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Proceeding Paper

Threats and Challenges for Conservation of Meloidae (Coleoptera) in a Global Change Context, Emphasizing the Iberian Peninsula †

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Abstract: Meloidae Gyllenhaal, 1810 (Coleoptera), presents a complex biology, but despite this, after several decades, there have been no significant advances in the understanding of its ecology nor distribution, information on which the most basic conservation tools are based. Furthermore, the discovery of pseudocryptic complexes has made the current situation even more difficult. In this delicate global change scenario, the generation of new knowledge is pressing. A literature study was carried out to summarize for the first time all known impacts. Furthermore, sampling was carried out from 2012 and is still in development, with the help of Citizen Science. At least 32 species are suffering from human impacts, mainly habitat fragmentation due to aggressive urban development and extensive agriculture with the use of pesticides. Concretely, for meloids of the Iberian Peninsula, more than 30% are endemic and many of them threatened: the information is, in general, very limited, with nine species having a greater coverage of information than the rest. Further studies are needed urgently.

Keywords: blister beetle; change in land uses; coleoptera; insect conservation; fragmentation; global change; meloidae; oil-beetle; pesticide

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1. Introduction

Meloidae Gyllenhaal, 1810 (Coleoptera, Insecta), constitutes an iconic beetle group distributed across all continents—except for Antarctica—represented by more than 2500 species distributed in more than 120 genera [1]. Members of this group have two very remarkable biological characteristics common to all of them.

First, these animals have antipredatory chemical defences. Specifically, they present the monoterpene cantharidin in their hemolymph, which they expel to the outside through autohemorrhaging when they feel in danger [2]. Cantharidin is a powerful toxin that acts as a vesicant upon skin contact, but also can be lethal in small doses if ingested [2]. This potential danger is indicated by Mullerian mimicry [2,3] in many of the species, usually constituted by red, orange, or yellowish colours combined with dark tones such as black, usually represented by dots/stripped patterns on different parts of their morphology.

The second remarkable characteristic, which also concerns us given the nature of this manuscript, is that meloids have a hypermetabolic development, probably the most complex in the animal kingdom, presenting up to eight different stages before reaching the imaginal stage, with markedly different morphological changes and lifestyles among them [2,4].

Other essential biological points should also be noted, which also reflect the diversity of these animals in terms of their evolutionary history. In their first instar larvae, they are obligate parasitoids of different groups of insects. Depending on the clade, hosts may vary, for example solitary bees (e.g., genera *Lampromeloe* Reitter, 1911; *Meloe* Linnaeus,

1758; *Megetra* LeConte, 1859; *Physomeloe* Germar, 1818) or grasshoppers (e.g., *Epicauta* Dejean, 1834; *Lytta* Fabricius, 1775; *Mylabris* Fabricius, 1775; *Zonitis* Fabricius, 1775) [2]. This biological aspect makes them vitally dependent on their host for their proper development and survival [2]. There are two large groups (these traits are not monophyletic, but comprise two major types of life cycle) in terms of how they manage to access the guest. The first of them, the non-phoretic species, the most ancestral (although this trait reappeared later due to plesiomorphy in more recent clades [1]), present a marcher first *instar* that actively seeks the nests of solitary bees to eat their reserves and larvae [2]. The second is constituted by those species that present a phoretic larva. The first instar detects the host in its adult stage, for example a bee that has landed on a flower, and clings to it to be transported to the nest [2], the bee acting as a Trojan horse.

In addition, meloids can be classified into two large groups in terms of lifestyle, a trait that is also not monophyletic (it has appeared several times in the different clades that make up the family), but helps us understand the two main environments where they develop their biology. The first of them would be the flying floricultural type [2], with longer dispersions and mobilities in space, and a second, epigean, creeping [2], with a massive and apterous morphology. The latter includes large species, such as the genus *Berberomeloe* Bologna, 1988, which is among the largest beetles in Europe, with sizes that reach up to 7 cm [5,6] and a limited dispersal capacity [5].

As can be seen, the complexity of the group increases given the amount of different and complex forms of life, from very large and easily observable species to very small, from meloids that feed on flowers and have phoretic larvae, through epigean meloids, but which present the same type of larvae, to epigean species with non-phoretic larvae, some of them linked to an obligate parasitoidism with hymenopterans, while others with orthopterans. This scenario presents a handicap for their study and therefore the knowledge about their ecology, the current global change adding to this, resulting in an undesirable combination with respect to conservation. It is known that the rate of anthropic transformation in ecosystems is alarming, causing many insects, including meloids, to suffer important impacts that affect their populations [7]. There are already indications that many meloids are suffering population regressions and local extinctions, with diverse species catalogued in red lists of various national and regional governments [8–10].

After several decades, apart from taxonomic reviews and molecular biology studies, there have been no significant advances in the understanding of their behaviour, ecology, and distribution, information on which the most basic conservation tools are based, such as distribution maps or evaluation criteria for threatened species. Specifically, the Iberian Peninsula constitutes a European biodiversity hotspot, presenting a highly diverse entomofauna, also for the Meloidae clade. Out of 69 blister beetles present, more than 30% constitute endemic species exclusive to this region [11,12]. Furthermore, and in the same way as has occurred in other regions of the world, the frequent discovery of new species (see [13–15] among others), and pseudocryptic complexes, e.g., as in [12] (considered one of the greatest challenges for current conservation [16]), has made the issue even more difficult, with new and poorly understood species.

Therefore, given the clear gaps in the existing knowledge, it is necessary to jointly analyse and study the impacts detected so far that are affecting Meloidae populations and carry out a specific study to generate new and necessary ecological information to be able to evaluate the conservation status of these complex insects.

2. Material and Methods

2.1. Literature Study

A literature study was conducted, consisting of a review to identify as many impacts as possible for the blister beetle clade, with special emphasis on Iberian species, which are in a situation of particular vulnerability, given that there are already diverse endemisms listed in red books, both nationally and regionally. The time range used for the study was from the first reference found to 2022. A search was performed on the databases Web of

Science (Clarivate Anlaytics) ("WOS") and Scopus (Elsevier) using "Meloidae", "Meloidae conservation", and "threatened Meloidae" as the search terms. Articles were also hand searched in ResearchGate, Google Scholar, and other sources. The criteria for including references in the study were that they dealt specifically with the conservation ecology of Meloidae or provided relevant information that had to be taken into account.

2.2. Sampling Campaigns

Sampling campaigns throughout the Iberian Peninsula were carried out from 2012 to 2021—still under development today—to describe, firsthand, some impacts suffered by this clade. The samplings consisted of detecting those areas conducive to meloid species [2] and carrying out samplings of these areas as completely and extensively as possible. Once a population was detected, the species were identified together with the type of environment: "natural" if conserved, "suburban" if they were near urban nuclei, or "crops" if they were in agroecosystems. Furthermore, possible threats that were affecting said population were characterized. If necessary, they were revisited in successive years.

Furthermore, in a complementary way, the "Meloidata" Citizen Science program was launched, covering the Ibero-Maghrebian region, with the help of citizens and diverse Citizen Science organizations such as Observation.org Spain (https://spain.observation.org/, accessed on 11 April 2022) and BiodiversidadVirtual (www.biodiversidadvirtual.org, accessed on 11 April 2022). In this project, users could participate by sending locations with georeferenced photographs that were subsequently verified. After filtering the observations, participants were requested to describe the environment where these sightings were made. Locations of interest were visited to characterize them.

3. Results

3.1. Literature Review

After a specific search with "conservation Meloidae" as the search term, only 22 results from the WOS and 11 from Scopus were obtained. After the filtering process, only five works were identified that dealt with a conservationist perspective [17–21]. Third, a specific search with the term "threatened Meloidae" only generated 5 results from the WOS and 1 from Scopus, from which 108 duplicate results were eliminated. The largest number of works was found by a manual search: 20 references, all of them non-indexed [8–10,22–37]. It is clear that for this reason, much of the literature and available regional or local reports will have gone unnoticed in this work.

In fact, given the scarcity of the results, an unforeseen search was carried out, with the name of the family "Meloidae" as the criterion, to observe the general results for the entire taxon in the last decade (2010–2020), and once the references were filtered with the same criteria, the same four manuscripts were obtained as in the previous searches. Most of the references were discarded because they dealt with Systematics, Taxonomy, and the morphological description of new species, the majority of the research that has prevailed over the rest in recent times.

In general, extant information is very scarce and outdated in most cases (references with more than 10–20 years). At the moment, there is no IUCN assessment for any species. There is also no legal protection for any of them. The main problem is, in view of the results, the scarcity of information available to evaluate these species adequately. At least 32 species are suffering from human impacts, mainly habitat fragmentation due to aggressive urban development and extensive agriculture with the use of pesticides.

From the total number of references, it should be noted 13 focused on the Iberian Peninsula [8–10,23–33], 11 of them belonging to initiatives carried out by Spanish regional and national governments to elaborate catalogues of threatened species, in the form of evaluation sheets [9,10,24–32]. Redundant information was detected in some manuscripts, due to these 11 references addressing nine different species; since two Andalusian endemisms, Berberomeloe insignis (Charpentier, 1818) and Mylabris nevadensis (Escalera, 1915), were first evaluated for the Andalusian region in 2008 [24,27] and two years later, those works

were used as a basis for national evaluation forms [28–30]. In the *Andalusian Red Book*, six more species are also cited, appearing catalogued as "data deficient" (DD), but without a possible explanation as to why they are believed to be threatened [9,10].

Outside the Iberian Peninsula, it is worth highlighting the initiative "Oil Beetle Hunt" carried out by the British-based nature conservation charity Buglife—The Invertebrate Conservation Trust, in partnership with the National Trust and Oxford University Museum of Natural History, consisting of a species recovery programme, launched in 2009, where a considerable amount of information of interest has been collected thanks to the use of Citizen Science, such as distribution maps to observe population trends throughout the years [35].

Most threats covered in the literature are related to changes in habitat due to degradation, aggressive urban planning, and inappropriate or aggressive agricultural practices. On the other hand, it is worth highlighting the use of biocides and the loss of hosts that these species parasitize. A summary of the anthropic impacts identified cited as possible problems for the conservation of meloids can be consulted in Appendix A, divided into species and reference. The scientific names of the species were updated based on the most recent systematic and phylogenetic studies.

In general, all species listed suffer from data deficiency, as can be consulted in the references of Table A1. It is also of interest that most of the listed species are epigean species without flight capacity. It seems that species of the same genus share similar threats, which have a clear coherence in biological and phylogenetic terms. Many of them are endemisms with a very restricted distribution, as is the case of Berberomeloe insignis from the southeast of Spain or Mylabris nevadensis from Sierra Nevada, Granada.

3.2. Field Work and Citizen Science Program

A total of 271 samplings were carried out. There were 800 individuals from 65 different locations studied. The regions sampled in this work were Albacete, Ávila, Cádiz, Ciudad Real, Málaga, and Madrid (Figure 1).

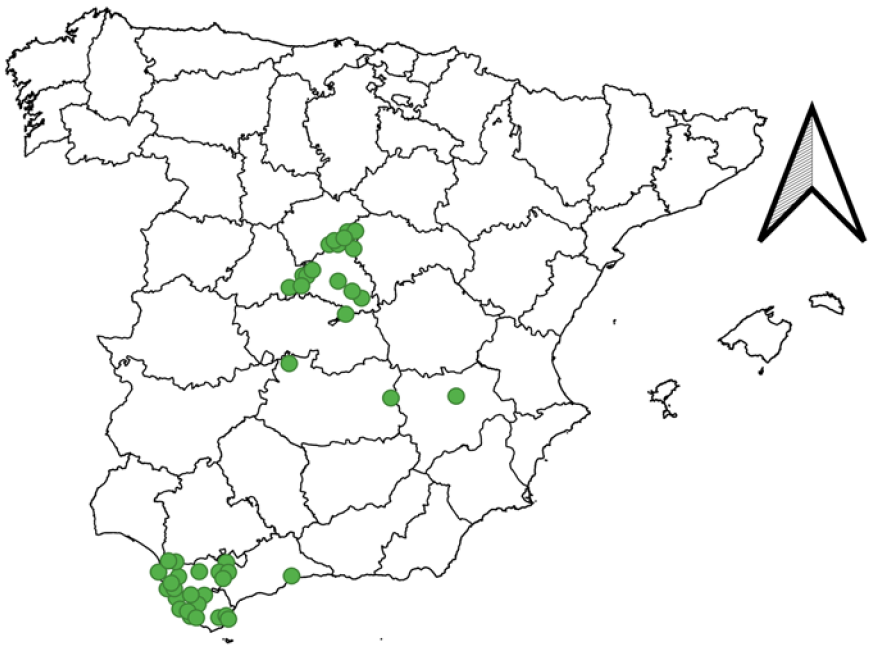

Figure 1. Point cloud of the sampled regions on the Iberian Peninsula as of July, 2021, generated with QGIS 3.16.1 Hannover using the layer "Líneas límite provinciales" from Instituto Geográfico Nacional (centrodedescargas.cnig.es). There were 271 samplings in total carried out in 60 different locations within the areas indicated on the map.

Clear signs of transformation were identified in at least 20 populations, most of them constituted by epigean blister beetle species. A list of potential impacts identified is collected in Table 1. Concretely, 18 affected nuclei were located along suburban environments and for three different Iberian endemisms, *Berberomeloe comunero* Sánchez-Vialas et al., 2020, *B. payoyo* Sánchez-Vialas et al., 2020, and *Physomeloe corallifer* Germar, 1818. Throughout the development of this research, two of them presumably suffered a local extinction, but further data are needed. Furthermore, the Citizen Science program provided five additional locations, of which two presented some type of threat to their conservation.

Table 1. Potential impacts identified classified by species and environment type, natural if conserved, suburban if location is near urban nuclei, and crop field if population was observed within agroecosystems.

Species Affected	Impact	Environment Type
Berberomeloe payoyo	Illegal dumping	Natural/suburban
Berberomeloe payoyo	Fragmentation	Suburban
Berberomeloe payoyo	Quarrying	Suburban
Berberomeloe payoyo	Phytosanitary treat.	Crops
Berberomeloe payoyo	Road traffic	Natural/suburban
Berberomeloe payoyo	Soil overexploitation	Crops
Berberomeloe payoyo	Urban development	Natural/suburban
Berberomeloe comunero	Fragmentation	Natural/suburban
Berberomeloe majalis	Human transit	Natural
Hycleus sp.	Fragmentation	Natural
Mylabris sp.	Illegal dumping	Natural
Meloe tuccia	Fragmentation	Natural/suburban
Physomeloe corallifer	Human transit	Natural
Physomeloe corallifer	Fragmentation	Suburban
Physomeloe corallifer	Road traffic	Natural
Physomeloe corallifer	Urban development	Natural/suburban

Most of the impacts are related to two main aspects. The first is the transformation of the environment, highlighting urban development, fragmentation, and changes in land use. The second is related to direct impacts on the species, such as the use of biocides and deaths from road traffic collisions or by human transit.

4. Discussion

The family Meloidae presents a very complex development and, in the context of global change, is facing great challenges. Conservation of the group is a fairly unexplored field, as we lack much relevant and necessary information for the environmental evaluation and management of the species if necessary. Advances are mainly centred on phylogenetic relationships, as well as evolutionary origins. New species are described very frequently, a fact that illustrates their richness. However, this seems to go hand in hand with a greater lack of ecological information as the number of species described increases.

In the last decade, there were no substantial advances in the knowledge of meloid conservation. Very few studies have dealt with this matter adequately and in depth, and there are very important information gaps that must be urgently covered. It is relevant to note that, to date, in Spain, there is no reliable or recent distribution maps for any species of meloid, not even for Iberian endemisms with a very restricted distribution. In fact, few ex profeso studies have been performed to reveal the distribution of any of the Iberian species. For example, for *Berberomeloe insignis*, a southeastern Iberian endemism, whose total distribution is predictably small and can be covered relatively easily, specific sampling campaigns have been carried to approach this issue. This is, probably, the only species that for the moment has come closest to a conservation evaluation, being included in the *Red Book of Threatened Invertebrates of Andalusia* [9] and the corresponding red book at the Spanish level [10]. However, there have been no new studies published in the last ten

years outside of the initiative that these governments carried out in the late 2000s. There are also no follow-up studies with periodic resampling in the region, in order to detect possible new grids in the UTM 10 × 10 distribution maps, in order to have a document as complete and up-to-date as possible, given that the area where this species is distributed also has a very high degree of human transformation, even knowing that the survival of the most impacted populations of the species is in great peril and the most conserved seem to present viability in the short to medium term [28]. In fact, and despite clear signs about the need to collect data, which can allow carrying out assessments according to the IUCN criteria, at the moment, neither *B. insignis* nor any other blister beetle has been evaluated nor included in the IUCN Red List of Threatened Species.

With respect to the threats that Meloidae communities are currently suffering, it can be stated by gathering all the results obtained that, probably, the main anthropogenic modification is related to changes in land use, including habitat loss due to urban development, which are having important impacts on insect communities. In this case, the impacts seem to be more appreciable in non-phoretic epigean species, maybe given their low dispersal capacity. On the other hand, there are documented cases of meloid populations and species that have already suffered local and even regional extinctions.

Despite their diversity, the whole clade presents similar traits in species' life cycle, so it is highly probable that the impacts presented are applicable to the rest, as many works have already suggested.

5. Conclusions

In general, ecological studies in the family Meloidae must be addressed urgently. The biggest problem to solve is the lack of basic and crucial information for the evaluation and conservation of its diversity, knowledge that is for the moment incomplete, obsolete, or has not yet been generated, even though there are documented cases of impacts including endemic species whose distribution is very restricted and which have a real risk of extinction. Therefore, in this scenario of accelerated anthropogenic change, it is essential to address this issue as soon as possible. Although the rest of the disciplines are crucial, concretely, it is necessary to carry out detailed and in-depth studies of conservation ecology on these complex beetles. Due to the lack of reliable data that allow in-depth knowledge, both the scientific community and the administrations that could implement tools and solid legal frameworks cannot advance the conservation of this entomofaunal wealth, while the clear regressions of populations and local, regional, and even national extinctions that these insects are suffering are pressing issues.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. Impacts cited in the literature studies classified by species and reference. The scientific name of the species has been updated based on the most recent systematic and phylogenetic studies.

Impact	Species
Biocides (species directed)	*Berberomeloe insignis* [28,29] *Berberomeloe payoyo* [33] *Eurymeloe nanus* [25] Meloini tribe [29] *Physomeloe corallifer* [8] *Lampromeloe variegatus* [29] *Taphromeloe foveolaus* [26]
Forest fires	*Taphromeloe foveolaus* [26]
Fragmentation	*Apalus bimaculatus* [19,34] *Berberomeloe insignis* [28,29] *Berberomeloe payoyo* [33] *Eurymeloe brevicollis* [35] *Eurymeloe rugosus* [35] *Lampromeloe variegatus* [29] *Meloe proscarabaeus* [35] *Meloe violaceus* [35]
Genetic impoverishment	*Gnathium minimum* [20]
Global warming	*Mylabris nevadensis* [27,30]
Habitat loss/degradation	*Apalus bimaculatus* [19,34] *Epicauta pensylvanica* [21] *Eurymeloe brevicollis* [35] *Eurymeloe nanus* [25] *Eurymeloe rugosus* [35] *Meloe proscarabaeus* [35] *Meloe scabriusculus* [18] *Meloe uralensis* [18] Meloini/Meloinae [35] *Micromeloe decorus* [18] *Meloe violaceus* [35] *Mylabris nevadensis* [26,29] *Sitaris rufipennis* [9] *Taphromeloe foveolaus* [31]
Host loss	*Apalus bimaculatus* [19,34] *Eurymeloe brevicollis* [35] Meloini/Meloinae [29,35] *Eurymeloe brevicollis* [35] *Eurymeloe nanus* [25] *Eurymeloe rugosus* [35] *Hycleus uhagonii* [8] *Meloe proscarabaeus* [35] *Meloe violaceus* [35] *Sitaris rufipennis* [9]
Illegal dumping	*Berberomeloe payoyo* [33]
Inadequate forestry practices/unnecessary reforestation	*Berberomeloe insignis* [28,29] *Eurymeloe nanus* [25] *Mylabris nevadensis* [27,30] *Taphromeloe foveolaus* [26]
Intensive agriculture/ damages due to agriculture	*Berberomeloe insignis* [28,29] *Eurymeloe nanus* [25] *Lampromeloe variegatus* [29] *Taphromeloe foveolaus* [26]

Table A1. *Cont.*

Impact	Species
Livestock overexploitation	*Mylabris nevadensis* [27,30]
Open-pit mining/quarrying	*Berberomeloe insignis* [28,29] *Eurymeloe nanus* [25]
Road traffic	*Berberomeloe payoyo* [33] *Berberomeloe* sp. [8] *Lampromeloe variegatus* [29] *Taphromeloe foveolaus* [26]
Soil composition changes/ change in land uses	*Berberomeloe insignis* [28,29] *Berberomeloe payoyo* [33] *Eurymeloe brevicollis* [35] *Eurymeloe rugosus* [35] *Meloe proscarabaeus* [18,35] *Meloe scabriusculus* [18] *Meloe uralensis* [18] *Meloe violaceus* [35] *Micromeloe decorus* [18]
Water reserve overexploitation	*Berberomeloe insignis* [28,29]
Unsustainable tourism	*Mylabris nevadensis* [27,30] *Taphromeloe foveolaus* [26]
Urban development	*Berberomeloe insignis* [28,29] *Berberomeloe payoyo* [33] *Berberomeloe* sp. [8] *Eurymeloe nanus* [8] *Eurymeloe tuccia* [8] *Lampromeloe variegatus* [29] Meloini tribe [29] *Physomeloe corallifer* [8] *Taphromeloe foveolaus* [26]
Unknown reasons, but: observed regression/very restricted range/supposed to be endangered/extinct in some regions	*Eurymeloe brevicollis* [8] *Eurymeloe mediterraneus* [8] *Euzonitis quadrimaculata* [8] *Hycleus duodecimpuctatus* [8] *Lampromeloe cavensis* [8] *Lampromeloe variegatus* [8,29,35,36] *Lytta hoppingi* [37] *Lytta insperata* [37] *Lytta moesta* [37] *Lytta molesta* [37] *Lytta morrisoni* [37] *Meloe proscarabaeus* [8] *Meloe violaceus* [8] *Meloegonius cicatricosus* [35] *Mylabris amorii* [28] *Mylabris deferreri* [28] *Mylabris dejeani* [8] *Mylabris quadripunctata* [8] *Mylabris uhagonii* [32] *Mylabris variabilis* [8] *Sitaris rufipenis* [9] *Sitarobrachys thoracica* [9] *Treiodus ajax* [22] *Treiodus autumnalis* [35]

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