

## Are water beetles good indicators of biodiversity in Mediterranean aquatic ecosystems? The case of the Segura river basin (SE Spain)

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**Abstract.** Water beetles were examined for use as potential biodiversity indicators in continental aquatic ecosystems in a semiarid Mediterranean region, the Segura river basin (SE Spain). The indicator value of water beetles was investigated by examining the degree to which their species richness patterns was correlated with other groups (Plecoptera, Trichoptera, Mollusca, Heteroptera and Ephemeroptera), and the efficiency of water beetle area networks (selected by complementarity) in conserving overall groups richness. The species richness patterns of Coleoptera, Ephemeroptera, Plecoptera and Trichoptera were significantly correlated with the *Remaining Richness value* (RR), defined as the total number of species found at a site (of all six groups examined) minus the number of species belonging to the considered indicator group. Area networks for Coleoptera selected by complementarity represented the highest RR percentage (84.46%) and contained more than 78% species of each group. Furthermore, water beetles meet most of the criteria proposed in the literature for choosing biodiversity indicator taxa. In our study, the correlation values and the percentage of species represented by family, genus and species complementary networks were similar and we suggest that the higher taxa of water beetles (genera or families) can be used as biodiversity surrogates for cost-effective practical surveys.

### Introduction

The maintenance of biodiversity has become one of the principal goals of conservation, so that it is necessary to identify particularly valuable areas for conservation on which to focus more detailed effort (Margules and Pressey 2000; Myers et al. 2000; Moore et al. 2003). Practical resources for measuring the overall biodiversity within a given area are limited (Williams and Gaston 1994; Kerr et al. 2000), and areas of high biological diversity are increasingly identified by means of biodiversity surrogates (Humphries et al. 1995; Caro and O'Doherty 1999). Among such surrogates, a wide range of biodiversity measures (such as climatic or vegetation data), higher taxonomic groups (genera or families) or indicator taxa are frequently used (Noss 1990; Williams 1996; Reyers and van Jaarsveld 2000; Heino et al. 2005).

Little attention has been paid to identifying possible indicator taxa for assessing freshwater biodiversity (Paszkowski and Tonn 2000; Heino 2002; Briers and Biggs 2003). Nevertheless, several aquatic macroinvertebrate groups, such as Odonata and Coleoptera, have been suggested as indicator taxa for monitoring population trends in other species, and for identifying areas of high regional biodiversity (Davis et al. 1987; Foster et al. 1990; Foster and Eyre 1992; Sánchez-Fernández et al. 2004a; Heino et al. 2005). However, the extent to which these or other taxa represent the biodiversity content of freshwater ecosystems has not been assessed (this is also the problem with the vast majority of studies that rely on bioindicators, which have generally used charismatic taxa). In this sense, several *a priori* suitability criteria have been proposed for the selection of indicators (Noss 1990; Pearson 1994; McGeoch 1998).

Biodiversity indicator taxa, in general, are groups of organisms with a sound taxonomy that have been well surveyed in a region. It is assumed that patterns of species richness, endemism, rarity or vulnerability in these taxa are indicative of similar patterns of unsurveyed taxa in the region (Pearson 1994). Nevertheless, the existence of a significant correlation between species or taxa richness does not necessarily indicate the extent to which sites selected on the basis of the indicator taxa represent wholesale species richness across all sites (Briers and Biggs 2003).

Such indicator taxa, so called biodiversity surrogates are useful for identifying areas for conservation management. Several methods for selecting areas of high biodiversity conservation value have been advocated, including hotspots of richness, hotspots of rarity and complementary areas (Williams 1996). As many authors have pointed out (Faith and Walker 1996; Williams et al. 1996; Howard et al. 1998; Abellán et al. in press), complementarity approaches are more effective than others methods involving scoring or richness and rarity hotspots to represent conservation targets, and should be integrated into the methodology for evaluating potential biodiversity indicators (Kati et al. 2004). Complementarity can provide an effective answer concerning where conservation efforts should be concentrated (Brooks et al. 2001; Sauberer et al. 2004).

In some cases, the number of higher taxonomic groups in a region is used as a surrogate for the number of local species within the same clade, given that a relationship between these different taxonomic levels can be established. The advantage of this approach is that the number of families or genera can be documented more rapidly than the number of species (Williams and Gaston 1994; Caro and O'Doherty 1999; Baldi 2003; Villaseñor et al. 2004). Moreover, aquatic organisms are usually larval stage forms, whose identification at species level is often problematic and sometimes impossible.

These kinds of criteria may help in the selection of indicators for species and higher taxa, but formal tests are required to assess how well the chosen indicators reflect the overall biodiversity.

We attempt to evaluate the use of water beetles, the most studied group of insects in the study area, as biodiversity indicators in freshwater ecosystems of

the Segura river basin (southeast Spain). The study area is a region of special interest, because, despite being one of the most arid zones of Europe, it has a high diversity of aquatic ecosystems and a rich and endemic biota (Médail and Quézel 1997; Myers et al. 2000; Abellán et al. 2005). Furthermore, most of these habitats are of special significance on a European scale and some of them are very unusual, such as hypersaline streams (Moreno et al. 1997; Sánchez-Fernández et al. 2004a).

The aim of this study is to answer the following questions:

- (i) Is species richness in water beetles correlated with overall species richness and, particularly, with the species richness of five macroinvertebrate groups (Heteroptera, Mollusca, Trichoptera, Ephemeroptera and Plecoptera)?
- (ii) Are complementary sets of sites based on water beetles more efficient in capturing the greatest number of species than those based on the other macroinvertebrate groups?
- (iii) Is the higher-taxon richness of water beetles suitable for predicting overall species richness in aquatic ecosystems?

## Methods

### *Study area and dataset*

The study was performed in the Segura river basin, a Mediterranean region located in the southeast of the Iberian Peninsula and encompassing an area of 18815 km<sup>2</sup> (Figure 1). Climatic patterns range from humid in the northwest mountains to semiarid in the rest of the study area. The geology ranges from limestone at the uplands headwaters to salt-rich tertiary marl in mid and lowlands, which also define the environmental conditions of the waterbodies in the area, allowing a high heterogeneity in the aquatic ecosystems present (Millán et al. 1996; Moreno et al. 1997).

Forty sites were selected to include the whole variety of water body types known within the study area and taking into consideration the available information on the six well studied taxonomic groups of macroinvertebrates in the study area: Coleoptera, Heteroptera, Mollusca, Trichoptera, Ephemeroptera and Plecoptera. The sites selected were grouped into four types of habitat: lotic freshwater (19 sites), lentic freshwater (10 sites), lotic saline (10 sites) and lentic saline waters (1 site).

Data on the species were obtained from our own fieldwork and literature records: Mollusca (Gómez 1988); Ephemeroptera and Plecoptera (Ubero-Pascal 1996); Coleoptera (Sánchez-Fernández et al. 2004b); Heteroptera (Millán et al. 1988); Trichoptera (Bonada et al. 2004). Macroinvertebrates were sampled with a D-frame net (500 µm mesh) and sampling collection generally took around 30 min per site. Samples were preserved in 75% ethanol and taken to the laboratory for identification. Although not visited with a regular

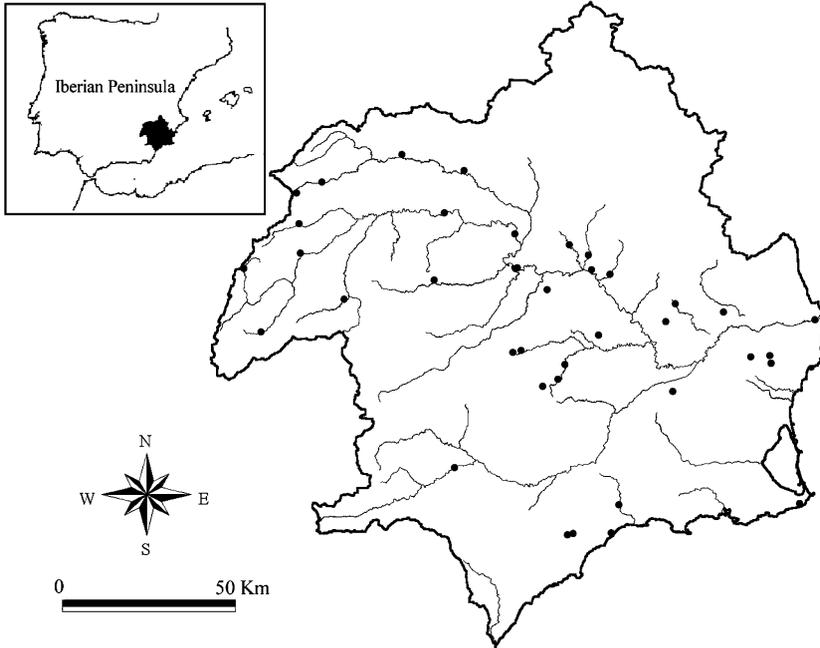


Figure 1. Map of the study area (Segura river basin) showing the main water courses. Location of sampling localities are indicated with a black solid dot.

frequency, each site was surveyed at least twice and most were sampled on five occasions. Thus, all published and unpublished data currently known to us were included.

#### *Data analysis*

Spearman correlations were used to evaluate the relationship between species richness patterns of the different groups of macroinvertebrates, and between the richness of each group and the total number of species found at a site (of all six groups examined) minus the number of species belonging to the considered indicator group a parameter (*RR* or *Remaining Richness*). This procedure avoids giving higher weight in the correlation of the groups with a greater number of species. Spearman correlations were used because data are not normally distributed. Statistical analyses were performed using Statistica for Windows (Release 4.5). We also examined how the habitat factor affects these relationships by analyzing data subsets corresponding to three of the four different habitat types (lotic freshwater, lentic freshwater and lotic saline waters). Saline lentic systems were not analyzed due to the insufficient number of sites.

Complementary networks for each indicator taxa were selected by applying an iterative algorithm based on the complementarity principle. This principle refers to the degree to which an area contributes otherwise unrepresented features (e.g. species) to a set of areas (Vane-Wright et al. 1991). We therefore used complementarity to maximise the number of species represented within a given number of areas (10 sampling sites) for each group of macroinvertebrates. The algorithm is a modification of that proposed by Kirkpatrick (1983) and it is applied as described below.

In a first step, the site with the greatest number of species was selected. The next site selected was that with the highest number of species not included in the first site (thus providing the greatest number of species by complementarity). In case of equality, the site selected was the one with the greater richness of species (included or not in the first site selected). This procedure was repeated until 10 sites (an arbitrary number) had been selected. Thus, a complementary network for each group was obtained. Finally, the RR percentage and the total number of species represented in each network were calculated as a measure of their effectiveness for preserving biodiversity.

Spearman correlation was also used to assess whether the higher taxon richness of water beetles is significantly correlated with the species richness of the other groups and with the RR value. The efficiency of the complementary network selected according to the higher taxa of water beetles was also evaluated using the same methodology as above.

## Results

We recorded 57 families, 138 genera and 295 species in 40 sampling sites of the Segura river basin (Table 1). Coleoptera and Heteroptera species were widespread in the study area (40 and 34 sites, respectively), and were present in all four types of habitat described. Ephemeroptera and Mollusca species were absent from one type of habitat (lentic saline waters) but appeared in 35 and 26 sites, respectively. Trichoptera species were found in 27 sites, including two types of habitat (freshwater and saline lotic waters). Plecoptera species were

*Table 1.* Number of families, genera and species of the six groups recorded in the study area.

	Families	Genera	Species
Coleoptera	10	52	147
Heteroptera	11	17	29
Ephemeroptera	7	8	10
Plecoptera	10	20	35
Mollusca	5	9	23
Trichoptera	14	32	51
Total	57	138	295

less widespread, being confined to freshwater lotic ecosystems and only appearing in 13 sites (Table 2).

Table 3 shows that the Trichoptera, Plecoptera, Ephemeroptera, Mollusca and Coleoptera species richness patterns were significantly correlated ( $p < 0.01$ ) with their respective *RR* values. The strongest correlation across groups was found between Trichoptera and Ephemeroptera, followed by Trichoptera and Plecoptera, and Ephemeroptera and Plecoptera. Coleoptera was significantly correlated with all groups, with the exception of Mollusca and Ephemeroptera. Mollusca species richness was significantly correlated with Ephemeroptera, Plecoptera and Trichoptera. Heteroptera species richness was significantly correlated only with Coleoptera.

Pairwise Spearman correlation coefficients of the species richness in each type of habitat are shown in Table 4. In lotic freshwater ecosystems, the results were similar to those obtained for combined habitats, with the same groups significantly correlated with *RR* values and the highest correlation was shown by Plecoptera. The strongest correlation across taxa was between Plecoptera and Trichoptera species richness patterns. In saline lotic systems and lentic freshwater systems, none of the correlations with *RR* values was significant, although the highest values were shown by Coleoptera.

Concerning the complementarity method, our results showed that the complementary network using overall species, maximised the representation of the total species (91.86%), as was expected. Within groups, the Coleoptera complementary network captured the highest *RR* percentage (84.46%),

Table 2. Number of sites with the presence of each group in the different types of habitat.

	Lotic-freshwater ( <i>n</i> = 19)	Lentic-freshwater ( <i>n</i> = 10)	Lotic-saline ( <i>n</i> = 10)	Lentic-saline ( <i>n</i> = 1)	All sites
Coleoptera	19	10	10	1	40
Heteroptera	16	7	9	1	33
Ephemeroptera	19	7	9	0	35
Plecoptera	13	0	0	0	13
Mollusca	17	5	4	0	26
Trichoptera	18	3	0	0	21

Table 3. Results of pairwise Spearman correlation coefficients for the species richness of the six groups of taxa studied (40 sampling sites).

	Coleoptera	Heteroptera	Ephemeroptera	Plecoptera	Mollusca	Trichoptera	<i>RR</i>
Coleoptera	–	0.50**	0.28	0.50***	0.14	0.51***	0.52***
Heteroptera		–	0.06	0.22	–0.10	0.13	0.31
Ephemeroptera			–	0.78***	0.67***	0.88***	0.54***
Plecoptera				–	0.52***	0.86***	0.73***
Mollusca					–	0.68***	0.42**
Trichoptera						–	0.75***

\* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

Table 4. Pairwise Spearman correlation coefficient of the species richness in each type of habitat.

Lotic-freshwater ( <i>n</i> = 19)	Coleoptera	Heteroptera	Ephemeroptera	Plecoptera	Mollusca	Trichoptera	Total	RR
Coleoptera	–	0.55*	0.41	0.70***	0.06	0.68**	0.87***	0.76***
Heteroptera		–	0.08	0.22	–0.07	0.22	0.45	0.33
Ephemeroptera			–	0.78***	0.12	0.72***	0.70***	0.68**
Plecoptera				–	0.09	0.88***	0.89***	0.87***
Mollusca					–	0.19	0.20	0.16
Trichoptera						–	0.90***	0.78***
<i>Lenitic-freshwater</i>								
<i>(n</i> = 10)								
Coleoptera	–	0.60	–0.11	–	–0.27	0.27	0.99***	0.56
Heteroptera		–	–0.24	–	–0.53	–0.25	0.65	0.55
Ephemeroptera			–	–	0.30	0.62	–0.06	–0.17
Plecoptera				–	–	–	–	–
Mollusca					–	0.29	–0.32	–0.41
Trichoptera						–	0.27	0.23
<i>Lotic-saline</i>								
<i>(n</i> = 10)								
Coleoptera	–	0.39	–0.30	–	0.07	–	0.91***	0.33
Heteroptera		–	–0.35	–	–0.48	–	0.63	0.18
Ephemeroptera			–	–	0.15	–	–0.19	–0.35
Plecoptera				–	–	–	–	–
Mollusca					–	–	–0.04	–0.18
Trichoptera						–	–	–

\* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

representing more than 78% species of each group, followed by Plecoptera, Trichoptera, Heteroptera, Mollusca and Ephemeroptera complementary networks with 80.88, 78.69, 77.82, 71.93 and 71.92% of their *RR* values, respectively. Trichoptera and Heteroptera complementary networks also retained a

Table 5. Percentage of species that would be represented in complementary networks for each group.

	Complementary network of						Overall species
	Heteroptera	Ephemeroptera	Coleoptera	Mollusca	Plecoptera	Trichoptera	
Heteroptera (%)	86.21	48.28	93.10	58.62	55.17	79.31	93.10
Ephemeroptera (%)	82.86	100	80	82.86	80	82.86	82.86
Coleoptera (%)	76.19	65.31	96.60	70.07	80.27	74.83	92.52
Mollusca (%)	90	90	90	100	80	90	90
Plecoptera (%)	73.91	86.96	91.30	78.26	100	91.30	100
Trichoptera (%)	78.43	94.12	78.43	74.51	98.04	100	92.16
Total (%)	78.64	75.25	90.17	72.88	82.37	82.37	91.86
RR (%)	77.82	71.92	84.46	71.93	80.88	78.69	–

high percentage of species of each other group (upper 73%). In general, the percentage of species of one group represented by any other group was not less than 48% (Table 5).

Table 6 shows that family, genus and species richness was significantly correlated with RR, and family richness showed the highest Spearman correlation coefficient. The percentage of species represented in the complementary networks of the beetle species, genera and families is shown in Table 7. In general, the correlation values and percentage of species represented by the family, genus and species complementary networks were similar.

**Discussion**

It is assumed that if species counts for a potential indicator taxa are strongly correlated with counts for other taxa, then, on average, regions where many species of the indicator taxa occur will also be characterised by high species counts of other taxa. In general terms, when Plecoptera, Trichoptera, Ephemeroptera or Coleoptera show high species richness, there is also a high degree of overall species richness. However, the status of particular taxa as indicators may vary with habitat type, and hence taxa that are good indicators in ponds may not necessarily be good indicators for lakes or other water bodies

*Table 6.* Spearman correlation coefficient between beetles richness at different taxonomic levels (families, genera and species), and the species richness of the other groups and RR value in the study area (40 sampling sites).

	Coleoptera	RR
Species	–	0.52***
Genera	0.98***	0.53***
Families	0.87***	0.63***

\* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

*Table 7.* Percentage of species represented in complementary networks using different taxonomic levels of water beetles (families, genera and species).

	Complementary network of		
	Coleoptera species	Coleoptera genera	Coleoptera families
Heteroptera (%)	93.10	89.66	86.21
Ephemeroptera (%)	77.14	88.57	82.86
Coleoptera (%)	95.24	93.20	88.44
Mollusca (%)	90.00	70.00	80.00
Plecoptera (%)	91.30	86.96	86.96
Trichoptera (%)	78.43	80.39	84.31
Total (%)	90.17	88.73	86.44
RR (%)	84.46	83.09	83.28

(Davis et al. 1987; Sahlen and Ekstubbé 2001; Briers and Biggs 2003). This study was carried out to select indicators of biodiversity in a variety of water bodies, rather than in one particular habitat type. If we only examine the degree of congruence of species richness patterns, Plecoptera or Trichoptera could be proposed as the best biodiversity indicators, despite the fact that they only occur in one or two types of habitat. In other words, only lotic freshwater systems would be selected if we used Plecoptera as indicator group, and other sites of special interest, such as saline streams or ponds, from which Plecoptera and Trichoptera are normally absent, would be excluded even though they contain specialised communities of rare or endemic species, perhaps with a low overall species richness (Moreno et al. 1997; Abellán et al. 2005). Coleoptera, on the other hand, present higher correlations than Heteroptera, the only other group found across all the habitat types analysed.

Nevertheless, examining the correlation between species richness patterns is only one of the possible ways to evaluate biodiversity indicators (Kati et al. 2004). In this sense and taking into consideration that environmental heterogeneity is one of the main factors generating biological diversity (Cellot et al. 1994; Huston 1994; Kati et al. 2004), the complementary network of water beetles encompasses the gradient of environmental heterogeneity and thus constitutes a reliable local aquatic biodiversity surrogate in semiarid Mediterranean regions.

Thus, water beetles can be selected as the best indicator group for selecting areas of high biodiversity in aquatic ecosystems from the Segura river basin, because their species richness patterns are significantly correlated with RR and, furthermore, their complementary network contains the greatest proportion of RR (84.46%) and more than 78% of the species of each group. Moreover, although Plecoptera, Ephemeroptera and Trichoptera showed higher correlation values with RR, the Coleoptera richness relationship was more consistent between habitats.

Biodiversity indicators will be useful if they cover a reasonably wide geographic range (Wilcox 1984; Caro and O'Doherty 1999) and occur in a broad range of habitat types. Within a geographic area, they should have high habitat fidelity because their absence (in the face of habitat disturbance) may be a sensitive indicator of the absence of other species (Panzer et al. 1995). In our case, water beetles comprise a great number of species, they show high functional diversity and they are capable of colonising a wide variety of habitats (Ribera and Foster 1993). In fact, together with Heteroptera, they are the only groups that were present in all the habitat types. Furthermore, beetles appeared in all 40 sites sampled. Thus, they met most of the criteria proposed in the literature for choosing indicator taxa (Noss 1990; Pearson and Cassola 1992; Pearson 1994).

Importantly too, beetles are taxonomically and faunistically well-known in the Iberian peninsula (Ribera et al. 1998; Ribera 2000), and their importance as indicators of the spatial and temporal changes that take place in aquatic systems has been demonstrated (Bournaud et al. 1992; Richoux 1994). They

have also been used for ranking sites in relation to their conservation value (Jeffries 1988; Foster et al. 1990).

Two types of biodiversity indicator can be differentiated depending, on the spatial scale: indicators at local scale (alpha-diversity) and indicators for biodiversity conservation at a regional or national scale (Duelli and Obrist 2003). In the first case, we suggest using Plecoptera or Trichoptera as biodiversity indicators in lotic freshwater systems, and Coleoptera in lotic saline and lentic systems, whether saline or freshwater. In the second case, the value of the measurable units of biodiversity depends on their rarity or uniqueness with regard to a higher level area, and water beetles can be selected as the best indicator group for selecting areas for conservation. In this context, areas with the highest aquatic biodiversity could be identified by using water beetles as a surrogate and then applying an iterative algorithm of complementarity. This algorithm makes an integrated selection of a network of sites which, in a complementary way, sometimes omits sites with a higher richness than others which would merely provide redundant information. Furthermore, this method presents the additional advantage of flexibility in the selection process, which means that new criteria can be included in the model, such as the proximity to already protected areas, the presence of at least two populations of each species, the irreplaceable character of some of these areas, etc. (Margules et al. 2002). We emphasise the importance of applying the principle of complementarity, instead of only testing the correlation of species richness patterns, when assessing the value of potential indicators for biodiversity conservation.

One limitation to the generalization of the results from this study is that it only aquatic invertebrate groups were considered, and the extent to which invertebrate taxa represent other groups, such as fish or plants, was not assessed. Nevertheless, in running waters, the congruence of species richness among bryophytes, macroinvertebrates and fish is generally low (Paavola et al. 2003; Heino et al. 2005).

Since it is difficult to express the components of a system representing a landscape or community using one group of species only, great care should be taken in the selection of areas based only on one group as a surrogate of total biodiversity and before extrapolating to other biological groups. The trend is to choose different, poorly related and representative of the different components of the system to study (Halffter et al. 2001) or to use overall available data of species in a zone. Thus, water beetles could be taken as a suitable complementary surrogate in biodiversity research.

The large number of species of water beetles would make survey work more difficult, and this might be a problem for their use as surrogates of aquatic biodiversity, this problem can be overcome using higher taxon richness values (genus or family). In our study, the correlation values and the percentage of species represented by family, genus and species complementary networks were similar. Several studies support the idea of a relationship between the number of higher taxa and the numbers of species in a given area (Williams and Gaston

1994; Williams et al. 1997; Baldi 2003) suggesting that the former would act as a good surrogate in more cost-effective practical surveys.

Although a group could be a good indicator of biodiversity in one geographical area, it may not be representative of species richness patterns elsewhere, due to biogeographical or climatic constraints (Su et al. 2004), but it could be valid for regions with similar environmental and ecological features. Our results suggest that water beetles are a good biodiversity indicator, both at local and regional scales, and can be used for the rapid and inexpensive monitoring of biodiversity in aquatic ecosystems of Mediterranean areas. In this sense, these results provide conservationists and managers with an efficient tool for identifying priority areas for freshwater biodiversity conservation in the Mediterranean Basin.

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