Arxius de Miscel·lània Zoològica, 15 (2017): 8–29 ISSN: 1698–0476

Biogeographic evaluation of the dragonflies and damselflies in the Eastern Iberian Peninsula

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Fontana–Bria, L., Frago, E., Prieto–Lillo, E. & Selfa, J., 2017. Biogeographic evaluation of the dragonflies and damselflies in the Eastern Iberian Peninsula. *Arxius de Miscel·lània Zoològica*, 15: 8–29.

Abstract

Biogeographic evaluation of the dragonflies and damselflies in the Eastern Iberian Peninsula.— Insects are one of the most diverse groups of animals in terrestrial ecosystems, and are thus a good model system to study macrogeographic patterns in species' distributions. Here we perform a biogeographical analysis of the dragonflies and damselflies in the Valencian Country (Eastern Iberian Peninsula). We also compare the species present in this territory with those in the adjacent territories of Catalonia and Aragon, and with those present in the whole Iberian Peninsula. Furthermore, we update the list of species of dragonflies and damselflies in the Valencian territory (65 species), and discuss the current status of two of them: *Macromia splendens* and *Lindenia tetraphylla*. Our results highlight that the Valencian Country has a higher proportion of Ethiopian elements but a lower proportion of Eurosiberian elements than Catalonia and Aragon. We also emphasize the importance of volunteer work in providing new knowledge on this group of iconic insects, and the relevance of museum collections in preserving them. The role of climate change in the distribution of Odonata is also discussed.

Key words: Odonata, Valencian Country, Spain, Iberian Peninsula, Biogeography, Climate change

Resumen

Evaluación biogeográfica de las libélulas y los caballitos del diablo del este de la península ibérica.— Los insectos son uno de los grupos de animales más diversos de los ecosistemas terrestres, por lo que constituyen un buen sistema modelo para estudiar los patrones macrogeográficos en las distribuciones de especies. En este trabajo se realiza un análisis biogeográfico de las libélulas y los caballitos del diablo del País Valenciano (este de la península ibérica). También se comparan las especies presentes en este territorio con las de los territorios vecinos de Cataluña y Aragón, y con las presentes en toda la península ibérica. Con este objetivo se actualiza la lista de especies de libélulas y caballitos del diablo del territorio valenciano (65 especies) y se discute el estatus actual de dos de ellas: *Macromia splendens* y *Lindenia tetraphylla*. Los resultados ponen de manifiesto que, con relación a Cataluña y Aragón, el País Valenciano está enriquecido con elementos etiópicos, pero tiene una menor proporción de elementos eurosiberianos. También debe destacarse la importancia del trabajo de voluntariado para proporcionar nuevos conocimientos sobre este

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grupo de insectos icónicos y la relevancia de las colecciones de museos para preservarlos. Se discute asimismo el papel del cambio climático en la distribución de los odonatos.

Palabras clave: Odonata, País Valenciano, España, Península ibérica, Biogeografía, Cambio climático

Resum

Avaluació biogeogràfica de les libèl·lules i els espiadimonis de l'est de la península Ibèrica.— Els insectes són un dels grups d'animals més diversos dels ecosistemes terrestres, raó per la qual constitueixen un bon sistema model per estudiar els patrons macrogeogràfics en les distribucions d'espècies. En aquest treball es fa una anàlisi biogeogràfica de les libèl·lules i els espiadimonis del País Valencià (est de la península Ibèrica). També es comparen les espècies presents en aquest territori amb les dels territoris veïns de Catalunya i Aragó, i amb les presents a tota la península Ibèrica. Amb aquest objectiu s'actualitza la llista d'espècies de libèl·lules i espiadimonis del territori valencià (65 espècies) i es discuteix l'estatus actual de dues d'elles: *Macromia splendens* i *Lindenia tetraphylla*. Els resultats posen de manifest que, amb relació a Catalunya i Aragó, el País Valencià està enriquit amb elements etiòpics, però té una proporció menor d'elements eurosiberians. També cal destacar la importància del treball de voluntariat a l'hora de proporcionar nous coneixements sobre aquest grup d'insectes icònics i la rellevància de les col·leccions de museus per preservar-los. Es discuteix així mateix el paper del canvi climàtic en la distribució dels odonats.

Paraules clau: Odonata, País Valencià, Espanya, Península Ibèrica, Biogeografia, Canvi climàtic

Rebut: 01/10/16; Acceptació condicional: 14/02/17; Final acceptance: 14/03/17

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Introduction

Patterns of animal distribution depend on several factors, including abiotic factors such as geological history, climate or environmental conditions, and biotic factors such as food resources or competition. These factors vary at the spatial scale (*i.e.* local, regional or global) and depend on the taxonomic level at which the organisms are considered (Cox & Moore, 2000). As one of the most diverse taxa in terrestrial ecosystems, insects have provided a large body of knowledge on the interactions between species and their environment. In this group, biogeographic patterns of distribution have been studied with data from entomological collections (Fountain et al., 2016), along with data from specimens directly observed in the field. Observational data often come from volunteers, especially in North America and in Europe where an emerging citizen science is becoming increasingly popular. This type of data collection is becoming an effective way to monitor spatiotemporal changes in species distributions in large geographical areas (Donnelly et al., 2014) and is particularly relevant in the face of current global changes, which can, for example, generate spatial and temporal mismatches in species interactions (Schweiger et al., 2008).

As an iconic group, the global diversity of damselflies and dragonflies is well known (Balian et al., 2008). Hence, published knowledge and the volunteer effort allows in some cases to use species distributions to explore their macrogeographic patterns of distribution. In dragonflies and damselflies, publications such as the recent study by Dijkstra et al. (2013) compile extensive data that provide an overview of species richness at the global level. Local studies that are limited to smaller territories, or revisions of particular taxonomic groups, however, are those that often provide new species to science (Zhang & Cai, 2013, 2014; Chen & Yeh, 2014; Von Ellenrieder, 2014). In addition to the individuals observed and/or sampled *in situ*, those deposited in museums can also help to confirm the existence of species in a specific area. These collections can also help to clarify phylogenetic questions, or determine correct synonyms. This has proven useful not only in Odonata (Bailowitz et al., 2013; Von Ellenrieder, 2013), but also in other animal taxa (Fountain et al., 2016).

Based on their distribution, different biogeographic systems have been used to classify the species of Odonata in the Iberian Peninsula. The system by St. Quentin (1960) established two biogeographic categories: a Mediterranean component or refuge fauna and a Eurosiberian component or invasion fauna. This system has been criticized because not all species were correctly classified, and others were not included. For this reason, Ocharan (1988) created a new classification system, which established seven biogeographic categories for the entire odonatofauna of the Iberian Peninsula. The biogeographic analyses used in subsequent works, such as those of Ferreras–Romero (1989) and Martín Casacuberta (2004), were based on the reference system of Ocharan (1988) and the system of St. Quentin (1960) (this latter system had been used with additions to improve it). However, for some species, the biogeographic classification proposed by Ocharan (1988) was later affected by the information provided by Davies & Tobin (1984, 1985), Tsuda (1991), Dumont (2003), Askew (2004) or Dijkstra & Lewington (2006). In addition, some studies included new species that were not found in the work of Ocharan (1988). All these changes were ultimately compiled in the work of Torralba Burrial & Ocharan (2007b), a study that provides information on the biogeography of the species found in different Spanish regions, with special emphasis on Aragon. In the present study we update the odonatofauna in the *País Valencià* (the Valencian Country), a Spanish territory located in the Eastern Iberian Peninsula. We also analyse the biogeography of the different species found, and we perform a comparison with Catalonia and Aragon, two adjoining regions in Spain. We selected these two regions because there are sufficient faunal data to allow such comparison. Since the study of Torralba Burrial & Ocharan (2007b), there have been new findings throughout the Iberian Peninsula, and we include these here to provide novel insights into the biogeography of these species.

Material and methods

Odonatofauna of the Valencian Country

The study of dragonflies in the Valencian Country (which includes the provinces of València, Castelló and Alacant in eastern Spain) has been enriched by the above–mentioned studies and by more territory–specific studies, including those by Andréu (1911), Boscá Seytre (1916), Navás (1922), Pardo (1942), Docavo Alberti (1983), Docavo Alberti et al. (1987), Navarro Matheu et al. (1988), Bonet Betoret (1990) and Julián i Natividad & Barrachina i de Gracia (1995). A provisional catalogue of the Valencian dragonflies was elaborated by Domingo Calabuig (2002), and in a subsequent work all knowledge on the Valencian Odonata was carefully collected in the catalogue by Baixeras et al. (2006).

Since these studies, however, there have been new Odonata records. Hence, to update the Valencian odonatofauna, we have compiled information from: (1) the catalogue '*Les libèl·lules de la Comunitat Valenciana*' (Baixeras et al., 2006); (2) the on–line resource database '*Banco de Datos de Biodiversidad de la Comunidad Valenciana'* (BDBCV), which is available at http://bdb.cma.gva.es/ (in collaboration with the group of volunteers '*Voluntariat Parotets'*, *Grup d´Estudi d´Odonats de la Comunitat Valenciana*); (3) revisions of museum collections (Fontana Bria, 2011; Fontana–Bria & Selfa, 2012); and (4) recent publications.

The catalogue by Baixeras et al. (2006) had 58 species, but new species of dragonflies have been added, including: *Aeshna juncea* (Prieto–Lillo et al., 2009), *Lestes sponsa*, *Sympetrum sanguineum* and *Sympetrum flaveolum* (Prieto–Lillo et al., 2012a), *Onychogomphus costae* (Fontana–Bria et al., 2012), *Trithemis kirbyi* (Prieto–Lillo et al., 2012b) and *Brachytron pratense* (Voluntariat Parotets, 2013; Tirado Bernat, 2014). Moreover, the distribution of some species has been expanded as they have been found in new locations within the same province, or in new provinces within the Valencian territory. These new records include: (1) *Zygonyx torridus* by Soler & Arlés (2007), *Lestes sponsa* by Evangelio Pinach & Monedero Ramos (2014), *Libellula quadrimaculata* by Evangelio Pinach et al. (2014) and *Sympetrum sanguineum* by Evangelio Pinach (2016); (2) information found at the '*Banco de Datos de Biodiversidad de la Comunidad Valenciana'* (BDBCV); (3) studies of Odonata diversity with the works of Sendra Pérez et al. (2012) and Evangelio Pinach et al. (2015), or studies of Odonata distribution with the work of *Sympetrum vulgatum ibericum* by Díaz Martínez & Evangelio Pinach (2015).

Odonatofauna of Catalonia and Aragon

The list of Catalan dragonflies is based on the studies by Martín Casacuberta (2004), Lockwood (2005), Luque Pino & Serra Sorribes (2006), Lockwood (2007), Lockwood et al. (2007), Escolà (2008a, 2008b), Lockwood (2010), Maynou i Señé (2010–2011), Escolà et al. (2011), Martín (2011), Cano–Villegas et al. (2012), Herrera–Grao et al. (2012), Martín & Maynou (2015), the catalogue '*Les libèl·lules de Catalunya*' (Martín et al., 2016) and on the information found in the web catalogue developed by the '*Grup d'estudi dels odonats de Catalunya (Oxygastra)'*: http://www.oxygastra.org/arxius/recursos/cataleg_odonats_catalunya/cataleg.htm. Similarly, the list of Aragonese dragonflies is based on the work by Torralba Burrial & Ocharan (2005a, 2005b, 2005c), Kéry & Muñoz López (2006), Ocharan et al. (2007), Torralba Burrial & Ocharan (2007a, 2007b), Alonso Naveiro & Torralba Burrial (2008), Torralba Burrial & Alonso Naveiro (2008a, 2008b), Torralba Burrial & Ocharan (2008a, 2008b, 2008c), Torralba Burrial (2009a), Martín (2011), Murria & Jarne (2012), Prieto–Lillo & Jacobo–Ramos (2012), Luque Pino et al. (2013), Torralba–Burrial (2013), Alcocer & Bischoping (2014) and Curk et al. (2014).

Odonatofauna of the Iberian Peninsula

The study of the Odonata of the Iberian Peninsula was greatly developed in the twentieth century, with a series of pioneer works including those by Navás (1906, 1907, 1924), Benítez Morera (1950) and Compte Sart (1965). During the 1980s, the work by Ocharan Larrondo (1987) became a reference for Odonata research in the Iberian Peninsula and it triggered a series of studies on the diversity, ecology and distribution of this group. More recently, the work by Torralba Burrial & Ocharan (2007b) included a total of 76 species, corresponding to 77 taxa if all subspecies are considered. This number has increased in recent years based on different works. Torralba–Burrial (2009b) includes the discovery of *Cordulia aenea* by Lockwood et al. (2007) and *Trithemis kirbyi* by Chelmick & Pickess (2008). These additions expanded the total number of species to 78. With the first data of *Orthetrum albistylum* by Mezquita Aranburu et al. (2011), the total number of Iberian dragonfly species has risen to 79 (París et al., 2014; Prunier et al., 2015). In addition, the discovery of the subspecies *Onychogomphus forcipatus forcipatus* (Mezquita–Aranburu & Torralba–Burrial, 2015) increased the number of Iberian taxa to 80.

Biogeographic classification of dragonflies

Based on the list of species in these four areas, we assigned the different species to a particular biogeographic category according to Ocharan (1988) and Torralba Burrial & Ocharan (2007b). This biogeographic classification system is organized into categories based on their current area of distribution. In polytypic species, we assigned the element (or biogeographical character) based on the subspecies present in each area. The categories are the following: ES. Eurosiberian elements; ET. Ethiopian elements; IM. Iberian–Maghrebi elements; HM. Holo–Mediterranean elements; HO. Holarctic elements; MO. Occidental (or Western)–Mediterranean elements; PO. Oriental (or Eastern)–Pontic elements (see table 1).

Taking into account the publication of Dijkstra & Matushkina (2009), we replaced the species *Brachythemis leucosticta* by *B. impartita*. Moreover, we maintained *B. impartita* in the biogeographic category of *B. leucosticta* (*i.e.* an Ethiopian element) based on the works by Dijkstra & Matushkina (2009) and Boudot & Kalkman (2015). Based on this latter work, we also removed *Calopteryx haemorrhoidalis asturica* from the Iberian list, and considered it as *C. haemorrhoidalis* because comparative molecular and morphological studies consider the subspecies as invalid.

We identified the biogeographic element of most species based on Torralba Burrial & Ocharan (2007b). However, we changed the biogeographical assignment of the following 11 taxa using taxonomic information and new details on distribution ranges compiled in the recent book by Boudot & Kalkman (2015):

Coenagrion caerulescens caerulescens and *Coenagrion mercuriale mercuriale* were both considered as Iberian–Maghrebi elements, but currently the subspecies are considered invalid. Based on the distribution area of *Coenagrion caerulescens* and *Coenagrion mercuriale*, these two species were considered as Occidental (or Western)–Mediterranean elements. *Enallagma cyathigerum* records from North–America were found to be incorrect because they belong to *E. annexum*. Therefore, the distribution of this species is not Holarctic, and we considered it a Eurosiberian element.

In other species, we did not use the biogeographic categories suggested by Torralba Burrial & Ocharan (2007b) either. These authors assigned in some cases the biogeographic identity based on species current distribution and their possible secondary origin. This implies that species with similar current distributions may belong to different categories. In our study we classified the species exclusively based on their current distribution. Hence *Chalcolestes viridis and Pyrrhosoma nymphula* are considered as Holo–Mediterranean elements instead of Occidental (or Western)–Mediterranean elements; *Brachytron pratense, Orthetrum brunneum, Orthetrum cancellatum, Orthetrum coerulescens* and *Sympetrum sanguineum* are considered as Oriental (or Eastern)–Pontic elements instead of Holo–Mediterranean elements; *Sympetrum fonscolombii* is considered as an Ethiopian element instead of an Holo–Mediterranean element.

We incorporated *Cordulia aenea*, *Trithemis kirbyi*, *Orthetrum albistylum* and *Onychogomphus forcipatus forcipatus* into the list of Iberian dragonflies as Eurosiberian, Ethiopian, Eurosiberian and Oriental (or Eastern)–Pontic elements, respectively. These species were not found in the study of Torralba Burrial & Ocharan (2007b) and we associated them to a particular biogeographic character following the classification criteria used in this work. We also used information found in Askew (2004), Dijkstra & Lewington (2006), Boudot et al. (2009), Escolà et al. (2011), Boudot & Kalkman (2015), and the following on–line resources: http://www.africa–dragonfly.net/, http://www.asia–dragonfly.net/ and http://www.iucnredlist.org/.

One important consideration is that *Cordulia aenea* was included in the Iberian list because we considered the Iberian Peninsula in a broad sense (as the area of continental Europe occupied by Spain, Portugal and Andorra) (Torralba–Burrial, 2009b), and adding two areas which do not belong to the Iberian Peninsula in a strict sense: la Vall d'Aran and a zone of Pallars Sobirà (Martín et al., 2016).

Statistical analyses

We performed all analyses in R (R 3.0.2 http://www.r–project.org/). To test whether the presence of the different species and biogeographic elements varies among the three territories studied, we built a generalised linear model with a binomial error distribution. We included as a response variable the presence or absence of each species in each of the three territories studied. We included as explanatory variables the territory and the biogeographical element of each taxon. In this model we also included the interaction term between these two explanatory variables. A significant interaction would indicate that the presence of the different biogeographic elements varied among territories. To assess which biogeographic elements were more variable among regions, we built an independent binomial model for each biogeographic category. In these models we only included the territory as an explanatory variable. Since in these latter analyses we performed multiple comparisons, we corrected the significance level using the Bonferroni correction. Binomial regression models are usually overdispersed and we accounted for this with the quasi family in R.

Results

The compilation that we present here contains a total of 79 Iberian species (or 80 Iberian taxa if subspecies are included), of which 65 were registered in the Valencian Country, 70 in Catalonia and 63 in Aragon. Species are listed in table 1 with their corresponding biogeographic element.

Among the Valencian species, 23 species (35.38%) are Zygoptera and 42 (64.62%) are Anisoptera. Dragonflies in the Valencian Country are mostly Oriental (or Eastern)–Pontic elements (15 species, 23.08%), Iberian–Maghrebi elements (14 species, 21.54%) and Ethiopian elements (11 species, 16.92%).

Comparing the Valencian Country, Catalonia, Aragon and the Iberian Peninsula, we found that they share the same Iberian–Maghrebi elements (14 species), Holo–Mediterranean elements (8 species), Occidental (or Western)–Mediterranean elements (8 species) and Holarctic elements (3 species). Regarding the other biogeographic elements, the four regions have in common some Oriental (or Eastern)–Pontic (14 species), Eurosiberian (6 species) and Ethiopian elements (6 species). These results emphasize the small amount of Eurosiberian elements and the large amount of Ethiopian elements in the Valencian Country as compared to Catalonia and Aragon. The Valencian Country has 11 of the 12 Ethiopian species found in the whole Iberian Peninsula.

In the Iberian Peninsula, most categories have between eight and 15 elements. The least abundant category corresponds to Holarctic elements, with three elements, whereas the most abundant corresponds to Oriental (or Eastern)–Pontic elements, with 20 elements (fig. 1).

The presence of the different species varied among the Valencian Country, Catalonia and Aragon (χ^2 = 7.43, d.f. = 2, P = 0.024), and the presence also varied depending on whether these species belonged to the different biogeographic elements (χ^2 = 88.20, d.f. = 6, P < 0.0001). As revealed by a significant region per biogeographic element interaction, the different elements were found at different proportions in the three different regions (χ^2 = 41.61, d.f. = 12, P < 0.0001). To further understand this interaction, we compared the number of species belonging to each biogeographical category among these three regions. For most of the categories, the proportion of species in each area was not significantly different (P > 0.0071, after Bonferroni correction). For Eurosiberian elements, however, Catalonia had a significantly larger number of species (χ^2 = 21.20, d.f. = 2, P < 0.0001). Relative to the other two regions, the Valencian Country had a larger number of Ethiopian elements (χ^2 = 12.40, d.f. = 2, P = 0.0020) (fig. 2).

Table 1. Registered species in the Valencian Country, Catalonia, Aragon and Iberian Peninsula, with the corresponding biogeographic element (BE) assigned (ES. Eurosiberian elements; ET. Ethiopian elements; IM. Iberian–Maghrebi elements; HM. Holo–Mediterranean elements; HO. Holarctic elements; MO. Occidental (or Western)–Mediterranean elements; PO. Oriental (or Eastern)–Pontic elements) according to Torralba Burrial & Ocharan (2007b): VC. Valencian Country; C. Catalonia; A. Aragon; IP. Iberian Peninsula; 1. Present; 0. Absent.

Taula 1. Espècies registrades al País Valencià, Catalunya, Aragó i la península Ibèrica, amb l'element biogeogràfic (BE) corresponent (ES. Elements eurosiberians; ET. Elements etiòpics; IM. Elements iberomagribins; HM. Elements holomediterranis; HO. Elements holàrtics; MO. Elements del Mediterrani occidental; PO. Elements ponticoorientals) assignat segons Torralba Burrial & Ocharan (2007b): VC. País Valencià; C. Catalunya; A. Aragó; IP. Península Ibèrica; 1. Present; 0. Absent.

Species	**BE**	**VC**	**C**	**A**	**IP**
Zygoptera					
Family Lestidae					
Chalcolestes viridis (Vander Linden, 1825)	HM	1	1	1	1
Lestes barbarus (Fabricius, 1798)	PO	1	1	1	1
Lestes dryas Kirby, 1890	HO	1	1	1	1
Lestes macrostigma (Eversmann, 1836)	PO	0	0	1	1
Lestes sponsa (Hansemann, 1823)	ES	1	1	1	1
Lestes virens virens (Charpentier, 1825)	IM	1	1	1	1
Sympecma fusca (Vander Linden, 1820)	HM	1	1	1	1
Family Calopterygidae					
Calopteryx haemorrhoidalis (Vander Linden, 1825)	MO	1	1	1	1
Calopteryx virgo meridionalis Selys, 1873	MO	1	1	1	1
Calopteryx xanthostoma (Charpentier, 1825)	IM	1	1	1	1
Family Platycnemididae					
Platycnemis acutipennis Selys, 1841	IM	1	1	1	1
Platycnemis latipes Rambur, 1842	IM	1	1	1	1
Platycnemis pennipes (Pallas, 1771)	ES	0	1	0	1
Family Coenagrionidae					
Ceriagrion tenellum (Villers, 1789)	MO	1	1	1	1
Coenagrion caerulescens (Fonscolombe, 1838)	MO	1	1	1	1
Coenagrion hastulatum (Charpentier, 1825)	ES	0	1	0	1
Coenagrion mercuriale (Charpentier, 1840)	MO	1	1	1	1
Coenagrion puella (Linnaeus, 1758)	PO	1	1	1	1
Coenagrion pulchellum (Vander Linden, 1825)	ES	0	1	1	1
Coenagrion scitulum (Rambur, 1842)	HM	1	1	1	1
Enallagma cyathigerum (Charpentier, 1840)	ES	1	1	1	1

Table 1. (Cont.)

Species	BE	VC	C	A	IP
Erythromma lindenii (Selys, 1840)	HM	1	1	1	1
Erythromma viridulum (Charpentier, 1840)	HM	1	1	1	1
Ischnura elegans (Vander Linden, 1820)	ES	1	1	1	1
Ischnura graellsii (Rambur, 1842)	IM	1	1	1	1
Ischnura pumilio (Charpentier, 1825)	PO	1	1	1	1
Pyrrhosoma nymphula (Sulzer, 1776)	HM	1	1	1	1
Anisoptera					
Family Aeshnidae					
Aeshna affinis Vander Linden, 1820	PO	1	1	1	1
Aeshna cyanea (Müller, 1764)	HM	1	1	1	1
Aeshna isoceles (Müller, 1767)	HM	1	1	1	1
Aeshna juncea (Linnaeus, 1758)	HO	1	1	1	1
Aeshna mixta Latreille, 1805	ES	1	1	1	1
Anax ephippiger (Burmeister, 1839)	ET	1	1	1	1
Anax imperator Leach, 1815	ET	1	1	1	1
Anax parthenope (Selys, 1839)	PO	1	1	1	1
Boyeria irene (Fonscolombe, 1838)	MO	1	1	1	1
Brachytron pratense (Müller, 1764)	PO	1	1	1	1
Family Gomphidae					
Gomphus graslinii Rambur, 1842	IM	1	1	1	1
Gomphus pulchellus Selys, 1840	IM	1	1	1	1
Gomphus simillimus Selys, 1840	IM	1	1	1	1
Gomphus vulgatissimus (Linnaeus, 1758)	PO	0	0	0	1
Lindenia tetraphylla (Vander Linden, 1825)	PO	1	0	0	1
Onychogomphus costae Selys, 1885	IM	1	1	1	1
Onychogomphus forcipatus forcipatus (Linnaeus, 1758)	PO	0	0	0	1
Onychogomphus forcipatus unguiculatus Vander Linden, 1820	MO	1	1	1	1
Onychogomphus uncatus (Charpentier, 1840)	IM	1	1	1	1
Paragomphus genei (Selys, 1841)	ET	0	0	0	1
Family Cordulegastridae					
Cordulegaster bidentata Selys, 1843	PO	0	1	1	1
Cordulegaster boltonii (Donovan, 1807)	MO	1	1	1	1
Incertae sedis					
Oxygastra curtisii (Dale, 1834)	IM	1	1	1	1

Table 1. (Cont.)

Species	**BE**	**VC**	**C**	**A**	**IP**
Family Macromiidae					
Macromia splendens (Pictet, 1843)	IM	1	1	1	1
Family Corduliidae					
Cordulia aenea (Linnaeus, 1758)	ES	0	1	0	1
Somatochlora metallica (Vander Linden, 1825)	ES	0	1	0	1
Family Libellulidae					
Brachythemis impartita (Karsch, 1890)	ET	1	0	0	1
Crocothemis erythraea (Brullé, 1832)	ET	1	1	1	1
Diplacodes lefebvrii (Rambur, 1842)	ET	1	0	0	1
Leucorrhinia dubia (Vander Linden, 1825)	ES	0	1	1	1
Leucorrhinia pectoralis (Charpentier, 1825)	ES	0	1	0	1
Libellula depressa Linnaeus, 1758	PO	1	1	1	1
Libellula fulva Müller, 1764	PO	0	1	0	1
Libellula quadrimaculata Linnaeus, 1758	HO	1	1	1	1
Orthetrum albistylum (Selys, 1848)	ES	0	0	0	1
Orthetrum brunneum (Fonscolombe, 1837)	PO	1	1	1	1
Orthetrum cancellatum (Linnaeus, 1758)	PO	1	1	1	1
Orthetrum chrysostigma (Burmeister, 1839)	ET	1	1	0	1
Orthetrum coerulescens (Fabricius, 1798)	PO	1	1	1	1
Orthetrum nitidinerve (Selys, 1841)	IM	1	1	1	1
Orthetrum trinacria (Selys, 1841)	ET	1	0	0	1
Selysiothemis nigra (Vander Linden, 1825)	PO	1	1	1	1
Sympetrum flaveolum (Linnaeus, 1758)	ES	1	1	1	1
Sympetrum fonscolombii (Selys, 1840)	ET	1	1	1	1
Sympetrum meridionale (Selys, 1841)	PO	1	1	1	1
Sympetrum pedemontanum (Müller in Allioni, 1766)	ES	0	1	0	1
Sympetrum sanguineum (Müller, 1764)	PO	1	1	1	1
Sympetrum sinaiticum Dumont, 1977	PO	1	1	1	1
Sympetrum striolatum (Charpentier, 1840)	ES	1	1	1	1
Sympetrum vulgatum ibericum Ocharan, 1985	IM	1	1	1	1
Trithemis annulata (Palisot de Beauvois, 1807)	ET	1	1	1	1
Trithemis kirbyi Selys, 1891	ET	1	1	1	1
Zygonyx torridus (Kirby, 1889)	ET	1	0	0	1

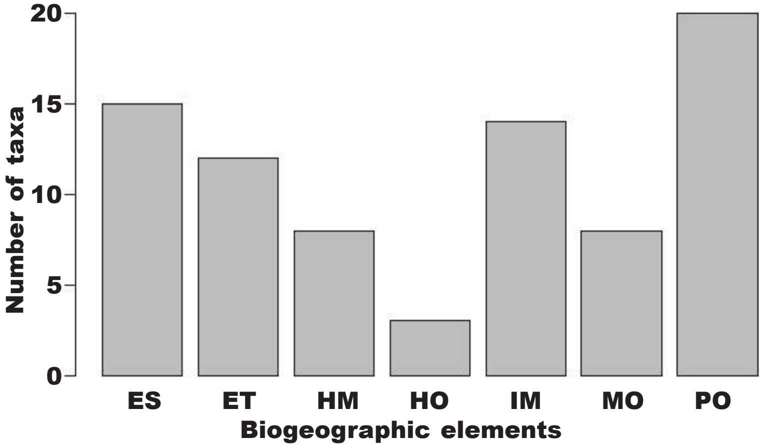

Fig. 1. Number of taxa belonging to the different biogeographic elements in the Iberian Peninsula: ES. Eurosiberian elements; ET. Ethiopian elements; IM. Iberian–Maghrebi elements; HM. Holo–Mediterranean elements; HO. Holarctic elements; MO. Occidental (or Western)–Mediterranean elements; PO. Oriental (or Eastern)–Pontic elements.
Fig. 1. Nombre de taxons pertanyents als diferents elements biogeogràfics de la península Ibèrica: ES. Elements eurosiberians; ET. Elements etiòpics; IM. Elements iberomagribins; HM. Elements holomediterranis; HO. Elements holàrtics; MO. Elements del Mediterrani occidental; PO. Elements ponticoorientals.

Discussion

In our list we found a total of 65 species of dragonflies and damselflies in the Valencian Country, accounting for 82.28% of the 79 species (81.25% of the 80 taxa) found in the Iberian Peninsula. The '*Banco de Datos de Biodiversidad de la Comunidad Valenciana*' (BDBCV) had recorded 65 species. This information was already mentioned in the works by Fontana–Bria & Selfa (2012) and by Prieto–Lillo et al. (2012a). However, BDBCV considered the species *Coenagrion pulchellum,* which was later removed from this list. The correct number of species at that time was therefore 64. In addition, Voluntariat Parotets (2013) erroneously reported a total of 65 Valencian species in 2011. Later, but before *C. pulchellum* was removed from the BDBCV, Prieto–Lillo et al. (2012b) counted 66 species with the discovery of *Trithemis kirby*i. But it was at that time when the number of species was correctly raised to 65. The species *Sympetrum vulgatum ibericum* was included in the catalogue by Baixeras et al. (2006), but Díaz Martínez & Evangelio Pinach (2015) considered that the only valid records for this species in the Valencian territory were those of Prieto–Lillo et al. (2012a). Therefore, these citations became the first evidence of the species in the Valencian Country. Thus, from 2006 to 2016 the number of Valencian dragonflies has increased by seven species.

Of the 65 species that configure this list, important considerations should be noted on *Macromia splendens* and *Lindenia tetraphylla.* These species represent situations where taxonomic issues and potential species extinctions need to be considered when performing biogeographic studies based on species citations that come from multiple sources.

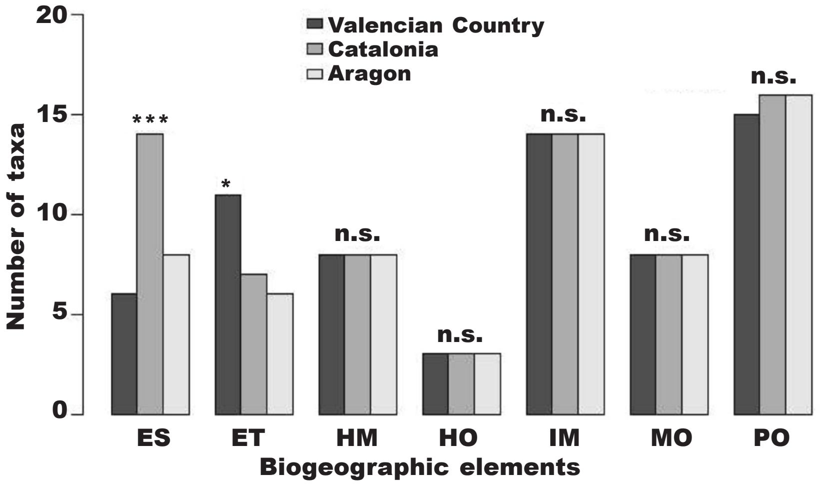

Fig. 2. Number of taxa belonging to the different biogeographic elements classified in the three compared areas Valencian Country, Catalonia and Aragon. For each biogeographic category, the number of species found in each area of study is compared with a generalised linear model assuming a binomial error distribution: ES. Eurosiberian elements; ET. Ethiopian elements; IM. Iberian–Maghrebi elements; HM. Holo–Mediterranean elements; HO. Holarctic elements; MO. Occidental (or Western)–Mediterranean elements; PO. Oriental (or Eastern)–Pontic elements. (Significant values after Bonferroni correction: *** $P < 0.00014$; ** $P < 0.0014$; * $P < 0.0071$; n.s. Not significant).

Fig. 2. Nombre de taxons pertanyents als diferents elements biogeogràfics classificats a les tres àrees comparades: País Valencià, Catalunya i Aragó. En cada categoria biogeogràfica, el nombre d'espècies que es troben en cada àrea d'estudi és comparat mitjançant un model lineal generalitzat assumint una distribució d'error binomial: ES. Elements eurosiberians; ET. Elements etiòpics; IM. Elements iberomagribins; HM. Elements holomediterranis; HO. Elements holàrtics; MO. Elements del Mediterrani occidental; PO. Elements ponticoorientals. (Valors significatius després de la correcció de Bonferroni: *** P < *0,00014;* ** P < *0,0014;* * P < *0,0071; n.s. No significatiu).*

Macromia splendens

Although this species has not been found in the Valencian Country since 1923, we have kept it in the Valencian odonatologic catalogue for the following reasons. Although its exact location is not certain, this species was found in Sogorb (Valencian Country) or in Camarena de la Sierra (Aragon) (Navàs, 1923). This work is not new, but more recent citations show that this species has been increasingly found in Spain as shown by Márquez Rodríguez & Ferreras–Romero (2008) or Campos et al. (2012). Despite being rare and very localised, this species is likely to inhabit other parts of Spain, particularly in zones where the altitude doesn't exceed the 500–600 m, and in sites where the species can find suitable rivers (Azpilicueta Amorín et al., 2008). Its location in the Valencian Country is also possible, first because this species has been found in nearby territories such as Aragon (Prieto–Lillo & Jacobo–Ramos, 2012) and Catalonia (Martín et al., 2016). Second, because it has similar ecological requirements to *Gomphus graslinii,* a species that is currently present in the Valencian territory (Baixeras et al., 2006).

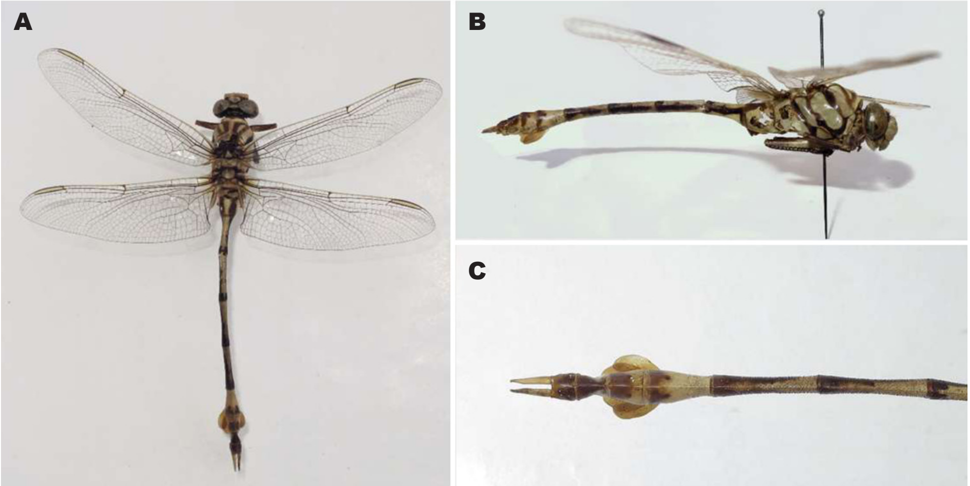

Fig. 3. *Lindenia tetraphylla* male in the Torres Sala Entomological Collection of the València City Hall: A. Dorsal view; B. Lateral view; C. Detail of long straight upper appendages. (Photographs: Joan J. Soto Àngel).
Fig. 3. Mascle de Lindenia tetraphylla *de la Col·lecció Entomològica Torres Sala de l'Ajuntament de València: A. Vista dorsal; B. Vista lateral; C. Detall dels apèndixs superiors llargs i rectes. (Fotografies:* Joan J. Soto Àngel).

Lindenia tetraphylla

This species is an Oriental (or Eastern)–Pontic gomfid that has only been mentioned in the Iberian Peninsula in the Valencian Country, as:

Old name of *Vanderia tetraphylla* in:
València by Navás (1906): 'Only found in Valencia! (Boscá, Mus. Nac.)'.
Godelleta by Navás (1922).
Godelleta by Navás (1924): 'It has only been found in the province of Valencia. I have it from Godelleta, 2 July 1921, leg. Cervera'.

Current name of *Lindenia tetraphylla* in:
València by Benítez Morera (1950): 'Localities: València (Inst. Esp. Entom. Leg. Colección Mazarredo)'.
Godella and Godelleta by Compte Sart (1965): "In Spain it has only been found five times, exclusively in the province of València (near the capital, in Godella and Godelleta)".
Since then, there have been no further citations. Bonet Betoret (1990) collects some of the records mentioned and adds a personal communication by Peris, who found the species in the city of València in 1937. However, both Bonet Betoret (1990) and Baixeras et al. (2006) mention that they have not found the species. Currently, in the Iberian Peninsula only two individuals of this species are available in museum collections. The first individual, a male, is found in the Torres Sala Entomological Collection of the City Hall of València and the second, a female, is found in the National Museum of Natural Sciences of Madrid (this specimen was incorrectly classified as a male by París et al. (2014)). Although the male has no label (fig. 3), the female is probably the specimen cited by Navás in 1906 and captured in València. The

Fig. 4. *Lindenia tetraphyll*a female in the National Museum of Natural Sciences of Madrid (Museo Nacional de Ciencias Naturales, MNCN–CSIC): A. Dorsal view; B. Lateral view; C. Lateral abdomen detail; D. Labels of the specimen. (This female was revised and cataloged [with its own number for the MNCN–CSIC] by Fontana Bria, 2011). (Photographs: A, B, and D, Mercedes París; C, Manuel Sánchez Ruiz).
Fig. 4. Femella de Lindenia tetraphylla *del Museu Nacional de Ciències Naturals de Madrid (Museo Nacional de Ciencias Naturales, MNCN–CSIC): A. Vista dorsal; B. Vista lateral; C. Detall lateral de l'abdomen; D. Etiquetes de l'exemplar. (Aquesta femella va ser revisada i catalogada [amb número propi per al MNCN–CSIC] per Fontana Bria, 2011). (Fotografies: A, B, i D, Mercedes París;* C, Manuel Sánchez Ruiz).

labels of this female have the following information: Valencia Boscá, *Vanderia tetraphylla* F. Bonet det., *Lindenia tetraphylla* ♀ A. Compte det. 1990, MNCN_Ent Nº Cat. 23722 (fig. 4). These data reveal that this species was found in València and highlight the importance of preserving historical collections in museums. As argued by Martín (2011) with regards to dragonflies, and as found in other insect groups (*e.g.,* Fountain et al., 2016), museum collections can provide essential information. In the case of *L. tetraphylla*, its presence in a museum collection confirms its past existence in the Iberian Peninsula, which represents one of its westernmost areas of distribution. This situation contrasts with *Ophiogomphus cecilia*, a species that has been cited in the past in the Iberian Peninsula, but whose references have been considered as invalid. Among other reasons, *O. cecilia* citations have been considered as invalid because Spanish larvae have not been preserved, and hence their identity can not be corroborated (Torralba–Burrial et al., 2012).

As already mentioned, the specimen of *L. tetraphylla* found in the Torres Sala Entomological Collection of the València City Hall has no label, which casts doubts on its origin, and whether this specimen was in fact collected in València. As reported by Baixeras et al. (2006), this specimen was likely collected 20 to 30 years ago, as explained by Ocharan et al. (2008, 2012) who states 'Captured between 1975 and 1985'. According to Baixeras (pers. comm.), this specimen is probably from a teaching collection, which may help to confirm its age, as the earliest collections of this kind at the University of València are from around 1980. Despite this, there is no certainty that the specimen is from València as it lacks any label, and thus other scenarios can be considered. Therefore, we propose alternative hypotheses, for example, this specimen might be that of leg. Cervera in the publication of Navás (1924), or that of the personal communication by Peris in 1937. In any case, the presence of this species in the past in the Valencian Country would be confirmed by the specimen found in the National Museum of Natural Sciences of Madrid. Hence, we believe *L. tetraphylla* should be kept in the list of Iberian and Valencian dragonflies. Future prospections, especially in suitable habitats, are needed to confirm the presence of this species in the Valencian Country. As indicated by Ocharan et al. (2012), it is important to locate any potential population of this species. If the species is not detected in the next few years, it should then be removed from the list, and considered extinct, as already suggested by Schorr et al. (1998).

As explained in the IUCN Red List, http://www.iucnredlist.org/details/165460/0 or in Boudot et al. (2013), *L. tetraphylla* adults can migrate long distances from their reproductive area. As reported in this work, many records of *L. tetraphylla* can thus be attributed to vagrant imagoes, although in some isolated locations the species has been found over several consecutive years, far from the central range of its distribution. Consistent with this idea, Bonet Betoret (1990) states that the individuals cited in the Valencian Country might be from populations that settled for several decades, but which eventually became extinct, possibly due to competition with native species. Baixeras et al. (2006) also mentions the possibility that the presence of the species may be occasional due to its migratory habits. In conclusion, future research may determine the actual status of this species in the Valencian Country and in the Iberian Peninsula. According to the IUCN category, this species is considered critically endangered (CR) in Spain (Ocharan et al., 2006, 2008). Potentially, the species can be found again in the Iberian Peninsula as occurred in Algeria, where the species was recorded in the 19th century, but was then considered extinct as it was not found in this region for more than a century and a half. A collected exuvia at Wadi Saoura in 2013, however, represented the first evidence of a breeding site for *L. tetraphylla* in Algeria, and the third record in North Africa (Hamzaoui et al., 2015).

Volunteer work

The information used in this study included data from the records of BDBCV. Information in such databases has proven to be very useful, although some limitations need to be identified so that future efforts are even more relevant. For example, information in this database is limited to the name of the observer, year, UTM coordinates, municipality and province. Adding details on the sex of the individual, dates of observation, number of individuals observed, and potentially a picture of the individual would help future studies on the phenology, biometrics and conservation status of the species. Although volunteer work is essential to maintain such information platforms, it is also fundamental that citations are checked by expert odonatologists. This implies that the species list can be updated and improved constantly. In addition, every time the information changes, a record and a justification of the changes would help to justify substitutions, deletions and additions. This would prevent cases like the aforementioned case of *Coenagrion pulchellum*, a species that was eliminated from the database probably because its identification was incorrect. As explained in Martín (2011), this species can easily be confused with *Coenagrion puella* as the two species are morphologically similar, have similar ecological requirements and their distribution areas partially overlap. With such a record of changes, BDBCV would exploit its full potential and its information could be used for scientific and conservation purposes.

Territorial differences in the composition of biogeographic elements

The Maghreb played an important role in the diversification process of thermophilic species during the Pleistocene as it was a glacial refuge. As such, it was a key source during the post–glacial colonization of Europe. Such colonisation was possible through adjacent regions of the Gibraltar and Sicily straits, which acted as biogeographic connections between North Africa and Europe (Husemann et al., 2014). Other glacial refuges that are important to understand the biogeography of the Iberian Peninsula are those found in areas in Asia (Sanmartín et al., 2001), in extra–Mediterranean refugia in geographically limited areas of southern Central and Eastern Europe (which were climatically favourable), and in other northern refugia (in the Carpathians or even in the north of the Alps) (Schmitt & Varga, 2012). This historical context could explain the differences in species composition that we found among the different regions studied. Future studies, particularly using molecular techniques, are therefore needed to further unveil whether these differences are caused by historic patterns of dispersion, or by climatic similarities.

The closest location of the Valencian Country to Africa and their more similar climate likely explains why this region is enriched with Ethiopian elements. This is exemplified with the species *Diplacodes lefebvrii* and *Brachythemis impartita* which are found in the Valencian Country but not in Catalonia or Aragon. This situation is likely to become more common in the future because there has been a northward expansion of several dragonfly species during the last decades. Several Mediterranean species have expanded to Central and Northern Europe, and some African species have expanded to southern Europe (Ott, 2010). Examples of this latter situation may include *Diplacodes lefebvrii* and *Brachythemis impartita* which have been detected in Italy (Rattu et al., 2014). Detection of these species in the Valencian territory is likely to represent a 'parallel expansion' of these species in areas with similar climate and latitude: the Valencian Country (Spain) and Sardinia (Italy). Other examples of Ethiopian elements which have expanded their distributions in recent years are *Crocothemis erythraea* (in central European countries) (Ott, 2010), *Trithemis annulata* and *Trithemis kirbyi* (in the Iberian Peninsula) (Torralba–Burrial, 2009b; Martín et al., 2016).

There is now unequivocal evidence that global warming is affecting most ecosystems on Earth. It has been confirmed that this allows dragonflies to colonise new habitats (Termaat et al., 2010). In a globally warmer climate, the biogeography of Odonata species will certainly change. It is possible that tropical species and those adapted to warmer conditions will extend their distribution areas to higher latitudes (Sánchez–Herrera & Ware, 2012). Furthermore, thermophilic species with a southern distribution are expected to successfully colonise northern habitats especially because some of them have high dispersal abilities (Rosset & Oertli, 2011). Although less marked in coastal zones and islands, a general rise in temperature and a reduction in rainfall level is predicted for the next 100 years in Spain (de Castro et al., 2005). This climate scenario will be ideal for the arrival of new Ethiopian elements. Recently, 60 new species of Odonata have been described from Africa (Dijkstra et al., 2015), which are potential species that can someday disperse and colonize Europe. In this context, southern areas like the Iberian Peninsula (and the Valencian Country in particular) might represent important stepping stones towards Europe, mainly because of their proximity, and climatic similarities.

In this article we provide information that updates and expands the knowledge of the Valencian dragonflies. We provide an updated list of species and their classification at the biogeographic level. Our study shows that the Odonatofauna in the Iberian Peninsula is not static, and that its composition can change over time. Future studies are needed to understand this, particularly in the context of climate change. In some situations global changes may contribute to dragonfly population recovery in areas where they declined (Termaat et al., 2015). Some species can even be found in areas where they were considered extinct, as found with *L. tetraphylla* in North Africa (Hamzaoui et al., 2015). Under a global change scenario, however, many species will also be lost (Sánchez–Herrera & Ware, 2012). For instance, if new species invade from the south endemic species can be lost. To understand these processes, dispersal traits and competitive abilities need to be better understood. To predict these changes, and to take potential conservation actions, it is thus necessary to carry out studies that will allow us to evaluate past, present and future changes in Odonata diversity and distribution. These studies will also allow further developments in the biogeographic analyses of this iconic group of insects and help to improve the biogeographic classification systems or create new of them.

Acknowledgements

We want to express our gratitude to Ricard Martín and Antonio Torralba–Burrial for sharing literature. Thanks also to Joaquín Baixeras for providing information. Additional thanks to Sergio Montagud for confirming the location of *L. tetraphylla* male and Alberto Sendra for access to this specimen. We also thank Joan J. Soto Àngel for the photographs of *L. tetraphylla* male, and Mercedes París and Manuel Sánchez Ruiz for those of *L. tetraphylla* female. This study was supported by the Conselleria d'Educació, Formació i Ocupació de la Generalitat Valenciana (VALi+d [ACIF/2011/100]).

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