The first record of Diplocephalus graecus (Araneae: Linyphiidae) in Germany with comments on its range expansion

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The first record of *Diplocephalus graecus* (Araneae: Linyphiidae) in Germany with comments on its range expansion

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Abstract. *Diplocephalus graecus* (O. Pickard-Cambridge, 1873), a very common holomediterranean species, has undergone a remarkable range expansion in the western Palaearctic region over the past two decades. Recently, the species was found for the first time in Germany in a field near Aachen (North Rhine-Westphalia). We traced the potential dispersal path of *D. graecus* and provide additional insights into the biology of this species. This record additionally highlights the considerable range expansion of *D. graecus*, which may have implications for the biodiversity and ecological dynamics of the region.

Keywords: distribution, faunistics, migration, money spider, zoogeography

Zusammenfassung. Erstnachweis von *Diplocephalus graecus* (Araneae: Linyphiidae) in Deutschland mit Kommentaren zur Arealerweiterung der Art. *Diplocephalus graecus* (O. Pickard-Cambridge, 1873), eine sehr häufige holomediterrane Art, zeigte über die letzten zwei Jahrzehnte eine bemerkenswerte Arealerweiterung. Kürzlich wurde die Art nun zum ersten Mal für Deutschland in einem Feld bei Aachen gefunden (Nordrhein-Westfalen). Der potentielle Ausbreitungsweg der Art wird dargestellt und weitere Informationen zur Biologie der Art präsentiert. Der Nachweis verdeutlicht die erhebliche Expansion des Nachweisgebiets von *D. graecus*, was möglicherweise Auswirkungen auf die Biodiversität und ökologische Dynamik in der Region hat.

The linyphiid genus *Diplocephalus* Bertkau, 1883 is distributed worldwide, currently encompassing 50 valid species (World Spider Catalog 2023) with most of them occurring in the western Palaearctic (Nentwig et al. 2023). In Central Europe, males of this genus can be easily distinguished based on distinct modifications of their head regions (Roberts 1987) which are presumed to have effects on mating processes by producing secretions (Kunz et al. 2012, Meijer 1976, Uhl & Maelfait 2008). *Diplocephalus graecus* (O. Pickard-Cambridge, 1873) is widespread in the Mediterranean region, occurring in various habitats like grazed meadows, deciduous forests (Ijland et al. 2012), xerophyte low grass pasture (Komnenov 2014), limestone grassland (Breitling 2020), river beds (Ijland & Helsdingen 2014, Pantini & Isaia 2008) including anthropogenic ones like olive groves (Picchi 2020, Russell-Smith 2014), citrus groves, hazelnut- and cherry-orchards (Pantini et al. 2013), abandoned rural construction sites (Matevski et al. 2022) or arable land (Blick et al. 2000). A comprehensive overview can also be found in Bosmans (1996). It is worth noting that this species is particularly dominant in agroecosystems located in the Mediterranean region (Bouseksou et al. 2015, García-Ruiz et al. 2018). Earlier it was considered a holomediterranean species (Thaler 1977) with a northern distribution limit near Paris (Denis 1968), but recent observations have demonstrated a range expansion in various directions. A northward spread was first shown by a record in Belgium (Bonte et al. 2002) and subsequently in Great Britain (Dawson et al. 2011). Recently, Danışman & Coşar (2022) documented the easternmost record of this species in Turkey. In this study, we present the first evidence of the presence of *D. graecus* in Germany, demonstrating a continuing range shift for this species leading here to its north-westernmost occurrence record. By aggregating publicly available records in Central Europe, this study further aims to determine the expansion pathway of *D. graecus* into Germany.

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Material and methods

The specimens presented in this study were collected in a conventionally managed field located in Aachen, North Rhine-Westphalia, Germany. The study site is situated in Orsbach, the westernmost part of the city, adjacent to the Netherlands, and is characterized by being situated in an agriculturally intensive landscape with low structural diversity. The prevailing climate in this region is temperate oceanic with moderate temperatures in summer, mild winters and an annual narrow temperature range leading to less extreme temperature events (Beck et al. 2018, Peel et al. 2007). Based on climatological data recorded between 1991–2020, Aachen experiences an average temperature of +19.2°C during the warmest month in July, while the coldest month of the year occurs in January with an average temperature of +3.4°C. Furthermore, an average of 7.8 frost days per year and an average annual precipitation of 852 mm were measured (Ketzler & Leuchner 2021). During the sampling period (27. Apr. – 3. Aug. 2021), the field was cultivated with winter wheat (Fig. 1, right). Pitfall traps were employed to collect arthropods from the field at two-week intervals, as part of an ecological study. Propylene glycol with a drop of detergent was used as the capture and preservative fluid. Collected arthropods were stored afterwards in 70% ethanol. Voucher specimens are deposited in the collection of the Staatliches Museum für Naturkunde Karlsruhe (SMNK). The identification of the specimens shown here was accomplished by consultation of the relevant literature, which is cited in the results section. Photographs of habitus, palpus and epigyne (Fig. 2) were taken with Software "Automontage" (Syncroscopy, Cambridge, UK) and a Leica DFC 495 Digital camera, connected to a Leica Z6 APO (Leica Microsystems, Wetzlar, Germany) by Hubert Höfer (SMNK). Study site coordinates are presented in the geodetic datum WGS84. To gain deeper insights into the immigration pathway towards Germany, a consolidation of all available occurrence records for Central Europe was undertaken (Bonte et al. 2002, Dawson et al. 2011, GBIF.org 2023). Of particular interest, the GBIF.org (2023) dataset was subject to a constraint mandating that only occurrence records containing a preserved specimen were considered for inclusion in the mapping process by us. The map of records

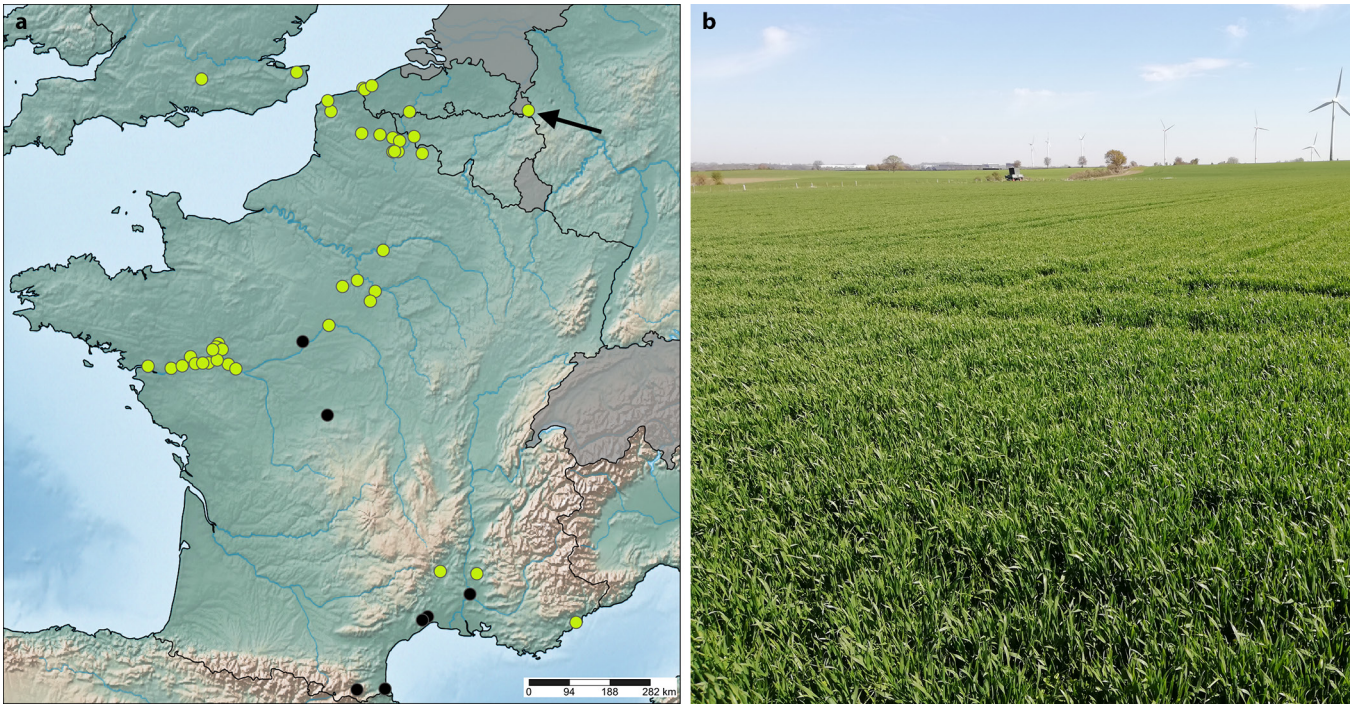

Fig. 1: Geographical distribution and habitat of *Diplocephalus graecus* in Western Europe. **a.** Black circles indicate records before the first sighting in Belgium (in 1999), while yellow circles represent sightings from 1999 onwards. Black arrow indicates first record in Germany. Grayed out countries denote those without records; **b.** sampling locality of *Diplocephalus graecus* in Aachen, photo was taken on 27.04.2021

(Fig. 1, left) was created with SimpleMappr (Shorthouse 2010). Phenological data shown in Fig. 3 is based on unpublished data from Theo Blick collected in 2017 (Arachnologische Gesellschaft 2023). In this study sampling took place with pitfall traps on organic lavender fields in Auvergne-Rhone-Alpes, France. The plot was created using RStudio 2023.03.0+386 (R version 4.2.3) with the ggplot2 package (Wickham 2016).

Results

Diplocephalus graecus (O. Pickard-Cambridge, 1873) (Fig. 2)

Material. GERMANY: 1 ♂ (SMNK-ARA 19610), Aachen-Orsbach (Fig. 1a), 50.802056°N, 6.010778°E, 202 m a.s.l., pitfall trap on arable land cultivated with winter wheat (Fig. 1b), 25. May 2021; 1 ♀ (SMNK-ARA 19611), same locality, 8. June 2021

Remarks. In the same project, three more fields and their associated field margins were surveyed in Aachen. Furthermore, during another research project spanning from 2020 to 2021, a total of 27 grassland sites displaying varying levels of management intensity were sampled over the vegetation period of both years using pitfall traps. Although the collected specimens from both projects are mostly determined, no additional individuals of *D. graecus* have been found so far.

Determination. Specimens were identified using Bosmans (1996). In Central Europe, males can be reliably distinguished by the slightly elevated cephalic lobe (Fig. 2a) and the very simple retrolateral tibial apophysis (Fig. 2d). Females can be distinguished by the wide median fissure with a median constriction between the epigynal plates (Fig. 2f), which is notably wider compared to other species of the genus in Central Europe.

Phenology. The population of *Diplocephalus graecus* in France exhibits a distinct phenological pattern (Fig. 3), characterized by a pronounced concentration during the winter months spanning from November to February. Conversely, minimal presence of individuals was observed from April to October.

Discussion

The individuals of *Diplocephalus graecus* sampled in a field near Aachen, at the western border of Germany represent the first records of this species for Germany and confirm the expansion of the species within the western Palaearctic region. Based on the hitherto known records, it is likely that immigration occurred primarily through the Paris basin leading to the coastal regions in the northernmost parts of France and Belgium. Subsequently, it dispersed further along the coastline from these locations (see Bonte et al. (2002) and Fig. 1a). Despite its distance from the coast, Aachen experiences a maritime climate caused by relatively unchanged westerly incoming Atlantic air masses, which can be attributed to the flat terrain profile in Belgium and the Netherlands (Havlik 2009). This renders the region conducive for species that follow similar climatic dispersal pathways (Csősz et al. 2015, Deepen-Wieczorek & Schönhofer 2013, Frahm & Klaus 1997, Hochkirch et al. 2021, Mertens & Hoffmann 2017, Savelsbergh 1994, Trautner & Schüle 1996). The westerly air masses, which flow into the Aachen region, are an additional factor that could have facilitated the migration route of *D. graecus* as an active ballooning species (Bonte et al. 2002, Dentici et al. 2022). The potential for further spread of *D. graecus* within Germany remains uncertain, with current evidence insufficient to confidently predict its range expansion. It is currently unclear what factors are driving the spread of *D. graecus*. Narimanov et al. (2022) demonstrated that the invasive linyphiid *Mermessus trilobatus* (Emerton, 1882), originating from North America, benefits from high dispersal behavior, which appears to be the main driver of its rapid spread. However, this does not appear to be the primary factor driving the current spread of *D. graecus*. Despite the relatively short distance (~280 km) a sub-

Fig. 2: *Diplocephalus graecus*. **a.-e.** male; **f.** female. **a.** habitus, lateral, scale bar = 0.5 mm; palp in **b.** retrolateral; **c.** ventro-retrolateral; **d.** dorsal; **e.** prolateral; **f.** epigyne, ventral. Both specimens are from Aachen

stantial temporal gap exceeding two decades exists between the initial detection of *D. graecus* in Belgium (Bonte et al. 2002) and its recent confirmation in Germany indicating a slower expansion rate compared to the invasion speed of other linyphiid spiders like *Ostearius melanopygius* (O. P.-Cambridge, 1880) (Růžička 1995) or *M. trilobatus* (Řezáč et al. 2021). Maybe the former distribution limit near Paris (Denis 1968) of *D. graecus* was already the beginning of its expansion beyond its original range in the Mediterranean region (Thaler 1977). If the species has not been overlooked, this temporal disparity may further suggest that the current geographic range represents its ecological boundary until now. However, it is worth noting that niche expansion can occur rapidly and unexpectedly, as demonstrated for *Argiope bruennichi* (Scopoli, 1772) or *Cheiracanthium punctorium* (Villers, 1789) (Krehenwinkel et al. 2015, 2016, Krehenwinkel & Tautz 2013) and on a different regional scale for *Steatoda nobilis* (Thorell, 1875) by Bauer et al. (2019). Therefore, it is advisable to carefully monitor relevant habitats, particularly those located in coastal regions and those with comparable climatic conditions, to identify any future range dynamics of *D. graecus*. Care should be taken here in the identification of especially female individuals of *D. graecus*, as a confusion with other similar species, such as *Silometopus ambiguus* (O. Pickard-Cambridge, 1906), which also occurs in coastal habitats (Blick 2014), is possible (Barrientos 2014). In this regard, considering the species' phenology is crucial, as its peak activity has been observed in the winter months of November and December (Bonte et al. 2002, Fig. 3). The phenological niche, as a strategy for avoiding competition, could be one of the factors that facilitates the dispersal of *D. graecus*, as only a fraction of spider species in Central Europe are active during the winter months (Buchar 1968). In regions with suitable climates, this should be considered when designing and conducting studies to ensure accurate assessment of its presence.

Since the impact of *Diplocephalus graecus* on the spider assemblage of the newly reached ecosystem remains uncertain, further research is needed to evaluate the potential ecological effects of this species in its new range. Given that *D. graecus* appears to readily colonize strongly anthropogenically influenced habitats, future competition with other typical agrobiont species (Blick et al. 2000, Samu & Szinetár 2002) can be anticipated. Especially other agrobiont linyphiid species exhibiting activity during winter like *Centromerita bicolor* (Blackwall, 1833) (Blick et al. 2003, Schaefer 1977), may be potentially affected. However, it is worth noting that the comparably sized *M. trilobatus* has invaded and established in similar habitats without having (measurable) negative effects on the local ecosystem until now (Eichenberger et al. 2009, Narimanov et al. 2021, 2022, De Smedt & Van Keer 2022).

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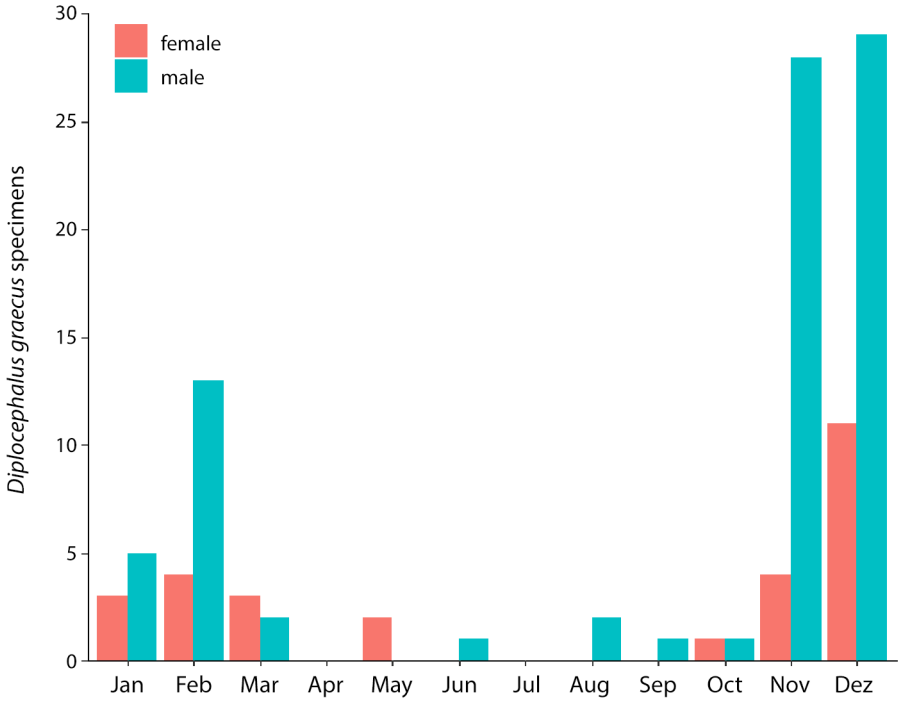

Fig. 3: Monthly captures of *Diplocephalus graecus* from lavender fields in Auvergne-Rhône-Alpes, France (Arachnologische Gesellschaft 2023). The bar chart illustrates the number of specimens of *Diplocephalus graecus* captured per month, from January to December

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