed using Pearson coefficients.
10 Covarying (redundant) environmental variables were removed for subsequent model
11 development since the primary objective of the research was to determine the most
12 important flow components influencing macroinvertebrate assemblages and not to
13 distinguish the independent effect of hydrological and environmental drivers.

14
15 Distance based linear models (DistLM) were developed to assess the importance of
16 hydrological components driving taxonomical differences among sites. DistLM
17 calculates a multivariate multiple regression analysis between any symmetric distance
18 matrices, including a permutation test, as described by McArdle and Anderson (2001).
19 The final models were selected following a forward-stepwise procedure. For each
20 taxonomic level, marginal tests determined the variance explained by each flow
21 component and the sequential procedure discarded the variance shared by more than one
22 thereby avoiding the overestimation of their effect on the community.

23
24 Similarly, generalised linear models (GLM) were employed to determine how
25 hydrological components (independent variables) affected faunal richness patterns.
26 Models were constructed using log-transformed data following a forward-stepwise
27 procedure, assuming a Gaussian error distribution for the dependent variables. These
28 variables were the richness of Coleoptera species, number of macroinvertebrate genera,
29 number of macroinvertebrate families and the ratio EPT/EPTOCHD (defined by the
30 richness of Ephemeroptera, Plecoptera, Trichoptera, Odonata, Coleoptera, Heteroptera
31 and Diptera families). The latter is based on the EPT/EPTOCH ratio, which is used to
32 characterise temporary and lotic-lentic conditions in Mediterranean-climate regions
33 (Bonada *et al.*, 2006).

34

1 A non-metric single-factor Analysis of Similarity (ANOSIM) was used to test whether
2 assemblage composition differed among hydrological classes and, therefore, if natural
3 regimes can be used to differentiate distinct groups of invertebrate communities. Global
4 R indicates if assemblages are randomly grouped (i.e., $R=0$) or not (usually $0 < R \leq 1$,
5 although negative values are possible *sensu* Clarke (1993)). R pairwise values were also
6 obtained for each pair of classes, indicating whether intra-class similarities were greater
7 than inter-class similarities (R value close to 1).

9 Indicator taxa were defined for each hydrological class using the Indicator Species
10 analysis (IndVal) of Dufrene & Legendre (1997). This analysis generates an indicator
11 value index (IV) for each taxon and class, calculated on the basis of the specificity
12 (maximum when a taxon only occurs in one class) and fidelity (maximum when all sites
13 in a class have the taxon) of each taxon to each class.

15 All permutation tests (DistLM, ANOSIM and IndVal) were undertaken using 999
16 permutations. PCFA was undertaken in STATISTICA v 6 (Statsoft, 2001). NMDS and
17 IndVal were conducted using PC-ORD software v 4.42 (McCune and Grace, 2002).
18 ANOSIM and DistLM were undertaken in PRIMER v6 (Clarke and Gorley, 2006).
19 GLM were performed using the R statistical software v 2.12.2 (R Development Core
20 Team, 2008).

22 Results

23 Hydrological components

24 The three first PCFA axes were selected to represent the set of hydrological indices
25 since all of them explained greater than 10% of the variance (46, 28 and 12%,
26 respectively) and the forth axis only explained an additional 4%. The first axis was
27 positively correlated with mean and maximum monthly flows (Table IIa), representing
28 the flow magnitude component of the IHA. The second axis was negatively correlated
29 with the inter-annual coefficients of variation in monthly flows, the intra-annual
30 coefficient of variation in maximum monthly flows and the percentage of time without
31 flows. These variables characterise the inter- and intra-annual variability of the flow
32 regime and as a result this axis was defined as the flow stability component (Table IIb).
33 The third axis, magnitude of minimum flows, was correlated with all the minimum
34 monthly flows and their average value (Table IIc).

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4 2 These three hydrological components (PCFA axes) displayed significant positive
5 3 correlations with mean altitude and precipitation in the watershed, and negative
6 4 correlations with mean temperature (Table III). In addition, karst surface and slope were
7 5 positively correlated with flow stability and minimum flows, while drainage area was
8 6 associated with the magnitude of flow. As anticipated, conductivity displayed a negative
9 7 association with flow magnitude and stability.
10 8
11 9 *Hydrological components determining assemblage composition*
12 10 The macroinvertebrate NMDS ordinations for different taxonomic resolutions identified
13 11 similar patterns (Figure 2). Sites were structured along a flow stability gradient from
14 12 perennial headwater streams (left side, class 4) to intermittent streams (right side, class
15 13 7), although some classes were widely dispersed (particularly class 6 - spring peak flow
16 14 seasonal streams). This gradient was associated with several environmental variables
17 15 and hydrological components (PCFA axes). Perennial stable streams (classes 3 and 4)
18 16 were predominately located on karstic rocks and sites in higher altitude areas with
19 17 steeper slopes, higher flow stability and relatively high minimum flows. In contrast,
20 18 intermittent streams were associated to low slopes, reduced flow stability and low
21 19 minimum flows, but higher conductivity and air temperature.
22 20
23 21 DistLM models indicated that hydrological components accounted for a significant
24 22 proportion of the variance in the macroinvertebrate community that increased with
25 23 taxonomic resolution (Table IV): 28% for families, 30% for genus and 38% for
26 24 Coleoptera species. In all cases, flow stability and minimum flows were the dominant
27 25 hydrological drivers of taxonomical differences among sites.
28 26
29 27 *Response of taxonomic richness to hydrological components*
30 28 GLM results showed a moderate effect of hydrological variables on the richness of
31 29 macroinvertebrate families, genera and species (Table V). However, the model obtained
32 30 for the EPT/EPTOCHD ratio explained 36 % of the variance using flow magnitude and
33 31 flow stability as independent variables. Gradual changes to the relative richness of EPT
34 32 families were observed from perennial to intermittent hydrological classes, decreasing
35 33 along the flow magnitude gradient, whilst the OCHD families displayed the opposite
36 34 pattern (Figure 3).
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Differences in assemblage composition among hydrological classes

The hydrological classes identified supported significantly different invertebrate assemblages at the family (ANOSIM, $R = 0.39$; P -value < 0.05), genus (ANOSIM, $R = 0.34$; P -value < 0.05) and species taxonomic level (ANOSIM, $R = 0.40$; P -value < 0.05) (Table VI). Pair-wise comparisons revealed significant assemblage differences at all taxonomic resolutions between the extremes of the hydrological gradient, perennial stable streams (creeks and headwaters, classes 3 and 4 respectively) and intermittent streams (class 7). Differences between creek and medium river communities (class 2) as well as between creeks and perennial seasonal streams with peak flows during the winter (class 5) increased with the taxonomic resolution, except for the genus level. However, intermittent streams and perennial seasonal streams, both with winter (class 5) and spring peak flows (class 6), differed at the genus or at the genus and species levels, respectively. No significant differences were found both between creeks and headwater streams or within seasonal streams (winter and spring peak flows) (Table VI).

The IndVal analyses determined indicator families for medium rivers (class 2), headwater streams (class 4), spring peak flow seasonal streams (class 6) and intermittent streams (class 7) (Table VII). Medium rivers were characterised by Polycentropodidae (Trichoptera) and Potamanthidae (Ephemeroptera). Headwater streams were defined by one Ephemeroptera (Leptophlebiidae), five families of Trichoptera (Limnephilinae and Beraeidae showed slightly higher Indicator Values) and one Crustacea (Astacidae). Spring peak flow seasonal streams were characterised by Syrphidae (Diptera), which presented the highest Indicator Value in the Segura Basin. Intermittent streams were defined by the presence of Coenagrionidae and Libellulidae (Odonata), Pleidae (Heteroptera) and Noteridae and Hydrophilidae (Coleoptera).

Indicator genera were found for all classes except creeks (class 3) and winter peak flow seasonal streams (class 5). Medium rivers (class 2) and headwater streams (class 4) were characterised by Ephemeroptera: *Habrophlebia* and *Potamanthus* for the former and *Epeorus* and *Rhithrogena* for the latter. Headwaters were also characterised by seven Coleoptera genera (*Oreodytes*, *Graptodytes*, *Esolus*, *Limnebius*, *Normandia*, *Hydrocyphon* and *Oulimnius*), two Trichoptera (*Rhyacophila* and *Sericostoma*), one

Crustacea (*Austropotamobius*) and two Plecoptera (*Perla* and *Isoperla*). Spring peak flow seasonal streams (Class 6) were characterised by one genus of Coleoptera (*Dytiscus*), Hirudinea (*Helobdella*), Molusca (*Pseudamnicola*) and Odonata (*Platycnemis*), with identical indicator values. Intermittent streams (class 7) highlighted the highest number of indicator genera, with the highest Indicator Values for two Diptera (*Dasyhelea* and *Anopheles*), two Heteroptera (*Heliocorisa* and *Anisops*), two Odonata (*Anax* and *Sympetrum*) and two Coleoptera (*Enochrus* and *Berosus*).

Coleoptera indicator species were detected for all classes except spring peak flow seasonal streams (class 6) (Table VII). Medium rivers (class 2) were primarily characterised by *Hydraena manfredjaechi* and *Normandia nitens*; creeks (class 3) by *Hydraena exasperata*; headwater streams (class 4) by *Helophorus alternans*; winter peak flow seasonal streams (class 5) by *Eretes griseus* and *Ranthus suturalis*; and intermittent streams (class 7) by *Ochthebius delgadoi*.

Discussion

The importance of hydrological components on macroinvertebrate assemblages

The research presented herein supports the general hypothesis that streams with similar flow regimes express greater than random similarity in macroinvertebrate assemblages composition (Resh *et al.*, 1988; Poff, 1996). Our results demonstrate relatively strong relationships between community composition and the flow regimes at different taxonomic levels. The strength of these relationships increased with taxonomic resolution suggesting that the species level data yields the strongest relationships and that, where it is available, it should be used in ecohydrological investigations (Monk *et al.*, 2012). Flow stability and minimum flows were shown to be the principal hydrological drivers/descriptors of the macroinvertebrate community assemblages in the Segura River Basin. Similar results were reported by Chinnayakanehalli *et al.* (2011) in western USA, where baseflows and seasonality were the main predictors of invertebrate composition. However, these results contrast with studies performed in temperate-maritime regions where the magnitudes of mean flows or high flows were reported to be the best predictors of macroinvertebrate assemblages (Clausen and Biggs, 1997; Monk *et al.*, 2006; Monk *et al.*, 2008).

Flow stability and minimum flows are major determinants of habitat availability and connectivity that affect aquatic macroinvertebrate assemblages. Flow stability reflects seasonal and interannual patterns of variation, associated with the predictability of flows (Poff, 1996) and the stability of habitat conditions in terms of depth, flow velocity and hydraulic forces (Suen and Herricks, 2009). The variation of stream flow velocity configures stream morphology, water temperature, bed stability and consequently the availability of aquatic habitats for instream organisms (Jowett and Duncan, 1990). Minimum flows represent an extreme of the flow, particularly in the dry season, and reflect the magnitude of seasonal droughts (Smakhtin, 2001). Habitat heterogeneity is reduced under low flow conditions because wetted width, water depth and flow velocity also diminishes (Walters and Post, 2011). In addition, extreme low flows can reduce longitudinal connectivity and increase physical stresses transforming streams into series of isolated pools with higher water temperature and elevated conductivity (Stanley *et al.*, 1997). Consequently, droughts have been recognised as an important part of the natural flow regime in intermittent streams (Boulton, 2003; Lake, 2003; Sheldon and Thoms, 2006, Chase, 2007). Species inhabiting intermittent streams must have physiological, behavioural or life-history adaptations to cope with higher conductivities, predation pressures and habitat isolation, such as short life-histories, generalist feeding, aerial respiration or active aerial dispersal (e.g. Bonada *et al.*, 2007b). Under these conditions, dispersal abilities and distances between or along water bodies have been found to be primary determinants of community composition (McAbendroth *et al.*, 2005), because active movement when the riverbed is dry is limited to a small number of taxa such as dytiscid and hydrophilid beetles (Boulton *et al.*, 2006; Larned *et al.*, 2010).

Our results indicate a moderately strong relationship between flow regime and faunal richness at the different taxonomic resolutions, weaker than that between flow regime and community composition (especially at species level). Other studies have also reported a moderate effect of minimum flows (Walters and Post, 2011), flow seasonality or the number of days with zero flow (Chinnayakanahalli *et al.*, 2011).

In Mediterranean regions, ephemeral and intermittent streams are recognised to be significantly less diverse than perennial streams (Bonada *et al.*, 2007b) and to differ in community composition (e.g. Bonada *et al.*, 2006; Argyroudi *et al.*, 2009). Our results

1 found a strong relationship between flow magnitude, and stability, and the ratio of
2 EPT/EPTOCHD. This supports the findings of Bonada *et al.* (2006) and Sánchez-
3 Montoya *et al.* (2007), who reported a decrease in EPT richness as hydrological
4 isolation and the length of the dry period (temporality) increased. EPT taxa in particular
5 tend to occur in riffles, whereas pools support the majority of OCHD taxa (Vivas *et al.*,
6 2002; Oscoz *et al.*, 2011). Therefore, riffle permanence has a strong effect on the
7 structure of benthic assemblages in streams (Feminella, 1996).

8
9 *Biological significance of hydrological classes*

10 The six hydrological classes examined in this study indicate distinct macroinvertebrate
11 assemblages at all of the taxonomic resolutions considered. Taxonomic differences were
12 greatest between the classes at both extremes of the flow stability gradient, and are
13 similar to results reported by other studies in the Iberian Peninsula (Sanchez-Montoya *et al.*,
14 2007) and in the Segura Basin (Millan *et al.*, 2006; Diaz *et al.*, 2008; Carbonell *et al.*,
15 2011). However, when the other classes were considered, only minor and gradual
16 biological changes along the gradient were detected. Consequently, a simpler
17 classification with four broad hydrological types (Belmar *et al.* 2011) is more
18 appropriate for management purposes in the Segura River Basin and other semi-arid
19 Mediterranean basins: (1) mainstream rivers (classes 1 and 2), (2) perennial stable
20 streams (classes 3 and 4), (3) perennial seasonal streams (classes 5 and 6) and (4)
21 temporary streams (classes 7 and 8).

22
23 We found a clear agreement between the selection of indicator taxa in this study and
24 those from other studies in the Mediterranean region in Spain (e.g., Bonada *et al.*, 2004;
25 Mellado, 2005; Sanchez-Montoya *et al.*, 2007). Headwater streams were characterised
26 by taxa that inhabit the upper reaches of rivers with colder and oxygen-rich waters, in
27 areas of cobbles and small boulders. These sites supported the greatest presence of
28 Ephemeroptera (Leptophlebiidae) and Trichoptera (e.g. Limnephilinae and Beraidae)
29 families and were also characterised by the presence of typically reophilic
30 Ephemeroptera (*Epeorus* and *Rhitrogena*) and Plecoptera (*Perla* and *Isoperla*) genera.
31 In general, these taxa are considered to have high oxygen requirements and their
32 presence is associated with good water quality (Jacobsen *et al.*, 2003). Medium rivers
33 were characterised by Ephemeroptera genera, such as *Potamanthus* and *Habrophlebia*,
34 typical of reaches of large rivers where low to moderate flow velocities, associated with

1 gravel and sand substrates, predominate (Puig *et al.*, 1984). Intermittent streams were
2 associated with taxa from shallow standing waters or those with reduced velocities, such
3 as numerous Coleoptera (e.g., *Enochrus*, *Berosus* and *Noterus*), Odonata (e.g., *Anax*,
4 *Sympetrum* and *Ischnura*) and Heteroptera (e.g., *Heliocoris*, *Anisops* and *Sigara*),
5 with highly mobile adults (Bilton *et al.*, 2001) and short life-history development times
6 (Velasco *et al.*, 1990; Barahona *et al.*, 2005). The importance of Coleoptera in
7 temporary streams highlighted in this study has also been demonstrated in several
8 previous studies (Picazo *et al.*, 2012).

9 10 *Implications to river restoration and conservation*

11 Based on the results presented, the magnitude of monthly minimum flows and the inter-
12 and intra-annual natural variation of flows are two key flow components for the
13 definition of environmental flows in Mediterranean basins. Currently, many historically
14 perennial streams have already become intermittent due to excessive abstraction and
15 impoundment, while others exhibit an inverse seasonal pattern due to water release from
16 reservoirs during the summer months (Belmar *et al.*, 2010). Such hydrological
17 modifications could become more intense in the future as a result of climate change
18 (European Environment Agency, 2008), which is expected to intensify supra-seasonal
19 droughts and lead to more anthropogenic water withdrawals. This may lead to the
20 depletion of groundwater in local aquifers and, therefore, flow intermittency in
21 previously perennial streams. Such intermittency could result in significant changes to
22 the faunal community, increasing the risk of local extinctions of drought-sensitive taxa.
23 This effect has already been documented in desert streams (Bogan and Lytle, 2011),
24 where simplified pools composed of the most tolerant and resilient species have been
25 described (*sensu* Cote and Darling, 2010). Therefore, the conservation and, where
26 appropriate, restoration of natural hydrological variability is crucial for the maintenance
27 of riverine ecosystem integrity (i.e., ecosystem structure and function) (Thoms, 2006;
28 Vaughan *et al.*, 2009).

29
30 Future research should focus on how the degree of hydrological alteration affects
31 aquatic communities and ecosystem functioning. Aquatic macroinvertebrates are ideal
32 candidates for the development of hydro-ecological models to quantify the effects of
33 flow reduction (Castella *et al.*, 1995; Niu and Dudgeon, 2011a; Niu and Dudgeon,
34 2011b). Using the four broad hydrological types stated we will be able to provide a

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1 reference framework in the near future to achieve a more sustainable management of
2 ecohydrological resources in the Segura River Basin and other Mediterranean basins,
3 fulfilling the objectives of ELOHA and EU Water Framework Directive criteria.

4
5 Acknowledgements

6 We wish to thank the University of Murcia and the *Fundación Séneca* for their financial
7 support to Óscar Belmar and Cayetano Gutiérrez-Cánovas, respectively, by means of
8 pre-doctoral grants; the Euromediterranean Institute of Water for its support to the
9 project “Hydrological classification of the rivers and streams in the Segura basin and
10 associated macroinvertebrate communities”; the *Confederación Hidrográfica del*
11 *Segura* for providing the climatic data and the SIMPA model; and the *Instituto*
12 *Geográfico Nacional* as well as the *Instituto Geológico y Minero de España* for the GIS
13 data.

Table I. Mean and standard deviation of the mean annual flow (MADIS), time with zero flow (D_L) and coefficient of variation in annual flows (CV_{INTER}) for the natural flow regime classes defined in the Segura River Basin (Belmar *et al.* 2011).

Hydrological class	Number of stream sections	MADIS (m^3/s)	D_L (%)	CV_{INTER}
Class 1: Perennial large size rivers	17	11.30 (± 0.74)	0.00 (± 0.00)	0.52 (± 0.01)
Class 2: Perennial medium size rivers	31	3.76 (± 2.26)	0.00 (± 0.00)	0.50 (± 0.13)
Class 3: Perennial stable creeks	21	1.00 (± 0.45)	0.00 (± 0.00)	0.32 (± 0.09)
Class 4: Perennial stable headwater streams	43	0.18 (± 0.17)	0.00 (± 0.00)	0.26 (± 0.13)
Class 5: Perennial winter peak flow seasonal streams	26	0.37 (± 0.09)	2.31 (± 2.06)	1.39 (± 0.29)
Class 6: Perennial spring peak flow seasonal streams	110	0.06 (± 0.06)	4.46 (± 6.32)	0.81 (± 0.30)
Class 7: Temporary intermittent streams	101	0.04 (± 0.04)	24.88 (± 13.15)	1.71 (± 0.38)
Class 8: Temporary ephemeral streams	41	0.01 (± 0.01)	61.90 (± 20.21)	3.43 (± 0.84)

Table II. Pearson correlation coefficients between the three rotated PCFA axes and the 73 hydrological indices. Coefficients higher than |0.70| are in bold letter. Horizontal lines separate indices associated to the three flow components represented by the axes: (a) magnitude (average and maximum flows), 1st axis (46% of variance); (b) flow stability, 2nd axis (28% of variance); and (c) minimum flows, 3rd axis (12% of variance).

	Variable	Description	PCFA axis		
			1 st	2 nd	3 rd
(a)	M _A 1	Mean monthly flow (October)	0.98	0.13	0.02
	M _A 2	Mean monthly flow (November)	0.98	0.13	0.02
	M _A 3	Mean monthly flow (December)	0.99	0.12	0.05
	M _A 4	Mean monthly flow (January)	0.98	0.14	0.04
	M _A 5	Mean monthly flow (February)	0.98	0.14	0.04
	M _A 6	Mean monthly flow (March)	0.99	0.12	0.03
	M _A 7	Mean monthly flow (April)	0.98	0.14	0.02
	M _A 8	Mean monthly flow (May)	0.98	0.15	0.04
	M _A 9	Mean monthly flow (June)	0.98	0.15	0.03
	M _A 10	Mean monthly flow (July)	0.97	0.16	0.04
	M _A 11	Mean monthly flow (August)	0.97	0.16	0.05
	M _A 12	Mean monthly flow (September)	0.98	0.13	0.02
	M _A 16	Mean annual flow divided by catchment area	0.18	0.50	0.35
	MEDDIS/A	Median annual discharge divided by catchment area	0.22	0.52	0.35
	M _H 1	Mean of the maximum monthly flows (October)	0.96	0.08	0.01
	M _H 2	Mean of the maximum monthly flows (November)	0.96	0.06	0.07
(b)	M _H 3	Mean of the maximum monthly flows (December)	0.91	0.00	0.05
	M _H 4	Mean of the maximum monthly flows (January)	0.97	0.14	0.08
	M _H 5	Mean of the maximum monthly flows (February)	0.97	0.15	0.11
	M _H 6	Mean of the maximum monthly flows (March)	0.94	0.03	0.02
	M _H 7	Mean of the maximum monthly flows (April)	0.98	0.10	0.04
	M _H 8	Mean of the maximum monthly flows (May)	0.98	0.15	0.08
	M _H 9	Mean of the maximum monthly flows (June)	0.98	0.13	0.00
	M _H 10	Mean of the maximum monthly flows (July)	0.98	0.13	-0.03
	M _H 11	Mean of the maximum monthly flows (August)	0.98	0.13	-0.03
	M _H 12	Mean of the maximum monthly flows (September)	0.95	0.05	-0.04
	M _H 13	Mean of the mean maximum flows for all months	0.98	0.08	0.04
	MADIS	Mean annual flow for all years	0.98	0.14	0.03
	RANGE	Maximum annual discharge minus minimum annual discharge	0.98	0.06	-0.05
	Q1	Percentile flow with the annual discharge exceeded 1% of time	0.99	0.09	0.01
	Q50	Median annual flow for all years	0.97	0.14	0.03
	CV _A 1	Coefficient of variation (October)	-0.08	-0.83	-0.30
	CV _A 2	Coefficient of variation (November)	-0.12	-0.86	-0.15
	CV _A 3	Coefficient of variation (December)	-0.09	-0.84	-0.19
	CV _A 4	Coefficient of variation (January)	-0.19	-0.88	-0.21
	CV _A 5	Coefficient of variation (February)	-0.21	-0.89	-0.17
	CV _A 6	Coefficient of variation (March)	-0.19	-0.81	-0.25
	CV _A 7	Coefficient of variation (April)	-0.26	-0.90	-0.20
	CV _A 8	Coefficient of variation (May)	-0.02	-0.91	-0.19
	CV _A 9	Coefficient of variation (June)	0.02	-0.83	-0.35
	CV _A 10	Coefficient of variation (July)	0.09	-0.82	-0.37
	CV _A 11	Coefficient of variation (August)	0.09	-0.84	-0.36
	CV _A 12	Coefficient of variation (September)	-0.03	-0.81	-0.34
	M _A 13	Range divided by median monthly flow	-0.06	-0.90	-0.03
	M _A 14	Interquartile divided by median monthly flow	0.09	-0.80	0.05
	CV _{INTRA}	Coefficient of variation in mean monthly flows	0.02	-0.90	-0.03
	M _A 15	Mean minus median monthly flow divided by median monthly flow	-0.15	-0.73	0.06
	M _A 17	Range divided by median annual flow	-0.22	-0.93	-0.10
	M _A 18	Interquartile divided by median annual flow	-0.17	-0.83	-0.05
	M _A 19	Mean minus median annual flow divided by median annual flow	-0.17	-0.84	0.03
	CV _H	Coefficient of variation in mean maximum monthly flows	-0.27	-0.79	-0.08
	D _L	Percentage of months with zero flow	-0.38	-0.75	-0.24
	CV _{INTER}	Coefficient of variation in annual flows for all years	-0.21	-0.92	-0.25
	Q5/Q50	Q5 divided median monthly flow	-0.23	-0.88	-0.08
	Q10/Q50	Q10 divided median monthly flow	-0.21	-0.87	-0.06
	STDEV	Standard deviation of annual discharge	0.99	0.07	-0.09
	AMAX/Q50	Maximum annual discharge divided by Q50	-0.23	-0.92	-0.08
	AMIN/Q50	Minimum annual discharge divided by Q50	-0.25	0.63	0.42
	I _H	Q5 divided mean monthly flow	0.08	-0.04	-0.27
	I _L	Q95 divided mean monthly flow	-0.26	0.60	0.48
(c)	M _L 1	Mean minimum monthly flow (October)	0.02	0.19	0.92
	M _L 2	Mean minimum monthly flow (November)	0.04	0.19	0.92
	M _L 3	Mean minimum monthly flow (December)	0.03	0.19	0.92
	M _L 4	Mean minimum monthly flow (January)	0.11	0.20	0.77
	M _L 5	Mean minimum monthly flow (February)	0.08	0.18	0.88
	M _L 6	Mean minimum monthly flow (March)	0.04	0.18	0.93
	M _L 7	Mean minimum monthly flow (April)	0.10	0.23	0.78
	M _L 8	Mean minimum monthly flow (May)	0.03	0.17	0.93
	M _L 9	Mean minimum monthly flow (June)	0.00	0.17	0.90
	M _L 10	Mean minimum monthly flow (July)	0.01	0.17	0.90
	M _L 11	Mean minimum monthly flow (August)	0.04	0.16	0.89
	M _L 12	Mean minimum monthly flow (September)	0.05	0.16	0.88
	M _L 13	Mean of the mean minimum flows for all months	0.06	0.20	0.96

Table III. Pearson correlation coefficients between environmental variables and hydrological components (PCFA axes). Significant correlations ($p < 0.05$) are in bold letter.

Environmental variable	Flow magnitude	Flow stability	Minimum flows
Mean precipitation (mm)	0.26	0.64	0.39
Conductivity ($\mu\text{S}/\text{cm}^2$)	-0.28	-0.54	-0.21
Mean altitude (m)	0.34	0.64	0.34
Mean slope ($^\circ$)	0.24	0.37	0.27
Karst surface (%)	0.21	0.36	0.37
Mean temperature ($^\circ\text{C}$)	-0.37	-0.57	-0.27
Drainage area (km^2)	0.83	-0.16	-0.14

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Table IV. Results of the DistLM analyses for each taxonomic level. Significance levels are indicated with asterisks (*: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$).

Hydrological component	Macroinvertebrate families		Macroinvertebrate genera		Coleoptera species	
	Marginal (%)	Sequential (%)	Marginal (%)	Sequential (%)	Marginal (%)	Sequential (%)
Flow magnitude	7	6*	6	5	4	3*
Flow stability	12***	9**	24***	24***	27***	27***
Minimum flows	13**	13***	11**	6*	16***	8***
Total (%)		28		30		38

Table V. GLM analyses for the different dependent variables, based on richness. Significance levels are indicated with asterisks (*: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$).

Dependent variable	Variance explained (%)	Explanatory hydrological components
EPT/EPTOCHD	36	Flow magnitude**, flow stability*
Macroinvertebrate families	21	Minimum flows**
Macroinvertebrate genera	24	Minimum flows**
Coleoptera species	17	Minimum flows**

Table VI. Results of ANOSIM analyses. Significance levels are indicated with asterisks (*: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$).

Classes	Macroinv. families	Macroinv. genera	Coleop. species
2, 5	0.22	0.15	0.50**
2, 7	0.59*	0.62*	0.49**
3, 2	0.26*	0.06	0.56**
3, 5	0.25*	0.20	0.76***
3, 6	0.49**	0.30*	0.05
3, 7	0.50**	0.53**	0.86***
4, 2	0.85**	0.67**	0.37**
4, 3	0.00	-0.02	-0.09
4, 5	0.81**	0.80**	0.66***
4, 6	0.53**	0.77**	0.09
4, 7	0.88**	0.86**	0.77***
5, 7	0.29	0.42*	0.17
6, 2	0.27**	0.33**	-0.01
6, 5	0.12	0.02	0.16
6, 7	0.09	0.44*	0.38**
Global R	0.39***	0.34***	0.40***

Class 2: Perennial medium rivers
Class 3: Perennial stable creeks
Class 4: Perennial stable headwater streams
Class 5: Perennial winter peak flow seasonal streams
Class 6: Perennial spring peak flow seasonal streams
Class 7: Temporary intermittent streams

Hydrological class	Macroinvertebrate families	IV (%)	Macroinvertebrate genera	IV	Coleoptera species	IV (%)
2. Perennial medium rivers	Polycentropodidae	31	<i>Habrophlebia</i>	28	<i>Hydraena manfredjaechi</i>	47
	Potamanthidae	27	<i>Potamanthus</i>	27	<i>Normandia nitens</i>	47
					<i>Limnius intermedius</i>	44
					<i>Ochthebius difficilis</i>	34
					<i>Limnius opacus</i>	28
3. Perennial stable creeks					<i>Pomatinus substriatus</i>	25
					<i>Hydraena exasperata</i>	55
					<i>Ilybius meridionalis</i>	50
					<i>Ochthebius bellieri</i>	46
					<i>Limnius volckmari</i>	34
					<i>Agabus brunneus</i>	32
					<i>Hydroporus marginatus</i>	30
					<i>Ochthebius bonnairei</i>	30
					<i>Anacaena bipustulata</i>	29
					<i>Deronectes moestus</i>	29
					<i>Hydraena carbonaria</i>	29
					<i>Hydraena capta</i>	27
					<i>Hydraena rufipennis</i>	26
					<i>Stictonectes epipleuricus</i>	26
					<i>Agabus didymus</i>	25
4. Perennial stable headwater streams	Leptophlebiidae	41	<i>Oreodytes</i>	45	<i>Helophorus alternans</i>	29
	Limnephiliinae	29	<i>Epeorus</i>	35	<i>Helophorus brevipalpis</i>	28
	Beraeidae	29	<i>Rhyacophila</i>	31	<i>Laccobius obscuratus</i>	28
	Brachycentridae	28	<i>Graptodytes</i>	30	<i>Hydroporus tessellatus</i>	26
	Rhyacophilidae	27	<i>Austropotamobius</i>	30	<i>Limnebius cordobanus</i>	26
	Sericostomatidae	26	<i>Esolus</i>	29		
	Astacidae	26	<i>Sericostoma</i>	29		
			<i>Limnebius</i>	28		
			<i>Normandia</i>	27		
			<i>Hydrocyphon</i>	27		
			<i>Rhithrogena</i>	27		
			<i>Oulimnius</i>	25		
			<i>Perla</i>	25		
			<i>Isoperla</i>	25		
5. Perennial winter peak flow seasonal streams					<i>Eretes griseus</i>	76
					<i>Rhantus suturalis</i>	76
					<i>Hydrochus nooneinus</i>	52
					<i>Stictotarsus duodecimpustulatus</i>	52
					<i>Berosus hispanicus</i>	34
					<i>Hydrophilus pistaceus</i>	32
6. Perennial spring peak flow seasonal streams	Syrphidae	85	<i>Dytiscus</i>	35	<i>Laccobius moraguesi</i>	31
			<i>Helobdella</i>	35	<i>Agabus ramblae</i>	29
			<i>Pseudamnicola</i>	35		
			<i>Platycnemis</i>	35		
7. Temporary intermittent streams	Noteridae	35	<i>Dasyhelea</i>	63	<i>Ochthebius delgadoi</i>	42
	Pleidae	35	<i>Anopheles</i>	63	<i>Enochrus politus</i>	38
	Coenagrionidae	30	<i>Helicorisa</i>	63	<i>Helophorus fulgidicollis</i>	38
	Libellulidae	28	<i>Anisops</i>	63	<i>Laccophilus minutus</i>	38
	Hydrophilidae	26	<i>Anax</i>	52	<i>Ochthebius auropallens</i>	38
			<i>Enochrus</i>	48	<i>Ochthebius grandipennis</i>	38
			<i>Sympetrum</i>	48	<i>Ochthebius viridis fallaciosus</i>	38
			<i>Berosus</i>	45	<i>Ochthebius jaime</i>	35
			<i>Sigara</i>	45	<i>Helochares lividus</i>	27
			<i>Plea</i>	45		
			<i>Ischnura</i>	45		
			<i>Noterus</i>	42		
			<i>Potamopyrgus</i>	42		
			<i>Cercion</i>	42		
			<i>Libellula</i>	42		
			<i>Helochares</i>	41		
			<i>Bidessus</i>	40		
			<i>Procambarus</i>	40		
			<i>Limnophora</i>	40		
			<i>Tipula</i>	40		
			<i>Microvelia</i>	40		
			<i>Agabus</i>	36		
			<i>Dryops</i>	32		
			<i>Laccobius</i>	32		
			<i>Orthetrum</i>	32		
			<i>Gerris</i>	30		

Appendix A. Taxa collected in the Segura Basin grouped by taxonomic order.

Hirudinea	Oreodytes
<u>Erpobdellidae</u>	Stictonectes
Dina	<i>Stictonectes epipleuricus</i> (Seidlitz, 1887)
<u>Glossiphoniidae</u>	<i>Stictonectes optatus</i> (Seidlitz, 1887)
Helobdella	Yola
Mollusca	<i>Yola bicarinata</i> (Latreille, 1804)
<u>Ancylidae</u>	Elmidae
Ancylus	Elmis
Ferrissia	<i>Elmis aenea</i> (Müller, 1806)
<u>Hydrobiidae</u>	<i>Elmis maugetii maugetii</i> Latreille, 1798
Mercuria	<i>Elmis rioloides</i> (Kuwert, 1890)
Potamopyrgus	Esolus
Pseudamnicola	<i>Esolus parallelepipedus</i> (Müller, 1806)
<u>Lymnaeidae</u>	Limnius
Lymnaea	<i>Limnius intermedius</i> Fairmaire, 1881
<u>Melanopsidae</u>	<i>Limnius opacus</i> Müller, 1806
Melanopsis	<i>Limnius volckmari</i> (Panzer, 1793)
<u>Physidae</u>	Normandia
Physella	<i>Normandia nitens</i> (Müller, 1817)
<u>Planorbidae</u>	<i>Normandia sodalis</i> (Erichson, 1847)
Gyraulus	Oulimnius
Planorbarius	<i>Oulimnius troglodytes</i> (Gyllenhal, 1827)
<u>Sphaeriidae</u>	<i>Oulimnius tuberculatus perezii</i> Sharp, 1872
Pisidium	Potamophilus
Crustacea	Riolus
<u>Astacidae</u>	<i>Riolus cupreus</i> (Müller, 1806)
Austropotamobius	<i>Riolus illiesi</i> Steffan, 1958
<u>Atyidae</u>	Gyrinidae
Atyaephyra	Aulonogyrrus
<u>Cambaridae</u>	<i>Aulonogyrrus striatus</i> (Fabricius, 1792)
Procambarus	Gyrinus
<u>Gammaridae</u>	<i>Gyrinus dejeani</i> Brullé, 1832
Echinogammarus	Orectochilus
Coleoptera	<i>Orectochilus villosus</i> (Müller, 1776)
<u>Dryopidae</u>	<u>Haliplidae</u>
Dryops	<i>Peltodytes rotundatus</i> (Aubé, 1836)
<i>Dryops gracilis</i> (Karsch, 1881)	Haliplus
<i>Dryops sulcipennis</i> (Costa, 1883)	<i>Haliplus lineatocollis</i> (Marsham, 1802)
Pomatius	<i>Haliplus mucronatus</i> Stephens, 1832
<i>Pomatius substriatus</i> (Müller, 1806)	<u>Helophoridae</u>
<u>Dytiscidae</u>	Helophorus
<i>Eretes griseus</i> Motschulsky 1849	<i>Helophorus alternans</i> Gené, 1836
<i>Hygrotus confluens</i> (Fabricius, 1787)	<i>Helophorus brevipalpis</i> Bedel, 1881
<i>Hyphydrus aubei</i> Ganglbauer, 1892	<i>Helophorus fulgidicollis</i> Motschulsky, 1860
<i>Ilybius meridionalis</i> Aubé, 1836	<i>Helophorus occidentalis</i> Angus, 1983
<i>Meladema coriacea</i> Castelnau, 1834	<i>Helophorus nubilus</i> Fabricius, 1776
<i>Rhantus suturalis</i> (McLeay, 1825)	<i>Helophorus seidlitzii</i> Kuwert, 1885
<i>Stictotarsus duodecimpustulatus</i> (Fabricius, 1792)	<u>Hydraenidae</u>
Agabus	Hydraena
<i>Agabus biguttatus</i> (Olivier, 1795)	<i>Hydraena capta</i> Orchymont, 1936
<i>Agabus bipustulatus</i> (Linnaeus, 1767)	<i>Hydraena carbonaria</i> Kiesenwetter, 1849
<i>Agabus brunneus</i> (Fabricius, 1798)	<i>Hydraena exasperata</i> Orchymont, 1935
<i>Agabus didymus</i> (Olivier, 1795)	<i>Hydraena hernandoi</i> Fresneda & Lagar, 1990
<i>Agabus nebulosus</i> (Forster, 1771)	<i>Hydraena mantredjaechi</i> Delgado & Soler, 1991
<i>Agabus nitidus</i> (Fabricius, 1801)	<i>Hydraena pygmaea</i> Waterhouse, 1833
<i>Agabus paludosus</i> (Fabricius, 1801)	<i>Hydraena quilisi</i> Lagar, Fresneda & Hernando, 1987
<i>Agabus ramblae</i> Millán & Ribera, 2001	<i>Hydraena rufipennis</i> Boscá Berga, 1932
Bidessus	<i>Hydraena servilla</i> Orchymont, 1936
<i>Bidessus minutissimus</i> (Germar, 1824)	Limnebius
Deronectes	<i>Limnebius cordobanus</i> Orchymont, 1938
<i>Deronectes depressicollis</i> (Rosenhauer, 1856)	<i>Limnebius maurus</i> Balfour-Browne, 1978
<i>Deronectes fairmairei</i> (Leprieur, 1876)	<i>Limnebius oblongus</i> Rey, 1883
<i>Deronectes hispanicus</i> (Rosenhauer, 1856)	Ochthebius
<i>Deronectes moestus</i> Leprieur, 1876	<i>Ochthebius auropallens</i> Fairmaire, 1879
Dytiscus	<i>Ochthebius bellieri</i> Kuwert, 1887
Graptodytes	<i>Ochthebius bonnairei</i> Guillebau, 1896
<i>Graptodytes fractus</i> (Sharp, 1880-82)	<i>Ochthebius delgadoi</i> Jäch, 1994
<i>Graptodytes ignotus</i> (Mulsant, 1861)	<i>Ochthebius difficilis</i> Mulsant, 1844
<i>Graptodytes varius</i> (Aubé, 1836)	<i>Ochthebius dilatatus</i> Stephens, 1829
Hydroglyphus	<i>Ochthebius (Enicocerus) exsculptus</i> Germar, 1824
<i>Hydroglyphus geminus</i> (Fabricius, 1792)	<i>Ochthebius grandipennis</i> Fairmaire, 1879
<i>Hydroglyphus signatellus</i> (Klug, 1834)	<i>Ochthebius jaimie</i> Delgado & Jäch, 2007
Hydroporus	<i>Ochthebius quadroveolatus</i> Wollaston, 1854
<i>Hydroporus discretus</i> Fairmaire, 1859	<i>Ochthebius tudmirensis</i> Jäch, 1997
<i>Hydroporus lucasi</i> Reiche, 1866	<i>Ochthebius viridis fallaciosus</i> Ganglbauer, 1901
<i>Hydroporus marginatus</i> (Duftschmid, 1805)	<u>Hydrochidae</u>
<i>Hydroporus nigrita</i> (Fabricius, 1792)	Hydrochus
<i>Hydroporus pubescens</i> (Gyllenhal, 1808)	<i>Hydrochus grandicollis</i> Kiesenwetter, 1870
<i>Hydroporus tessellatus</i> Drapiez, 1819	<i>Hydrochus nooreinus</i> Henegouven & Sáinz-Cantero, 1992
Laccophilus	<u>Hydrophilidae</u>
<i>Laccophilus hyalinus</i> (De Geer, 1774)	<i>Anacaena bipustulata</i> (Marsham, 1802)
<i>Laccophilus minutus</i> (Linnaeus, 1758)	<i>Anacaena globulus</i> (Paykull, 1798)
Nebioporus	<i>Anacaena lutescens</i> (Stephens, 1829)
<i>Nebioporus bucheti cazorlensis</i> (Lagar, Fresneda & Hernando, 1987)	<i>Coelostoma hispanicum</i> (Küster, 1848)
<i>Nebioporus clarki</i> (Wollaston, 1862)	<i>Hydrophilus pistaceus</i> (Castelnau, 1840)

Appendix A (cont.).

Berosus	<u>Corixidae</u>
<i>Berosus hispanicus</i> Küster, 1847	Heliocoris
Enochrus	Micronecta
<i>Enochrus ater</i> (Kuwert, 1888)	Sigara
<i>Enochrus politus</i> Küster, 1849	<u>Gerridae</u>
Helochaeres	Aquarius
<i>Helochaeres lividus</i> (Forster, 1771)	Gerris
Laccobius	<u>Hydrometridae</u>
<i>Laccobius bipunctatus</i> (Fabricius, 1775)	Hydrometra
<i>Laccobius hispanicus</i> Gentili, 1974	<u>Naucoridae</u>
<i>Laccobius gracillis gracillis</i> Motschulsky, 1849	Naucoris
<i>Laccobius moraguesi</i> Régimbart, 1898	<u>Nepidae</u>
<i>Laccobius neapolitanus</i> Rottenberg, 1874	Nepa
<i>Laccobius obscuratus</i> Rottenberg, 1874	<u>Notonectidae</u>
<i>Laccobius sinuatus</i> Motschulsky, 1849	Anisops
<i>Laccobius ytenensis</i> Sharp, 1910	Notonecta
<u>Noteridae</u>	<u>Pleidae</u>
Noterus	Plea
<i>Noterus laevis</i> Sturm, 1834	<u>Veliidae</u>
<u>Scirtidae</u>	Microvelia
Cyphon	Velia
Elodes	Odonata
Hydrocyphon	<u>Aeshnidae</u>
Diptera	Anax
<u>Anthomyiidae</u>	Boyeria
Limnophora	<u>Calopterygidae</u>
<u>Athericidae</u>	Calopteryx
Atrichops	<u>Coenagrionidae</u>
Ibisia	Cercion
<u>Ceratopogonidae</u>	Ischnura
Dasyhelea	Pyrrhosoma
<u>Chironomidae</u>	<u>Cordulegastridae</u>
Chironomini	Cordulegaster
Corynoneura	<u>Gomphidae</u>
Tanytarsini	Gomphus
<u>Culicidae</u>	Onychogomphus
Anopheles	<u>Libellulidae</u>
<u>Diamesinae</u>	Libellula
<u>Dixidae</u>	Orthetrum
<u>Empididae</u>	Sympetrum
<u>Ephydriidae</u>	<u>Platynemididae</u>
<u>Hemerodromiinae</u>	Platynemis
<u>Limoniidae</u>	Plecoptera
Eloeophyla	<u>Leuctridae</u>
Pseudolimnophila	Leuctra
<u>Orthocladinae</u>	<u>Nemouridae</u>
<u>Simuliidae</u>	Nemoura
<u>Stratiomyidae</u>	Protonemura
Oxycera	<u>Perlidae</u>
<u>Syrphidae</u>	Dinocras
<u>Tabanidae</u>	Eoperla
Tabanus	Perla
<u>Tanypodinae</u>	<u>Perlodidae</u>
<u>Tipulidae</u>	Isoperla
Tipula	Trichoptera
Ephemeroptera	<u>Beraeidae</u>
<u>Baetidae</u>	<u>Brachycentridae</u>
Baetis	Micrasema
Centroptilum	<u>Drusinae</u>
Cloeon	<u>Hydropsychidae</u>
Procloeon	Cheumatopsyche
<u>Caenidae</u>	Hydropsyche
Caenis	<u>Hydroptilidae</u>
<u>Ephemerellidae</u>	Agraylea
Ephemerella	Hydroptila
Serratella	<u>Lepidostomatidae</u>
Torleya	Lasiocephala
<u>Ephemeridae</u>	<u>Leptoceridae</u>
Ephemer	Athripsodes
<u>Heptageniidae</u>	<u>Limnephiliidae</u>
Ecdyonurus	Allogamus
Epeorus	Halesus
Rhithrogena	Stenophylax
<u>Leptophlebiidae</u>	<u>Limnephiliinae</u>
Habroleptoides	<u>Polycentropodidae</u>
Habrophlebia	<u>Psychomyiidae</u>
Paraleptophlebia	Metatype
<u>Polymitacidae</u>	Tinodes
Ephoron	<u>Rhyacophilidae</u>
<u>Potamantidae</u>	Rhyacophila
Potamanthus	<u>Sericostomatidae</u>
Hemiptera	Sericostoma
<u>Aphelocheiridae</u>	
Aphelocheirus	

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Figure 1. Location of the study area, hydrological classes in the river network and sampling sites.
290x533mm (300 x 300 DPI)

Figure 2. NMDS plots of sites for each taxonomic level. The magnitudes of the correlations between the NDMS axes and the hydrological components as well as the environmental variables are shown as vectors.
289x431mm (300 x 300 DPI)

Figure 3. Variation of the percentage of families of the EPT and OCDH groups in the different hydrological classes along the flow magnitude gradient.
140x130mm (300 x 300 DPI)