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Aquatic Coleoptera distribution patterns and their environmental drivers in central Portugal, Iberian Peninsula

Amaia Pérez-Bilbao[a,*], Ana Raquel Calapez[b], Maria João Feio[b]

[a] Ecology and Animal Biology Department, Faculty of Biology, University of Vigo, Campus Lagoas-Marcosende, 36310 Vigo, Spain
[b] Dept. Zoology & IMAR, University of Coimbra, Largo Marquês de Pombal, 3004-517 Coimbra, Portugal

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ABSTRACT

Here, we present the distribution patterns of aquatic Coleoptera species collected in Central Portugal (240 samples, 136 stream sites) and their most important environmental drivers. A total of 81 species were identified from which 16 were endemic of the Iberian Peninsula confirming the high species richness and importance for conservation of this area. The families with higher species richness were Dytiscidae (24 species), Hydraenidae (16 species), Elmidae (13 species) and Hydrophilidae (12 species). We found six groups mainly based on altitudinal, conductivity and lithology gradients. We found a replacement of families, filling different niches over the catchments environmental gradients. According to the distribution maps, the families Dytiscidae and Hydrophilidae appeared in lowland streams while Hydraenidae were collected in upper stretches of the rivers. Various species appeared widely distributed along the different watersheds, most of them belonging to the families Elmidae and Hydraenidae. The highest species richness was found for the *Hydraena*, represented by 13 species in our study area. Some *Hydraena* species tend to co-occur at the same sites and have a high similarity in their distribution. This first study of ecological patterns of Coleopteran species in Portugal brought thus new insights to knowledge of this invertebrate group.

Introduction

Rivers are aquatic ecosystems with a high ecological and biological value, but very vulnerable to anthropogenic impacts (Benetti et al. 2012). In future decades, human pressure on water resources will endanger biological diversity of freshwater habitats (Strayer 2006). The Water Framework Directive (Council of the European Communities 2000) specifies several quality elements necessary for assessing the ecological state of a river.

One of these biological elements is the benthic fauna, including aquatic Coleoptera. They inhabit almost every type of aquatic ecosystems, and their great variety of morphological and ecological adaptations makes them the most diverse animal order, with about 12,600 aquatic beetle species described so far (Jäch and Balke 2008). Aquatic beetles are considered good indicators of biological diversity (Bilton et al. 2006; Sánchez-Fernández et al. 2004, 2006; Guareschi et al. 2012) and ecological quality of the aquatic ecosystems they inhabit (Pérez-Bilbao and Garrido 2009; Benetti and Garrido 2010). It is well known that aquatic Coleoptera can be categorized by their main habitat association into species of running waters (lotic) and species of stagnant waters (lentic), with few species able to inhabit both type of habitats (Ribera and Vogler 2000). Other factors such as altitude (Valladares et al. 1990; Garrido et al. 1994), conductivity (García-Criado 1999; Valladares et al. 2002; Pérez-Bilbao and Garrido 2009), aquatic vegetation (Diehl and Kornijów 1998; Nilsson et al. 1994) or temporal variability of the habitat (Hanquet et al. 2004) also play an important role in aquatic beetle assemblage composition and species distribution.

The Iberian Peninsula is a recognized hotspot for biodiversity of many biological groups and more than 500 species of aquatic beetles have been reported in this region. According to Ribera et al. (2003), the Iberian Peninsula is the only region of Europe where the proportion of lotic/lentic species differs from other areas. Iberian lotic habitats present a higher species richness than lentic ones, excluding the species that can be found in both type of habitats. For Portugal, data on aquatic Coleoptera was mainly provided by taxonomical studies (see Valladares and Ribera 1999; Fery and Fresneda 2007) and few environmental quality studies (Ferreira et al. 2004; Feio et al. 2007; Del Arco et al. 2012), but no work has been done with emphasis on species distribution.

Therefore, the main objective of the current study is to provide robust and integrative information of the Coleoptera species and the distribution patterns of adults collected in a large number of sites in central Portugal. Moreover, we aim to determine which

* Corresponding author. Tel.: +34 986 81 25 81; fax: +34 986 81 25 56.
E-mail address: amaiapb@uvigo.es (A. Pérez-Bilbao).

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are the most important environmental drivers of species distribution and investigate patterns of species co-existence or segregation, namely those of the same genus.

Material and methods

Study area

The study area comprised sites sampled in four watersheds in central Portugal (Tejo, Mondego, Vouga, Lis) and several small streams discharging directly to the ocean, called West and Northwest streams, according to their location (Fig. 1). The climate of this region is considered temperate with Atlantic influence, with precipitation distributed all over the year, even though more concentrated in autumn and winter seasons and that can be of snow in the mountains. The highest mountains of this region include the upper Mondego basin and reach 2000 m. The temperatures are higher in summer and lower in winter, but vary considerably from the interior where they can reach below zero values during winter to the coast where they are milder (minimum average winter temperatures of 10–12 °C).

The Tejo River is the longest one in the Iberian Peninsula with a total area of 80,600 km^2, 30% of this area belonging to Portugal (24,850 km^2). It runs to the Atlantic Ocean in a NE–SW orientation. In Portugal, the Tejo creates a natural division between the northern and southern parts of the country. While in the North the climate is typically temperate with Atlantic influence, in the south it becomes typically Mediterranean. Here we have sampled in northern tributaries of the Tejo River.

The Mondego is the largest river entirely in Portuguese territory (227 km) and its catchment covers an area of 6670 km^2 (Marques et al. 2002). It runs to the Atlantic Ocean in a NE–SW orientation. In the high and medium section, the bedrock is dominantly composed of granite and schist and stream substrates are coarse. In the low section, the river and streambeds are mainly composed sand or cobbles with mixed origin and limestone.

The Vouga catchment (3600 km^2) is located to the north of the Mondego, with bedrock dominated by schists and granites. Large eucalyptus plantations are located in the basin (Feio et al. 2007).

The Lis, southern from Mondego River, is the smallest catchment (945 km^2). The river runs its 40 km from SE to NW. In its first section, the river runs through a limestone massif to finish in alluvial floodplains not higher than 100 m. Part of the coastal tributaries run through an old pine forest covering sand dunes (Feio et al. 2007).

Field and laboratory work

We selected 95 sampling sites in the Mondego River basin, 21 in the Vouga, nine in West and Northwest streams, eight in the Lis, and three in the Tejo. These sites were sampled at least once during the years 2001, 2002, 2004, 2005, 2007, 2011 and 2012 and a total of 240 samples were analyzed.

Aquatic Coleoptera were sampled with a hand-net (500 μm mesh size), each sample composed by six composite sub-samples. The sub-samples were distributed proportionally to the area occupied by the most representative habitats (stones, sand and silt, blocks, submerged plants and algae) and defined by an area of 1 m × 0.25 m (hand net side) toward upstream. The composite sample was fixed with formalin (4%) and in the laboratory aquatic coleopterans were sorted and preserved in ethanol (80%). Adults of aquatic Coleoptera were identified to species level following mainly Franciscolo (1979), Valladares (1988), Angus (1992) and Gayoso (1998).

The environment was characterized by different variables describing geographical location, drainage area, atmospheric conditions, stream morphology and hydrology, and water characteristics (Tables 1 and 2). Current velocity (m/s), pH, dissolved oxygen (mg/l) and conductivity (μS/cm) were measured in the field. Altitude (m a.s.l.) was measured with a GPS (Garmin) while distance to the source (km), drainage area (km^2) and slope of drainage basin (%) were calculated using GIS tools. Alkalinity (mg/l) was obtained by titration (APHA 1995). Finally, mean annual air temperature (°C) and precipitation (mm), lithology and mineralization values were obtained from cartographic sources of the Portuguese Instituto do Ambiente.

Data analysis

According to the chorological scheme proposed by Ribera et al. (1999) and Fery and Fresneda (2007), the collected species were assigned to a biogeographical category:

- Trans-Pyrenean (N): Species present in Europe, north of the Pyrenees and some areas of the Iberian Peninsula, but not in North Africa.
- Southern (S): Species present in North Africa and in some areas of the Iberian Peninsula, but not extending north of the Pyrenees.
- Trans-Iberian (T): Species present in Europe north of the Pyrenees, the Iberian Peninsula and North Africa.
- Endemic (X): Species present only in the Iberian Peninsula, although exceptionally their distribution can reach the northern face of the Pyrenees or southern areas of France.

For statistical analyses, samples with only one individual were removed from the data matrix, considering that a species was present in a site when more than one individual was collected. Presence/absence of species was used.

The data were analyzed by multivariate statistical methods with PRIMER & PERMANOVA+ software (version 6, Primer-E Ltd.). Environmental data were previously standardized.

Similarity relationships among Coleoptera assemblages of all sites were then determined by the Bray–Curtis coefficient. Groups of similar sites in terms of Coleoptera composition were identified using a Cluster analysis (group average mode) and graphically represented by a non-metric Multi-Dimensional Scaling (NMDS) mapped in two dimensions. These analyses were also performed for the *Hydraena* genus.

To investigate the groups' consistency the SIMilarity PERcentages-species contributions (SIMPER) analysis was used to obtain dissimilarities between all pairs of groups and determine the most contributive species to within groups similarity. SIMPER examines the contribution of each species to the average Bray–Curtis dissimilarity between groups of samples and also determines the contribution to similarity within a group (Clarke and Warwick 2001).

Analysis of similarity test (ANOSIM) was used to test if the groups of sites, based on their biotic data, were significantly distinct. This is a simple non-parametric permutation procedure, which is applied to the rank similarity matrix underlying the ordination or classification of samples. The null hypothesis is that there are no differences in community composition of the groups. The procedure computes a test statistic (R), which is close to unity if there is complete segregation between groups and close to zero if there is little or no segregation, and a significance level (t) (Clarke and Warwick 2001).

A distance-based redundancy analysis (dbRDA) was done to investigate the relation between the assemblages and the environmental variables. This is a method for carrying out constrained ordinations on data using non-Euclidean distance measures (Anderson et al. 2008). To run this analysis, the original set of 13 environmental variables was first reduced to a smaller set of