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**Reliability, completeness and improvement
of our knowledge on Germany's parasitoid wasp fauna –
a case study in Chalcidoidea (Hymenoptera)**

Maximilian Weber¹, Ernst Klimsa², Gerd Reder³, Ralph S. Peters^{4,*}

^{1,4} *Zoologisches Forschungsmuseum Alexander Koenig, Arthropoda Department, Adenauerallee 160, D-53113 Bonn, Germany*

² *Zeisigstraße 2, D-92421 Schwandorf, Germany*

³ *Am Pfortengarten 37, D-67592 Flörsheim-Dalsheim, Germany*

*Corresponding author: E-mail: r.peters@leibniz-zfmk.de

¹ [urn:lsid:zoobank.org:author:9413F7B7-B1C4-492D-B293-D89055C45A71](https://nbn-resolving.org/urn:lsid:zoobank.org:author:9413F7B7-B1C4-492D-B293-D89055C45A71)

² [urn:lsid:zoobank.org:author:2BB938E2-57ED-4611-A43F-D8F481C506D3](https://nbn-resolving.org/urn:lsid:zoobank.org:author:2BB938E2-57ED-4611-A43F-D8F481C506D3)

³ [urn:lsid:zoobank.org:author:3A8EFCFD-DB6D-47C2-AF44-C4B24297C446](https://nbn-resolving.org/urn:lsid:zoobank.org:author:3A8EFCFD-DB6D-47C2-AF44-C4B24297C446)

⁴ [urn:lsid:zoobank.org:author:5C16658B-28A2-4D32-8B5D-1371553DDA18](https://nbn-resolving.org/urn:lsid:zoobank.org:author:5C16658B-28A2-4D32-8B5D-1371553DDA18)

Abstract. Parasitoid wasps account for a significant proportion of Germany's insect fauna. Detailed and accurate knowledge on this fauna is crucial in order to conduct thorough studies in, for example, ecology and conservation, and to adequately meet the challenges related to the recently reported dramatic biodiversity loss. However, our knowledge on many species-rich insect groups is error-prone and fragmentary. In this study, we evaluate our knowledge on the German fauna of Chalcidoidea, one of the most species-rich parasitoid wasps groups, for reliability and completeness. We show that more than one third of the 1,939 recorded chalcidoid species are known only from a single citation/record, and usually records are neither detailed nor vouchered. More than two thirds of the species have never been taxonomically revised. We also found that there are 344 species recorded from neighboring countries of Germany which might also occur in Germany. In this study, we report the first records from Germany of *Calosota aestivalis* Curtis, 1836 (Chalcidoidea: Eupelmidae: Calosotinae) and *Torymus cupreus* (Spinola, 1808) (Chalcidoidea: Torymidae: Toryminae). Both records are the result of close collaboration between citizen scientists and professional entomologists, and both records include detailed collecting information, life images and voucher specimens. We note that such collaboration is very valuable to increase our knowledge on previously widely neglected taxa. The necessary strategic goal of a well-known German insect fauna, however, will only be achieved by strongly intensifying the research on biodiversity and taxonomy of all insect taxa.

Keywords. Biodiversity; Chalcidoidea; Germany; parasitoid wasps.

INTRODUCTION

Approximately 33,000 insect species have been listed to occur in Germany (Völkl et al. 2004), and this number is frequently used in scientific or popular publications, comments or surveys. A significant proportion of them belong to so-called understudied taxa. Taxa in need of more study are, among others, many groups of Diptera and Hymenoptera; two insect orders referred to as the “big four” (together with Lepidoptera and Coleoptera) because of their exceptional species diversity, even in comparatively species-poor regions such as the western Palearctic (Schumann et al. 1999; Dathe et al. 2001). There is a long tradition of citizen entomologists studying certain groups of Lepidoptera and Coleoptera often by geographic region and in astonishing detail, though this is very unusual in many other insect groups such as Hymenoptera (excluding Aculeata).

A reliable assessment of insect faunas is becoming increasingly more important in the light of recent findings that report dramatic losses in insect biomass and potentially also species richness (Hallmann et al. 2017). Yet, existing species lists for non-aculeate Hymenoptera, for example, are putatively highly incomplete, error-prone or outdated (Dathe et al. 2001; Mitroiu et al. 2015). However, an assessment of Germany's biodiversity and its differences and changes over time and space cannot or should not be done without including these very species-diverse groups.

When discussing these understudied taxa and their decided importance for Germany's biodiversity, two main issues need to be considered: 1) How severe is the lack of knowledge, i.e., how reliable and complete are the published species lists? and 2) How can our knowledge on these groups be improved to meet the strategic goal of a well-known German biodiversity?

In this study, we exemplarily screened and evaluated the currently listed records of chalcidoid wasps (Chalcidoidea), one of the very species-rich and notoriously understudied groups of parasitoid Hymenoptera. To date, there are 1963 (Schmidt 2015) or 1964 (Noyes 2018) species of Chalcidoidea checklisted for Germany (i.e., approximately 6 % of the German insect fauna). To evaluate the reliability and completeness of these records, we checked the available information in detail (taken from the well-curated Universal Chalcidoidea Database (Noyes 2018; <http://www.nhm.ac.uk/our-science/data/chalcidoids/>)).

First, we checked the number of referenced records from Germany for all species and the respective year of publication. Few and/or old records might indicate lower reliability of a given recorded species to actually occur in Germany. Second, we checked how many recorded species belong to groups (i.e., genera, subgenera, species groups etc.) that have been taxonomically revised in the past, especially in the last 50 years. Taxonomic revision in groups as delicate as parasitoid wasps (delicate meaning small-sized, species-rich, subtle species differences) can result in significant changes of the number of recognized species (e.g., Hansson & Shevtsova 2012; Khatib et al. 2014). Species records in unrevised taxonomic groups need to be handled with caution *per se*. Third, to get an idea of the number of species that are most likely present, but have never been formally recorded, we searched for species that occur in at least two neighboring countries of Germany. These will most likely also occur in Germany.

In a second part, we show and discuss how knowledge on Germany's biodiversity can be improved via close collaboration between citizen scientists and professionals.

Citizen scientists in entomology have excellent knowledge about regionally important habitats, they collect, sort, and mount a lot of specimens, they have profound knowledge in special groups, but also in general entomology, they may be organized in groups where they regularly exchange specimens and expertise, and perform examinations of species biology. On the other hand, professional entomologists at museums or other research institutions have state-of-the-art infrastructure (collections, molecular laboratories, etc.), taxonomic expertise in groups that are not too attractive for amateurs, and they often have the expertise to put faunistic records in a scientific context or to develop new research questions from observations, often within an international network of researchers. These areas of expertise perfectly complement each other when it comes to improving knowledge on biodiversity, in a way that serves both public and science.

The connection and cooperation between citizen scientists and professionals works well in some animal taxa, and is also inherent part of the German Barcode of Life initiative (GBOL) (Geiger et al. 2016). However, even large-scale initiatives such as GBOL cannot cover all of

Germany's biodiversity. For example, most parasitoid Hymenoptera groups have been largely excluded from the first two phases of GBOL.

In this context, we add some records of chalcidoid wasps new to Germany that were found through collaboration between citizen scientists and professional hymenopterists. With our new records we demonstrate that, if collection by citizen scientists and collaboration between citizen scientists and professional entomologists is improved, new chalcidoid species can be easily found to complement our knowledge on local biodiversity. Ideally, this includes also live pictures, biological data, fine-scale distribution data and deposition of vouchers in scientific collections, i.e., species records that are far more valuable than "naked" lists, both in terms of scope and scientific validity.

Both aspects of this study in concert, however, demonstrate that collecting, collaboration and taxonomic expertise also have to be significantly expanded and improved to cover all of Germany's species diversity in a reasonable time.

MATERIAL & METHODS

Evaluating the Chalcidoidea species list for Germany

The superfamily Chalcidoidea comprises the following 23 extant families (Heraty et al. 2013; Janšta et al. 2017): Agaonidae (not occurring in Germany), Aphelinidae, Azotidae, Chalcididae, Cynipencyrtidae (not occurring in Germany), Encyrtidae, Eriaporidae (not occurring in Germany), Eucharitidae, Eulophidae, Eupelmidae, Eurytomidae, Leucospidae, Megastigmidae, Mymaridae, Ormyridae, Perilampidae, Pteromalidae, Rotoitidae (not occurring in Germany), Signiphoridae, Tanaostigmatidae, Tetracampidae, Torymidae, and Trichogrammatidae.

To evaluate the reliability and completeness of species records, we examined the information at Universal Chalcidoidea Database (UCD, Noyes 2018; <http://www.nhm.ac.uk/our-science/data/chalcidoids/>). In this database, all publications on Chalcidoidea and the data therein are implemented in a timely and highly complete manner by the enormous effort of John Noyes from Natural History Museum, London, a Chalcidoidea expert. John Noyes kindly provided the raw data underlying the published content at UCD, exported as a .csv file (status as of June 2017). The dataset contained all the published records of chalcidoid wasps for Germany and its neighboring countries, i.e., the Netherlands, Belgium, Luxembourg, France, Switzerland, Austria, Czech Republic, Poland, and Denmark. Each record includes the valid species name, valid genus name, author and country, and the full reference of the record, including the year of publication. Initially, all German records were sorted according to their reference year.



Fig 1. *Calosota aestivalis* (Eupelmidae: Calosotinae), a species newly recorded from Germany. **A.** female; **B.** male; **C.** female during oviposition. Live pictures are not from voucher specimen.

Next, we searched for species recorded from Germany with only one record or reference. Again, these single records were sorted according to their reference year.

Then, to locate species that have been taxonomically revised, we searched the references of all recorded species for the key terms “revision”, “reclassification”, “synonym”, “new combination”, “review”, “description”, “taxonomy” or any parts of the respective words. These terms should be included in the titles of at least the vast majority of taxonomic revision publications and also cover most of the respective terms in French and German. “New species” was not considered as species descriptions not necessarily include a taxonomic revision. For publications whose titles did not contain exact information about the revised taxa, the respective abstract was consulted. For all positive matches the corresponding taxa (i.e., species, genus, tribe, family) were marked as “revised” within the main excel sheet and the date of publication was noted. When a taxonomic unit was revised (e.g., genus), all subunits (e.g., species) were listed as revised. Based on the date of publication it was possible to determine how many of the revised species were taxonomically revised before and during the last 50 years.

Finally, we searched for species that occur in at least two neighboring countries of Germany that have no common borderline between them. These will most likely also occur in Germany. By specifying that the records are from two or more non-contiguous neighboring countries of Germany, we intended to exclude species that occur in geographic regions or habitats that are not necessarily present in Germany, e.g., eastern Palaearctic species or alpine species.

New Chalcidoidea records from Germany

Authors have routinely collected species of Hymenoptera in various habitats using hand nets. Live photos were taken with Canon EOS 5 Mark II, 100mm Macro (*Torymus cupreus* (Spinola, 1808)) and Nikon D7200, 60mm Macro (*Calosota aestivalis* Curtis, 1836). Specimens were killed with ethyl acetate, mounted, labelled, and identified. Specimen vouchers of the new records are deposited at Zoologisches Forschungsmuseum Alexander Koenig (ZFMK; Bonn, Germany).



Fig 2. *Torymus cupreus* (Torymidae: Toryminae), a species newly recorded from Germany.

Table 1. Records of Chalcidoidea from Germany and their distribution in terms of publication date. Records from neighboring countries not included.

Year	Proportion of records (Total = 100 %)	Number of records (Total = 5,183)
1700–1799	0.21 %	11
1800–1899	1.31 %	68
1900–1950	0.35 %	18
1951–2000	51.13 %	2,650
2001–2017	47.00 %	2,436

RESULTS

Evaluating the Chalcidoidea species list for Germany

According to the Universal Chalcidoidea Database (UCD) there are 1,964 species recorded from Germany. From this preliminary list, we excluded 29 species names or entries that were either erroneously listed twice, very recently synonymized, *nomina nuda*, or fossil taxa. There are four additional species recorded from Germany in the raw data provided by John Noyes, which are not listed in the “regional list” for Germany in the UCD website. Consequently, our final list included a total number of 1,939 chalcidoid species for Germany. For all these species a total of 5,183 records were listed. Virtually all records dated from 1951–2017 (98.13 %), and only a few (1.87 %) were from earlier publications (for details see Table 1).

Out of the 1,939 species listed from Germany, 764 (39.40 %) were documented with only one reference or record. The majority of single records (726) dated from 1951 to 2017. Regarding taxonomic revision, 551 species (28.42 %) belong to taxa that have been taxonomically revised within the last 50 years. Only 98 species (5.05 %) were revised before 1968, resulting in 649 species (33.47 %) that have ever been taxonomically revised. Regarding potential new species records for Germany, 344 species were listed in at least two neighboring countries that do not have a borderline between them. These species represent 11.3 % of the total of 3,043 species recorded from the neighboring countries. For these species an occurrence in Germany can be assumed to be probable. In summary, a total of 2,283 chalcidoid species have been recorded from Germany or can be expected to occur in Germany.

A full list of the species recorded from Germany plus those species recorded from neighboring countries which do not have a borderline between them, along with species-specific information as included in this study, is given in Appendix I.

New Chalcidoidea records from Germany

We report for the first time for Germany the occurrence of *Calosota aestivalis* Curtis, 1836 (Chalcidoidea: Eupelmidae: Calosotinae) (Fig. 1) and *Torymus cupreus* (Spinola, 1808) (Chalcidoidea: Torymidae: Toryminae) (Fig. 2).

Calosota aestivalis Curtis, 1836

Calosota aestivalis Curtis, 1836: 596.

For synonyms, distribution and associates see Noyes (2018).

Material examined. Germany: Bavaria, Landkreis Schwandorf, Schwandorf (GMS: N 49° 18' 15.347" W 12° 7' 53.025", DG: N 49.304263 W 12.131396), 29.iv.2015, south-facing woodpile next to small woodland, leg. E. Klimsa; det. E. Klimsa, G. Gibson (1 female, deposited at ZFMK, ZFMK-HYM-00012133).

Remarks. Specimens of this species were also observed on several occasions in the years 2016 and 2017 at woodpiles in Schwandorf and Kallmünz (Bavaria).

Torymus cupreus (Spinola, 1808)

Diplolepis cuprea Spinola, 1808: 212–213.

For synonyms, distribution and associates see Noyes (2018).

Material examined. Germany: Rheinland-Pfalz, Donnersbergkreis, Zell (GMS: N 49° 38' 58.87" O 8° 8' 5.031", DG: 49.649686 8.134731), ivy-covered hedge-row at the village outskirts, 01.x.2015, leg. G. Reder; det. G. Reder, vid. R. Peters (1 female, deposited at ZFMK, ZFMK-HYM-00020525).

DISCUSSION

Results show that the majority of published records of chalcidoid species from Germany date from the period after the Second World War, which may indicate an in-

crement of collecting, identification and publication activities during that time. For approximately one third of the recorded species only a single record is listed. Any single event is sought to be verified or falsified to be scientifically sound. We have no information on whether these single records are correct or not; in fact, they could well be correct, and on the other hand, also multiple records can be wrong. Ideally, we would have checked if records are vouchered in a scientific collection and could be verified accordingly. Our expectation was that the number of voucher-referenced records was very low, rendering most records not necessarily wrong but scientifically flawed. A thorough check for vouchers was not done, due to time constraints. However, when checking this for 20 randomly chosen species, we found almost no detailed collecting information or references to deposited vouchers. Almost half of the records (47 %, see Table 1) date from rather recently, which indicates that the study of Germany's chalcidoid fauna has accelerated, and that the quality of the records should increase with more and more recent records added.

The fact that only 33.5 % of the recorded species from Germany have been taxonomically revised (based on our search for key terms in the publication titles) might severely flaw the reliability of the known records. Taxonomic revisions in chalcidoid wasps usually result in significant additions or subtractions of recognized valid species. Recent examples from European chalcidoid taxa include the *Eupelmus urozonus* group (Eupelmidae) (now 21 valid species, but only nine species before revision; Khatib *et al.* 2014), *Dibrachys cavus* group (Pteromalidae) (now three valid species, but five species before Peters & Baur (2011) and 12 species before Gahan (1938)), the genus *Omphale* (Eulophidae) (now 37 valid species, but 31 species before Hansson & Shevtsova 2012), and the genus *Copidosoma* (Encyrtidae) (now 58 valid species, but 84 species before Guerrieri & Noyes 2005). Furthermore, *Pteromalus* Swederus, 1795, one of the most species-rich genera of Chalcidoidea with 271 species listed for Germany, has never been revised, but currently ongoing studies suggest a significant impact of revision on the number of valid species for this genus (unpublished). We need to stress that taxonomic work, in terms of revisionary work for taxonomic clarity, is crucial for any accurate species list and the basis for any further application of these lists in ecology, conservation, or biogeography. The low percentage of taxonomically revised taxa points towards two major problems in our knowledge of German Chalcidoidea: 1) the lists could well be grossly wrong in terms of true species, and 2) the number of scientists working on the taxonomy of chalcidoid (or any parasitoid) wasps is too low. There are very few specialists working on these groups. Actually, chalcidoid wasps range among the most studied and surveyed parasitoid wasp taxa in Germany, with a handful of specialists working on them; so, the situation is worse or

much worse in other diverse Hymenoptera groups. The result that only 33.5 % of the taxa have been taxonomically revised means that we have no clue about the taxonomic status of two-thirds of the chalcidoid wasp species in our own local fauna. Any study using the current list will be substantially flawed.

The number of species from neighboring countries is lower than we originally anticipated, but still, another 344 chalcidoid species are likely to be present in Germany (an increment of almost 18 % from the total). Most of these species are recorded from the Czech Republic, France and the Netherlands. This east-west axis includes the major part of the neighboring species that probably also occur in Germany. The examples of France and the Czech Republic show the positive impact on the species inventory by the work of taxonomic experts such as J.-Y. Rasplus and G. Delvare in France, and Z. Bouček in the Czech Republic.

If one looks into the chalcidoid fauna in more detail, new records for Germany can be found rather easily. We complemented our manuscript with two new species records from Germany for species already recorded from neighboring countries, collected by citizen scientists Gerd Reder and Ernst Klimsa. Both are active hymenopterists that frequently collect and photograph hymenopterans mainly in their local vicinity. Both authors approached the senior author (RSP) of this study with some photos and some questions on the identity of the depicted species and sent the specimens to the ZFMK for further examination. In collaboration with Gary Gibson, a well-renowned expert on Chalcidoidea at the Canadian National Collection (CNC, Ottawa, Canada), the specimens were identified. Both new records included exact collecting data as well as live pictures. This additional information is very rare and highly welcome. For many parasitoid species only very sparse additional information is recorded and often none at all. Of course, information on host association is most valuable. This information is also missing or fragmentary for many species. As an example, we checked the records of 200 randomly chosen species from Germany and found no or only one reference on host association for 17 % of the species. The two new German records presented here illustrate how rapid, easy and helpful joint efforts of citizen and professional entomologists can be, even in groups such as parasitoid Hymenoptera. Of course, many parasitoid groups are even more problematic than Chalcidoidea and harbor problems such as the need of taxonomic work, minute size and no available experts that will make improvement of knowledge of the local fauna exceedingly more difficult.

To provide reliable and complete species lists is only part of solving the problem of parasitoid wasps being widely neglected in science, politics and public. The other part, although tightly linked to the production of reliable species lists, is more taxonomic work and revi-

sions, the increased use of modern molecular and morphological tools in taxonomy and species identification, the publication of easy-to-use identification keys, and the education and funding of taxonomic experts. We call for future intensive collections of Germany's chalcidoid (and parasitoid) fauna, and for intensive collaboration of citizen and professional entomologists as well as for large-scale taxonomy and monitoring projects to overcome the unbearable situation that we have no or only meagre knowledge on a significant portion of Germany's biodiversity. The latest results showing that insect populations decrease at a rapid speed (Hallmann et al. 2017) urge for fast and sweeping assessments of biodiversity in order to drastically improve our understanding of local fauna and to guard against potential loss of Germany's biological heritage.

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APPENDIX I

(electronic supplement, available at www.bonnzoologicalbulletin.de)

List of Chalcidoidea species recorded from Germany, based on the Universal Chalcidoidea Database, with some corrections of the original data and with species-specific data on the record and the species' taxonomy. In red species recorded from Germany; in green species recorded from neighboring countries of Germany that do not have a border between them.

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Zoologisch-Botanische Datenbank/Zoological-Botanical Database

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