Thesis of PhD dissertation

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Taxonomy of Palaearctic Click-Beetles

(Coleoptera: Elateridae)

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1. BACKGROUND AND OBJECTIVES

1.1. Background

The aim of the present thesis is to continue my entomological research of almost 20 years, and to publish the taxonomic and faunistic results of the research I started before my doctoral studies. The present thesis is composed of several parts and it covers various sub-topics of insect taxonomy and classification.

Click beetles are one of the largest families of beetles, with about 10,000 species known worldwide. Many species are important from economic, evolutionary and ecological points of view. They are diverse in morphology and life history: they include pests, saproxylic species developing in undisturbed forests, or even predators of terrestrial snails, and they inhabit a broad variety of habitats ranging from rainforests to deserts and high mountains (BOUCHARD et al. 2017). They are of considerable importance from a conservation perspective both globally and in Hungary. Habitat specialist species associated with old-growth forest stands are important indicators of forest condition and are significant in creating microhabitats that are colonized by other species (ECKELT et al. 2017). However, the exact ecological preferences and habitat requirements, e.g. the quality of utilized deadwood, species composition, climatic conditions of the area, etc., are unknown for the vast majority of the species. Species occurring in the Palaearctic Region are relatively well studied, but currently only a dozen of specialists work on the group. Despite the considerable work that has been pubished on the family, their taxonomy and nomenclature are still unsatisfactorily known, and for ,many species or larger groups one can only rely on old literature (STIBICK 1979). Although published works have partially clarified the taxonomic status of many genera or species (MUONA 1995, LAWRENCE et al. 2007), filling up gaps in our knowledge is a much needed task for the taxonomists of the present and future.

Taxonomy is a descriptive-systematic science dealing with the units, categories, operations and rules of systematization, which is essentially comparative and analytical. It is a field of science with a history extending back several centuries, constantly evolving and changing, providing an increasingly accurate picture of the system of animals, including beetles, that occur around us. Without taxonomic foundations, disciplines such as ecology, biogeography or phylogenetics cannot stand on a strong base (LÖBL et al. 2023). However, its current situation is far from favourable in terms of recognition and future prospects, due to various social, funding and attitudinal changes (PÁLL-GERGELY et al. 2024). Zootaxonomical works can be, among others, species descriptions (PROSVIROV 2016), revisions of species groups and genus (MERTLIK et al. 2017), or catalogues (KUNDRATA et al. 2019). Morphology helps to make the results of taxonomic descriptions more accessible by means of an uniform terminology written in a concise language and often with illustrative figures. These articles often provide additional information on the distribution of these species, their possible conservation implications and their life history.

One of the target areas of my entomological research is the Levant, a historical geographical area, a part of the Middle East, where the target species of my representative studies typically occur. The term Levant is used to refer to the areas within the borders of Syria, Lebanon, Israel, Palestine and Jordan, as well as the Mediterranean margins and parts of Turkey. According to CSUZDI et al. (2007), this approximately 150 km wide stretch of land is situated between the

Mediterranean Sea and the Syrian-Arabian deserts, bordered by the Taurus Mountains in the north and the Suez Canal in the south. It is a unique region where the Palaearctic, Oriental and Afrotropical faunas meet, a so-called biogeographical hotspot (MÉDAIL & QUÉZEL 1997, MYERS et al. 2000). Its exploration is greatly hampered by the current geopolitical situation and the decades of war, making the importance of the natural history material from this region invaluable.

In the light of the above, my thesis may also provide answers to general taxonomic questions. These may include:

Can previously unknown species expected to occur in under-researched areas?

Are there any areas that are worth of exploring over a period of many years? If yes, what scientific results can be expected from such long-term research?

Is it worthwhile for present and future researchers to collect and publish all previously published knowledge on a given species or group of species, and to supplement it with the latest knowledge? If yes, how?

1.2 Concepts and aims of Study 1 (Catalogue of the genus *Elathous*)

A catalogue and revision of the known species of the genus *Elathous* Reitter, 1890. Species of this genus are distributed in the Nearctic and Palaearctic Regions (mostly in the Levant). They are rarely represented in collections, poorly studied, with a confused taxonomy. No comprehensive summary of the species of the genus is available, most of the published references consist of single species descriptions. In my previous article (NÉMETH 2019) concerning the Elateridae fauna of Lebanon I described a new species of *Elathous*. In the course of this description I gathered and studied type specimens and reviewed the published literature, thus gaining a basic knowledge about the genus. My aim in this study was to provide a single source of information on the references, synonyms, type specimens, distribution and, for the first time, colour illustrations of the known species of the genus aiding present and future researchers.

1.3 Concepts and aims of Study 2 (New species of *Elathous*)

Description of a new species of the genus *Elathous* from Lebanon. As a result of my collecting trips in Lebanon between 2015 and 2018, I discovered and described new species of click beetles (NÉMETH 2019) and had the opportunity to study the *Elathous* beetle fauna of the surrounding area, i.e. the Levant (NÉMETH et al. 2020a, NÉMETH et al. 2020b). During this research, an undescribed species of click beetles was discovered, and my aim was to describe this species.

1.4 Concepts and aims of Study 3 (*Plastocerus angulosus*)

Taxonomy, morphology and distribution of *Plastocerus angulosus* (Germar, 1844). The aim was to describe the specialized morphology of this emblematic beetle species of confused taxonomic status, to give an accurate distribution and a modern taxonomic description of its unknown female, and to review all its references in the literature. The study also aimed to clarify the taxonomic status of the species and to re-assess all its past changes.

1.5 Concepts and aims of Study 4 (*Elathous* larvae)

Comparative morphological analysis of the larvae of *Elathous agilis* Németh, 2019 and *Elathous brucki* (Candéze, 1878). Both the life history and the larval morphology of these species have remained unknown. Descriptions of larvae of related species in the genus were published several decades ago. The larvae collected during my 2015–2018 Lebanese and the 2013 and 2015 Greek expeditions represent the first available specimens since a long period and allowed an examination of the larvae of this rare group of beetles. The aim of this study is therefore to describe the larvae of the above-mentioned species using modern examination methods, which may shed light on the relationships within the subfamily (Elateridae: Dendrometrinae) and help to better understand the evolutionary relationships of the different groups of the click beetles.

1.6 Concepts and aims of Study 5 (*Lacon* larvae)

A morphological comparison of the larvae of three endangered species of saproxylic click beetles occurring in Europe, *Lacon lepidopterus, L. punctatus* & *L. querceus* (the latter is protected in Hungary). The aim of the study is to allow identification of the three species in larval form and to provide all the known distributional and ecological information about them.

2. MATERIALS AND METHODS

The standard methodology used for preparation of classical modern taxonomic articles was used. Specimens were studied under a stereoscopic microscope. Genitalia were dissected and prepared after a short bath in 10% aquaeous solution of KOH. Diagnostic characters were photographed using a Mitutoyo M Plan Apo 5X microscope lens attached to a Nikon D5200 camera. Photographs were stacked using Zerene Stacker software. Field photographs were taken using a Fuji Finepix HS25 EXR camera with a Raynox 150/250 lens. Larvae were rared in plastic boxes, sometimes up to 2 years. Body length was measured along the midline from the anterior margin of the frons to the apex of the elytra; elytral width was measured across the broadest part of the body, pronotum length were measured along the midline of pronotum. Type specimens of newly described species were deposited in a public collection. The morphological terminology of the descriptions follows the works of GLEN (1950), COSTA et al. (2010) and ROSA et al. (2019). For the catalogue we followed the format of the article by KUBACZKOVA & KUNDRATA (2017).

Approximately 180 specimens were loaned from various public and private collections in Europe, listed below:

Natural History Museum, London, United Kingdom; California Academy of Sciences, San Francisco, USA; coll. of Centre de Recherche Forestière, Rabat, Morocco; Florida State Coll. of Arthropods, Museum of Entomology, Gainesville, Florida, USA; Hayek Mirzayans Insect Museum, Tehran, Iran; Hungarian Natural History Musuem, Budapest, Hungary; Hacettepe University Zoology Museum, Ankara, Turkey; Museo Civico di Storia Naturale, Genova, Italy; Museo Civico di Storia Naturale, Verona, Italy; Museum of Comparative Zoology, Harvard University, USA; Museo Nacional de Ciencias Naturales, Madrid, Spain; Museum National d'Histoire Naturelle, Paris, France; National Museum, Prague, Czech Republic, National Museum of Nature and Science, Tokyo, Japan; coll. of A. Guglielmi, Verona, Italy; coll. of C. Wurst, Heilbronn, Germany; coll. of G. Kakiopoulos, Athens, Greece; coll. of G. Murzov, Stara Zagora, Bulgaria; coll. of G. Platia, Gatteo, Italy; coll. of H. Brustel, Toulouse, France; coll. of José Sáez Bolaño, Badajoz, Spain; coll. of Josef Mertlik, Opatovice nad Labem, Czech Republic; coll. of J. L. Zapata de la Vega, Madrid, Spain; coll. of N. Jansson, Linköping University, Sweden; coll. of N. Nemer, Tannourine, Lebanon; coll. of R. Preiss, Wimborne, Great Britain, coll of D. Szalóki, Budapest, Hungary; coll. of Georgios Gastouniotis, Nemea, Greece; coll. of George Kakiopoulos, Athens, Greece; collection of Martin Samek, Skalice, Czech Republic; coll. of Per Kristian Solevåg, Tranby, Norway; coll. of Petr Zahradník, Jesenice u Prahy, Czech Republic; coll. of Robin Kundrata, Olomouc, Czech Republic; coll. of Savvas Zafeiriou, Pirgoi Thermis, Lesvos, Greece; voucher collection of the laboratory of Biodiversity and Molecular Evolution, Palacký University, Olomouc, Czech Republic; Royal Belgian Institute of Natural Sciences, Brussels, Belgium; Senckenberg Deutsches Entomologisches Institut, Müncheberg, Germany; Steinhardt Museum of Natural History, Israel National Center for Biodiversity Studies, Tel Aviv University, Israel.

Several pecimens examined in the studies were collected by me between 2013 and 2023, in Albania, Greece, Croatia, Macedonia, Lebanon, Hungary and Syria.

3. RESULTS

3.1. Results of Study 1 (Catalogue of the genus *Elathous*)

An annotated catalogue of known *Elathous* species has been compiled and published. For each taxon synonyms, information on type material, type locality, distribution, and a bibliography were provided. The loaned type material, including about 80 specimens, borrowed from all over the world, allowed to create a 35-page summary, illustrated with photographs. This work will serve as a major reference for future workers on the genus.

3.2. Results of Study 2 (*Elathous nemeri* sp. n.)

In this study I described a new species of click beetle from northwest Lebanon under the name *Elathous nemeri* Németh, 2021. The results of my research on the click beetles previously reported from the country (NÉMETH 2019) and my collection trips in May 2015, June 2016, May 2017 and July and August 2018 led me to a thorough understanding of the species in the area and the recognition that a previously misidentified specimen represents a previously unknown species. The new species can be easily distinguished from its relatives occurring in the region by the shape of the antennomeres and the pronotum, and the male genitalia: antennae clearly extend beyond the posterior part of pronotum; pronotum longer than wide, widest at its midline; the parameres are distinctly narrowed towards the apex, curved laterally, and the outer margin is distinctly broad.

3.3. Results of Study 3 (*Plastocerus angulosus*)

The genus *Plastocerus* has a tortuous taxonomic history. Different authors considered it as representative of a family of its own (SCHWARZ 1907) or as member of Elateridae (MERTLIK & PLATIA 2008). Females have remained unknown until recently; some authors speculated that they might be soft-bodied forms with reduced wings (CROWSON 1972). Our article published in 2023 reviewed the morphology, intraspecific diversity, taxonomy and distribution of the species. We studied more than 80 specimens from public and private collections collected between 1845 and 2017, and made the following conclusions:

Intraspecific variability: the specimens studied exhibited considerable variation in colouration and in the morphology of several body parts. Significant differences were detected in the punctuation of the pronotum and in the structure of the male genitalia. No correlation was found between the geographical distribution and morphological differences resulting from the measurements.

Distribution: Based on literature data, this species occurs in Greece, Israel, Turkey and Syria. We provided the first report of the species from Lebanon.

3.4. Results of Study 4 (*Elathous* larvae)

In our study, we described the larvae of *Elathous agilis* Németh, 2019 and *E. brucki* (Candéze, 1878) for the first time, based on modern examination methods. All important diagnostic characters of the two species were documented and compared with each other and with their

close relatives. We found several differences between the examined larvae, which are: the size and density of punctation on thoracic tergites, the sides of head, the shape of the posterior part of frons, the length of the transverse branches of abdominal impressions and several details on the dorsal plate of abdominal tergite IX. Based on the available information, *E. brucki* is unique among its congeners in having rounded sides on the posterior part of the frons and a lozenge-shaped notch on tergite IX.

3.5. Results of Study 5 (*Lacon* larvae)

We present a comparative morphological analysis of the larvae of three species of *Lacon* species occurring in Europe, *Lacon lepidopterus* (Panzer, 1801), *L. punctatus* (Herbst, 1779) and *L.* querceus (Herbst, 1784), based on published literature and our own observations. Identification of their larvae is not only an important task from a conservation point of view, as *L. querceus* is an emblematic saproxylic species protected by law in Hungary, but also an important milestone for this little studied species group. We found that the species characters discussed in previous descriptions are partly correct: indeed, the larva of *L. querceus* differs significantly from the other two species discussed in the longitudinal edges on the lateral part of the head. However, a re-assessment of the characters provided by TARNAWSKI (2000) concluded that the sclerotized nasal tooth structure is not different among the species studied. Based on our field experience and available publications, we summarized information on the life history of the three species, with emphasis on the food plants, co-existing species, distribution and development.

4. CONCLUSIONS AND RECOMMENDATIONS

Publications contained in my doctoral thesis typically focus on poorly known beetle species (MERTLIK & DUŠÁNEK 2006). These species usually have criptic habits, therefore they are not often collected and they are rare in collections (PLATIA et al. 2018). They are important indicators of forest condition (ECKELT et al. 2017), may be remnant or flagship species, but as the results above show, they may include species that have remained unknown to science. In the published studies I have collected all available information and complemented it with new knowledge based on decades of our museological and field experience. Nevertheless, for each species it can be concluded that further material is needed to a better understanding of the boundaries of each species or species group, their relationships, and their largely unknown ecology, and their importance in ecological systems. Our aim was to provide knowledge about these groups of beetles, their evolutionary history and distribution, and their morphology in adult and larval stages for present and future scientific researchers.

All five studies involve species that occur in the Levant. The current political and social situation in the region makes any research almost impossible, but species descriptions (PREISS 2003, MERTLIK & DUŠANEK 2006) and catalogues (MERTLIK & PLATIA 2008) of the region have been published in recent decades. During a decade and a half of my research I have worked on several groups of beetles based on material collected on trips to Syria and Lebanon (DANILEVSKY & NÉMETH 2017, HÁVA & NÉMETH 2016, KUNDRATA et al. 2016, MÁRKUS & NÉMETH 2016, NÉMETH 2019, NÉMETH et al. 2019, 2020a, 2020b, PLATIA & NÉMETH 2011, SZÉNÁSI & NÉMETH 2019, SZÉNÁSI et al. 2019). However, this work is far from complete. It would be particularly important for the future to continue and complete a revision of the beetle material from the Levant that is deposited in public and private scientific collections worldwide. International cooperation, continuous consultation and programmes supporting scientific work, such as the Tempus Intergovernmental Fellowship Program or the Synthesys Programme between research institutions and museums, which have a significant outputs, are essential for achieving this goal (KUNDRATA & NÉMETH 2019).

The knowledge of the larval stages of click beetles is not only important from an ecological point of view (ROSA et al. 2020), but also contributes to the understanding of the taxonomic status of different species (SCHIMMEL & TARNAWSKI 2012). It is a rare occasion when there is a reliable and definitive material available for the study of beetle species with a hidden lifestyle. Two publications on larvae provide new insights into the relationships between subfamilies and within the genus (ÔHIRA 1962, 1989). The study of newly collected material (ROSA et al. 2019) may help to understand the relationships between subfamilies. This knowledge, supported by genetic results, can lead to new concepts and new phylogenetic hypotheses. The long-term goal could be a complex work, which would be completed by a genetic study and morphological description of the larvae and the associated adults from all the subfamilies of click beetles.

Although recent works on the *Lacon* species of the Levant (MERTLIK & NÉMETH 2014, KUNDRATA et al. 2019, NÉMETH et al. 2020b) significantly improved our knowledge on the fauna of the region, these papers also treated adult beetles and not their larvae. Almost nothing is known about the larvae of the species in concern, so it is important for future entomologists to have material available for this type of work. This can be achieved through further fieldwork and the study of material deposited in different museums, in both cases helping to understand the life history and distribution of the species under discussion and their potential conservation importance. This, and taxonomic work in general, would require appropriate training,

enthusiastic young researchers, well-maintained collections and overall recognition of taxonomic work. Unfortunately, international taxonomy (LÖBL et al. 2023), as well as taxonomy in Hungary (PÁLL-GERGELY et al. 2024), is in decline, even though "...everything in biology is meaningless if the organisms beeing studied are not named and defined" (DUBOIS et al. 2003).

5. NEW SCIENTIFIC RESULTS

5.1. Catalogue of the genus *Elathous*

We have compiled and published a world catalogue of the species of the genus *Elathous* Reitter, 1890 (Coleoptera: Elateridae: Dendrometrinae). The genus contains 48 species, of which six are known from the Nearctic, 40 from the Western Palaearctic from Morocco to Iran, and two from Japan. For each taxon we provided synonyms, information on type material, type locality, distribution, and bibliography. Photographs of types and original type labels have been included. The morphological differences of the species studied suggest that two species groups exist within the genus. As the limited data available suggest, they also differ in their life history, it is possible that their systematic and nomenclatural status will change in the future. Further research work on a complex genus revision could help to understand the evolution and taxonomy of this group.

5.2. New species of *Elathous* from Lebanon

In this study I described a species of click beetle from northwest Lebanon as *Elathous nemeri* Németh, 2021. The new species highlights the importance of understanding the biodiversity of the Levant, bringing the total number of known *Elathous* species to 49. My previous article on the known *Elathous* species in the country (NÉMETH 2019) and the results of several years of collecting led me to a thorough understanding of the species occur in the area, and to the discovery that a previously misidentified specimen represents a distinct, previously unknown species.

5.3. Morphology, taxonomy, literature records and distribution of *Plastocerus angulosus* (Germar, 1844)

More than 80 specimens from public and private collections, collected between 1845 and 2017, were studied to investigate the intraspecific, including sexual variability of the species. We found that specimens from different areas exhibit a significant variation in respect of the punctuation of the pronotum, colouration, and male genitalia. Furthermore, we recorded the species from Lebanon for the first time. We have compiled a complete overview of the nomenclatural history of the species, and illustrated the morphological features of the species with a detailed description and supporting figures.

5.4. Comparative morphology of larvae of *Elathous agilis* Németh, 2019 and *Elathous brucki* (Candèze, 1878)

During our work we re-assessed characters considered as diagnostic by previous authors. Based on an examination and description of the larvae using modern methodology, it is clear that the larva of *E. brucki* is morphologically different from those of all known species, and the larva of *E. agilis* can be diagnosed on the basis of several stable characters.

Complementing the few previously published data on the life history of the species of the genus, we provided information on the ecology of the larvae of the species studied, indicating that both species are saproxylic, associated with deadwood.

5.5. Larvae of European species of *Lacon* Laporte, 1838

Based on a comparative morphological analysis of *Lacon* larvae we supplemented the published results with our own results, allowing us to separate the larvae of the three species. We have found that the diagnostic characters proposed by previous authors are of limited use. We collected all previously published information and added our results, thus providing a complex picture of the ecological needs, diet, food plants and feeding habits of the species together with the beetle species that co-occur with them.

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7. PUBLICATIONS

7.1 Publications related to the topic of the thesis

KUNDRATA, R., NÉMETH T., PROSVIROV A. S. & HOFFMANNOVA J. (2021): Annotated catalogue of the click-beetle genus Elathous Reitter, 1890 (Coleoptera: Elateridae: Dendrometrinae), including habitus photographs for all species. In: *Zootaxa*, 4995 (2) 231–265.

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NÉMETH T., HOFFMANNOVA J., KAKIOPOULOS G., KRAMP K. & KUNDRATA R. (2023): Plastocerus angulosus (Germar, 1844) (Coleoptera: Elateridae: Dendrometrinae): an enigmatic click beetle with a convoluted taxonomic history. In: *Zootaxa*, 5284 (2) 271–290.

NÉMETH T., ROSA S. P. & KUNDRATA R. (2024): Comparative morphology of larvae of Elathous agilis Németh, 2019 and Elathous brucki (Candèze, 1878) (Coleoptera: Elateridae: Dendrometrinae), with notes on their biology and ecology. In: *Zoologischer Anzeiger*, 308 25–34.

NÉMETH T., ROSA S. P., JETELINA D., SÁROSPATAKI M. & KUNDRATA R. (2025): Emblematic European saproxylic Lacon click beetles (Coleoptera: Elateridae): what do we know about their immature stages? – *Scientific Reports*, in press.

7.2. Entomological publications, partly related to the topic of the thesis

BOROWSKY J. & NÉMETH T. (2024): Description of a male and redescription of a female of Bruchoptinus schatzmayeri (Pic, 1934) (Coleoptera: Ptinidae). In: *Zootaxa*, 5538 (3) 297–300.

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