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The need for a (non-destructive) method revolution in entomology

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ABSTRACT

There are worrying signs that arthropods are in decline both in density and diversity. This threatens global biodiversity as well as the ecosystem services provided by arthropods. Nonetheless, entomological research, even when studying arthropods with a conservation focus, frequently uses lethal methods. We analysed 1029 articles published in the major biological conservation journals between 2014 and 2020 and found that, while single-species-focused studies used more non-lethal than lethal methods (76.3 % vs. 23.7 %, respectively), the opposite was true for multiple-species ones (24.0 % vs. 76.0 %). In tropical regions, 74.6 % of studies used lethal methods vs. 18.5 % non-lethal ones. Of the major orders, Odonata, Lepidoptera and Orthoptera were generally studied using non-lethal methods (88.1 %, 80.7 %, and 70.8 %, respectively) in non-tropical regions, while in the tropics, only Lepidoptera were frequently (51.9 %) studied by such methods. We argue that even if the evidence for arthropod decline were uncertain, and even if research would not add much to the overall level of mortality, entomologists should be showing an example. If research on invertebrates continues to be ethically blind, entomologists risk losing public support for conserving arthropod diversity.

The traditional human view of arthropods is rarely a favourable one. While the eminent ecologist and entomologist E. O. Wilson famously claimed that “small things … run the world” (Wilson, 1987), this was disputed even within the ecologist community (Terborgh, 1988). The overall gross bias in ecological research towards big vertebrates continues (Titley et al., 2017). Whether in spite of this, or because of this, arthropods in general have not been an important part of the human research effort (Basset et al., 2019). An estimated 70 % of arthropods (Scheffers et al., 2012) and 80 % of insects (Stork, 2018) have not even been described or discovered yet. This imbalance comes at a cost, as Basset et al. (2019) argue: “the neglect of insects as study organisms has led to serious bias in our understanding of the functional ecology of ecosystems.” This state of affairs is also surprising because arthropods account for two thirds of the ca. 1.5 million known species of all organisms, with beetles (Coleoptera) alone representing 25 % of them (Stork et al., 2015). The importance of arthropods is underlined by the existence of several entomological sub-disciplines like economic, medical and veterinary entomology. With the emergence of the ecosystem services concept (Daily, 1997), the importance of arthropods has become better recognised, for example in pollination (IPBES et al., 2016). The valuation of ecosystem services provided by insects in the US (Losey and Vaughan, 2006) came to an estimated US$57 billion y^{-1}, amply justifying that more attention should be devoted to arthropods providing those ecosystem services.

Although the ongoing mass extinction is mostly associated with the dramatic decline in vertebrate populations (Grooten and Almond, 2018), arthropods are affected as much, if not more, as vertebrates (Dirzo et al., 2014; Sánchez-Bayo and Wyckhuys, 2019). According to IUCN criteria, 41 % of insect species, including the ones we generally regard as “common”, are currently declining, and an estimated 31 % of them are threatened with extinction (Sánchez-Bayo and Wyckhuys, 2019). Surprisingly, of the thousands of estimated insect extinctions, only 394 have been documented (Hochkirch, 2016). The risks related to arthropod diversity loss are enormous, including cascading effects on dependent organisms (Biesmeijer et al., 2006), worsening of ecosystem services (Potts et al., 2010), economic losses (Gallai et al., 2009), and declining global food security (Tscharntke et al., 2012). When a group of organisms becomes rare or threatened, the alarm is raised, and various measures are introduced to protect them. Many vertebrate species have become subjects of such regulations, and unfortunately, the list is

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becoming longer and longer, year by year. Such measures usually include various regulations concerning international trade (CITES, 2021), the use of products linked to such protected organisms, and restrictions on collecting or keeping them as pets. Research on protected vertebrates requires permission, and methods that kill or harm them are normally not allowed when studying those species. This does not seem to hold for research on arthropods, although a few species appear on CITES appendices (CITES, 2021).

Entomologists traditionally use methods that are destructive. Several of these are mass collecting methods that kill various arthropod groups with little discrimination. Pitfall traps, light traps, and Malaise traps (Henderson, 2021) are standard, widely used devices that collect (and kill) thousands of arthropods. This is consistent with the traditional perception of arthropods, namely that their life is worthless. Some ethical schools argue that arthropods are not "ethical subjects" (Rawls, 1993). Others even claim that they cannot feel pain (Eisemann et al., 1984). Consequently, killing uncounted numbers of them raises few objections.

Nonetheless, as arthropods started to decline, the field of "insect conservation" emerged. The name is unfortunate because it should really be called *arthropod* conservation. The arthropod conservation field has grown, evidenced by an increase from a mere 3 papers in 1970 to 163 by 2010 (Eggleton, 2020), and now has at least two journals (Journal of Insect Conservation, Insect Conservation and Diversity), plus several textbooks (e.g. Samways, 2019) dedicated to the subject. A few recent papers claiming or documenting serious declines in arthropod density and diversity (Hallmann et al., 2017; Sánchez-Bayo and Wyckhuys, 2019) have even made headlines in the public media. In light of these recent developments, it may be appropriate to look at the entomological practice with a critical eye.

1. Analysis of current practice in arthropod conservation research

As pest insects are frequently objects of destruction, one can hardly argue that economic entomology should be practiced using non-lethal methods. The question becomes more relevant when we consider research on protected or rare arthropods.

We retrieved all articles published in the period of 2014–2020 in two entomology journals devoted to the protection of insects: Journal of Insect Conservation (JIC) and Insect Conservation and Diversity (ICD). We also searched for articles devoted to arthropod conservation by checking the titles of all published articles during the same period in four other conservation biology journals: Conservation Biology, Biological Conservation, Biodiversity and Conservation, and Global Conservation and Ecology. We disregarded literature reviews, opinion pieces, and editorials. If necessary, we checked the abstract to decide whether that particular article was about arthropod conservation or not. Apart from bibliographic data, we extracted the following from relevant papers:

- taxonomic affiliation (order or family studied)
- focus of paper (single or multiple species or orders)
- region of study (tropical vs. non-tropical)
- method/s used

Here we distinguished whether a study was based on existing collections or on newly collected material and if the latter, whether it was obtained by lethal or non-lethal methods. Note that subtropical regions were considered as tropical, and that a study could employ multiple (i.e. more than one of the above) methods. By doing this, our aim was to explore whether there was a geographical or taxonomic imbalance in method use, and whether journals with the express purpose of protecting arthropods show any preference towards non-lethal study methods.

2. Prevalence of lethal methods in entomology

Overall, we found 1029 relevant articles where arthropods were collected or recorded (Table 1). More articles ($n = 753$) were from non-tropical than tropical regions ($n = 274$); two studies published in ICD included both regions. Studies that focused on a single species used more non-lethal than lethal methods (76.3 % vs. 23.7 %), while studies that focused on more than one species did the opposite (24.0 % vs. 76.0 %). Studies that focused on more than one order used more lethal than non-lethal methods (83.3 % vs. 16.7 %), and the same (although less pronounced) pattern was recorded when a single order was the focus (57.3 % vs. 42.7 %).

In non-tropical regions, 46.7 % of the studies used lethal methods against 43.0 % that used non-lethal ones and 10.2 % that used both lethal and non-lethal methods. In tropical regions, instead, substantially more studies (74.5 %) used lethal methods than non-lethal ones (18.6 %) or both (6.9 %). In a few examples, even protected or rare species were killed for study. In several papers, the fate of studied arthropods was not communicated.

In non-tropical regions, Odonata, Lepidoptera and Orthoptera were generally studied using non-lethal methods (88.1 %, 80.7 %, and 70.8 %, respectively). In tropical regions, Lepidoptera were frequently censused visually (51.9 % of the studies). For all other orders, lethal methods were predominant, more in tropical than non-tropical regions (Table 1).

The older journal of the field, JIC, published 639 articles during 2014–2020, of which we analysed 511 after discarding 128/639 (20 %) articles that used existing literature, databases, museum collections, or modelling. Of the analysed articles, 46.4 % used lethal methods ($n = 237$), 46.2 % ($n = 236$) non-lethal ones, and 7.4 % ($n = 38$) both. When the focus was more than one species, 72.1 % (248/344) of the studies used lethal methods, while in single-species-focused articles, only 16.2 % (27/167) used them. There was a striking difference in the use of lethal methods between tropical vs. non-tropical studies published in JIC: 73.9 % of the articles from tropical regions used lethal methods vs. 36.2 % from non-tropical ones.

ICD published 342 articles during 2014–2020. Seventy (20.5 %) of these used already existing or published data or material from museum collections and were excluded from further analyses. Of the relevant articles, 157 (57.7 %) employed lethal methods, and 82 (30.1 %) non-destructive ones; 12.1 % of the articles used both. When the focus of study was a single species, 57.4 % of the papers used non-lethal methods, while less than a quarter of them (22.3 %) did so when multiple species were studied. There was also a geographical difference: 34.9 % of studies (75/215) conducted in non-tropical regions used non-lethal methods, while only 11.9 % (7/59) did so in tropical studies.

Biodiversity and Conservation published 1501 articles between 2014 and 2020, of which 177 were arthropod-themed and 141 were relevant for this analysis. Of the analysed articles, 78.0 % (110/141) used lethal methods, 14.9 % (21/141) non-lethal ones, and 7.1 % (10/141) used both. Only three studies focused on single species (one of these used lethal methods), while 138 focused on more than one species (79 % of these used lethal methods). Non-lethal methods were similarly used in studies from tropical and non-tropical regions (17.8 % and 13.5 %, respectively). The journal Biological Conservation published 2893 papers during the 2014–2020 period. Ninety-one articles were retained, and after checking content, data were extracted from 74 relevant papers. Of these, 48.6 % (36/74) used lethal methods, 39.2 % (29/74) non-lethal ones, and 12.2 % (9/74) used both. Only ten studies focused on single species (6 of those used non-lethal methods), while 64 focused on more than one species (only 35.9 % of these used non-lethal methods). Lethal methods were more commonly used in tropical studies (61.9 %, 13/21) than in non-tropical ones (43.4 %, 23/53).

The other leading journal, Conservation Biology, brought forth little to evaluate: it published only 37 primary papers that focused on arthropods, which is a puny share of the 1321 papers published during that period. Data were extracted from 16 relevant papers; 7 of those used

Table 1
The number of articles based on collecting arthropods, published in journals of conservation biology, their focus, and use of lethal vs. non-lethal methods in tropical vs. non-tropical regions summarised by journal, and also by the main insect orders studied. Data are organised by decreasing numbers of relevant papers.

Journal/order studied	Number of papers (%)					Species focus (%)		No. studies (%) from tropical areas using			No. studies (%) from non-tropical areas using		
	All	Arthropod-themed[a]	Relevant[b]	Tropical	Non-tropical	Single	Multiple	Lethal	Non-lethal	Both	Lethal	Non-lethal	Both
Journal[c]													
JIC	639	639	511	138 (27.0)	373 (73.0)	167 (32.7)	344 (67.3)	102 (73.9)	29 (21.0)	7 (5.1)	135 (36.2)	207 (55.5)	31 (8.3)
ICD	342	342	272	59 (21.7)	213 (78.3)	61 (22.4)	211 (77.6)	49 (83.1)	7 (11.9)	3 (5.1)	108 (50.7)	75 (35.2)	30 (14.1)
Biodiv. Cons.	1501	177	141	45 (31.9)	96 (68.1)	3 (2.1)	138 (97.9)	33 (73.3)	8 (17.8)	4 (8.9)	77 (80.2)	13 (13.5)	6 (6.3)
Biol. Cons.	2893	91	74	21 (28.4)	53 (71.6)	10 (13.5)	64 (86.5)	13 (61.9)	5 (23.8)	3 (14.3)	23 (43.4)	24 (45.3)	6 (11.3)
Cons. Biol.	1321	37	16	7 (43.8)	9 (56.2)	4 (25.0)	12 (75.0)	3 (42.9)	2 (28.6)	2 (28.6)	3 (33.3)	5 (55.6)	1 (11.1)
GEC	1326	17	15	6 (40)	9 (60)	0	15 (100)	6 (100)	0	0	6 (66.7)	0	3 (33.3)
Order studied													
Multiple		295	244	65 (26.6)	179 (73.4)	0	244 (100)	54 (83.1)	7 (10.8)	4 (6.2)	112 (62.6)	35 (19.6)	32 (17.9)
Lepidoptera		303	239	52 (21.8)	187 (78.2)	123 (51.5)	116 (48.5)	16 (30.8)	27 (51.9)	9 (17.3)	25 (13.4)	151 (80.7)	11 (5.9)
Coleoptera		238	200	44 (22.0)	156 (78.0)	51 (25.5)	149 (74.5)	41 (93.2)	3 (6.8)	0	95 (60.9)	57 (36.5)	4 (2.6)
Hymenoptera		197	151	63 (41.7)	88 (58.3)	19 (12.6)	132 (87.4)	51 (80.9)	9 (14.3)	3 (4.8)	54 (61.4)	19 (21.6)	15 (17.0)
Odonata		73	53	11 (20.8)	42 (79.2)	20 (37.7)	33 (62.3)	7 (63.6)	2 (18.2)	2 (18.2)	2 (4.8)	37 (88.1)	3 (7.1)
Diptera		44	33	12 (36.4)	21 (63.6)	5 (15.2)	28 (84.8)	11 (91.7)	0	1 (8.3)	14 (66.7)	2 (9.5)	5 (23.8)
Orthoptera		34	30	6 (20.0)	24 (80.0)	13 (43.3)	17 (56.7)	5 (83.3)	1 (16.7)	0	2 (8.3)	17 (70.8)	5 (20.8)

[a] The total number of publications where arthropods were studied.
[b] The number of publications where arthropods were field-collected or observed.
[c] Journal abbreviations: JIC: *Journal of Insect Conservation*, ICD: *Insect Conservation and Diversity*, Biodiv Cons: *Biodiversity and Conservation*, Biol Cons: *Biological Conservation*, Cons Biol: *Conservation Biology*, GEC: *Global Ecology and Conservation.*

non-lethal methods, 6 lethal ones, and 3 more combined both (Table 1).

Global Ecology & Conservation published 1326 articles between 2014 and 2020 from which 60 articles were identified, and after checking the abstracts, data were extracted from 15 relevant articles. All of these used lethal methods, in the tropics or outside (Table 1).

3. A way forward

In spite of a persistent difference of method use in tropical vs. non-tropical sites and some imbalances by taxonomic groups, several studies with the express purpose of conserving arthropods aim to achieve this by killing them. This is in sharp contrast with methods development in other biological disciplines. During the 20th century, non-destructive methods in biological science progressed from virtual non-existence to (occasionally) obligatory use. For example, a gun was the main collecting device of an ornithologist in the early 20th century, while this is certainly not a necessary nor a widely acceptable tool today (Birkhead, 2008). Entomology is lagging behind, and although in several cases, we do not (yet) have alternative non-lethal methods (e.g. morphometric research, Csősz et al., 2021) several novel technologies create opportunities for more ethical research (van Klink et al., 2022), and a few entomologists have acknowledged the need for a realignment and action (Forister et al., 2019), and a better use of already-collected material.

However, why is a change needed? Should we not simply accept that entomologists cause much less harm to the arthropod world than, for example, passing cars do? Is it not possible that entomologists, by driving vehicles to their study sites, actually (and inadvertently) do kill more arthropods than with their lethal collecting methods (Hans Turin, Wageningen, The Netherland, pers. comm.)? The articles claiming to document steep declines in arthropod biomass (Hallmann et al., 2017) and diversity (Sánchez-Bayo and Wyckhuys, 2019), generated a flurry of articles and comments. Several of these argued that the papers claiming "insectageddon" are of limited validity (Simmons et al., 2019), not representative (Thomas et al., 2019), and/or biased (Mupepele et al., 2019). What if these doubters are correct?

We argue that even if the evidence for arthropod decline were uncertain, and even if research would not add much to the overall level of mortality, entomologists should be showing an example. If entomologists do not practice what they preach (i.e. to protect arthropods), how can we expect the public to understand and accept our arguments? Similar arguments were recently elaborated by Drinkwater et al. (2019), who called attention to the risk of losing public support if research on invertebrates continues to underestimate the ethical aspects. Even if for the purpose of environmental monitoring, the traditional mass collecting methods, such as the continent-wide pitfall trapping employed by the US ecological monitoring scheme (Hoekman et al., 2017), killing millions of ground beetles should not be acceptable.

There can be different ways to ease this oddity. The minimising 'waste' approach seeks to save and use everything that was previously obtained by non-selective, mass collection methods (Spears and Ramirez, 2015). This only indirectly reduces the number of arthropods killed in the name of science, but it is a step in this direction. Consulting a statistician to assess how to reduce the number of traps while keeping acceptable statistical power could be a reasonable way to decrease the number of arthropods collected. Using previously collected material and available databases (e.g. Fricke et al., 2022; Short et al., 2018) can also help to avoid further killing. Over and above the adoption in entomology of 3Rs (reduce, replace, refine) developed for animal experimentation (Fischer and Larson, 2019; Russell and Burch, 1959), there are several non-lethal methods available in the entomological toolkit. Some of these can still cause harm or discomfort to the studied species either by hampering their movement by attached trackers (Růžičková and Elek, 2023) or by exposing them to increased risk by modifying their behaviour. For example, a non-killing light trap, combined with artificial intelligence to identify moths lured to the light (Bjerge et al., 2021) may seem a harmless method. However, the light attracts arthropod predators too, such as bats (Cravens et al., 2018), exposing the moths lured to the light to higher predation risk.

Field observation, personal or automatic, allows for monitoring with little or no disturbance. For example, butterflies (Pollard and Yates, 1993), dragonflies (Pearce-Higgins and Chandler, 2020), or tiger beetles (Choudhury et al., 2020) can be (and often are) visually monitored. Acoustic surveys for Orthoptera are feasible (Jeliazkov et al., 2016) and are a reliable tool for taxonomic identification (Riede, 2018). Collecting from freshwater environments poses special challenges (Karasek and Koperski, 2015) but environmental DNA-based detection can be useful in various settings (Brodin et al., 2013; Todd et al., 2020), and pupal shells, exuviae (larval skins) or frass (Sweetapple and Barron, 2016) can serve to provide distribution records. In other contexts (e.g. agriculture), the focus is on the effect of arthropod activity, for example in ecosystem service research. During such studies, arthropods are routinely collected to estimate the levels of ecosystem services they provide. This could be quantified instead using non-lethal, direct approaches, such as the sentinel method (Ferrante et al., 2022).

These methods need wider publicity among the practitioners. Further developing, promoting and using them ought to be the entomologists' moral duty. Field entomology needs a new methods book with a different orientation; even from the latest edition of a classic book on ecological methods (Henderson, 2021) the idea of arthropod conservation is lacking. We note, moreover, that the groups where non-lethal study methods are most used (butterflies, dragonflies) are often the ones that appeal to human aesthetic preferences. Thus, the current use of non-lethal methods does not necessarily reflect the suitability of the various arthropod taxa to such study methods. Admittedly, a number of the non-lethal methods, while promising, are not yet sophisticated and/or reliable enough to be widely used. This poses a methodological challenge that entomologists can very well overcome. Nonetheless, we can set the general direction by arguing that the mentality of "arthropods do not matter, we can kill as many as we want" is neither good nor tenable.

4. Conclusion

While we do not question that many entomologists do care about the effect of their sampling on arthropods, from the published articles devoted to arthropod conservation it seems that the question of using non-lethal alternatives versus killing arthropods is scarcely considered an important issue. This underlines that there is a need for an express consideration of ethical aspects in entomological research, and -we dare to suggest- there is also a need for a methodological revolution in entomology. Mass killing of arthropods, even in the name of science, should no longer be acceptable. We acknowledge that, in several cases, we do not currently have methods to easily study arthropods without killing them. For a few groups (e.g. Odonata, Lepidoptera), non-lethal study and survey methods already are widely used. In many other cases, such methods exist but are not frequently used. Journals and research funders should consider making such non-destructive methods preferable and any deviation from them to be justified. We believe that at least the journals devoted to insect conservation should have explicit guidelines on the use of destructive vs. non-destructive methods in the author instructions. Entomologists need to consider various methods while planning their research, especially when the focus is arthropod conservation. We urge to reconsider and modify planned, standardised global biodiversity monitoring schemes that prescribe using non-discriminating methods that generate superfluous killing of various organisms. We are confident that with careful and innovative thinking, solutions can be found. Even if the ethical foundations were disputed, the currently near-dominant approach in entomology underpins a world view in which not only human interests, but human preferences and even whims are supreme, and all living beings are at their service. That attitude brought us to the grave situation we now collectively find ourselves – at the open gates of the sixth mass extinction. We entomologists need a close, hard look at our profession and a change in our practices to suit the changed circumstances.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

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CRediT authorship contribution statement

Conceptualization, GLL, MF; Data curation: all authors; Formal analysis GLL, MF; Investigation: GLL, MF, DM, GM, EV; Methodology: GLL, MF; Writing - original draft GLL, MF; Writing - review & editing: all authors.

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