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The Use and Prospects of Nonlethal Methods in Entomology

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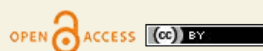
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Abstract

Arthropods are declining globally, and entomologists ought to be in the forefront of protecting them. However, entomological study methods are typically lethal, and we argue that this makes the ethical status of the profession precarious. Lethal methods are used in most studies, even those that aim to support arthropod conservation. Additionally, almost all collecting methods result in bycatch, and a first step toward less destructive research practices is to minimize bycatch and/or ensure its proper storage and use. In this review, we describe the available suite of nonlethal methods with the aim of promoting their use. We classify nonlethal methods into (a) reuse of already collected material, (b) methods that are damaging but not lethal, (c) methods that modify behavior, and (d) true nonlethal methods. Artificial intelligence and miniaturization will help to extend the nonlethal methodological toolkit, but the need for further method development and testing remains.

1. INTRODUCTION

We live in an era of extinctions. Even if documentation is uneven and uncertain, the estimated current extinction rates are up to a thousand times higher than the historical background extinction rate, and estimated future rates are even higher (3, 21). There are various manifestations of this biodiversity decline, including defaunation, extinction of large-bodied species, and a sharp decline in biomass of wild birds (26). Whether numbers of arthropods are also decreasing is debated by entomologists (17, 24), but the overall evidence provides reason for concern (20, 127).

There has been a change in how we treat the animals to which we feel emotional attachment. This is reflected in research resource allocation (59), but also in their living conditions in captivity, our ways of treating them, and methods of performing research on them in captivity and in the wild. Yet this same change in perspective has not yet happened in research on arthropods. We know that small things “run the world” (132)—yet the biggest of the unknowns in global biodiversity is the invertebrates, especially arthropods (111). Among entomologists, the general attitude is that individual specimens are dispensable if the existence of a species is not threatened. Current practices do not reflect the intrinsic value that these organisms have and that entomologists would like the public to recognize, and this should suggest that we need to reassess the way we practice entomology.

Arthropods can be studied using nondestructive techniques, but these methods are not commonly promoted or requested, for example, when proposing a research project. The description of a few nonlethal methods can be found in general books on methods in entomology and ecology (22, 42) but are not grouped together, nor do they form any sizeable part of these books. The result is that nonlethal methods are regarded as unconventional and less effective than lethal ones. We recognize that it would be difficult to argue that it is unethical to manage insect pests in agriculture or invasive species that decimate native tree populations and disrupt whole ecosystems. However, pest species constitute a small share of arthropod diversity; furthermore, ethical considerations should not be restricted to beneficial species. Undoubtedly, there are entomologists who practice self-restraint when collecting, yet there is no consensus in the profession that a shift toward nondestructive techniques would be desirable. Today, even familiar groups in well-studied regions can be researched using lethal methods without providing any justification.

This review argues that the lives of even individual insects are not always expendable, especially when we aim to monitor arthropods of conservation concern, those that provide important ecosystem services, or arthropod populations in general. To provide readers with inspiration for how they could adjust their monitoring practices to be nonlethal, we synthesize the available nondestructive methods to study arthropods, discuss the advantages and disadvantages of the available nondestructive tools, and provide recommendations to favor the transition toward ethically more acceptable research practices in entomological studies.

The ethical status of arthropods as sentient beings is rarely debated, but this is not because there is an easy answer to this question. Classical ethics regarded arthropods as nonobjects because it was argued that they do not have interests (87). Additionally, some argue that arthropods (and other so-called primitive beings in general) do not feel pain (29) and do not even have the neural architecture to feel pain (53); the ethical consequence of this would be that they cannot be harmed. These arguments have been disputed (70). Several philosophers argue that every living being has interests, at a minimum to remain alive and to avoid harm to itself (36, 89, 102).

The German philosopher Immanuel Kant argued against cruelly treating dogs because it would make human actors more cruel toward each other (10)—not because he thought dogs can feel pain. Since then, nonhuman consciousness has been recognized (79), and in parallel with this recognition, society started to introduce regulations on how to treat vertebrates in general, including their use in research.

An alternative ethical school, consequentialism, posits that actions should be evaluated on their consequences (44). If an action helps an organism to prosper, then it is a positive action. If, in contrast, the action hampers the flourishing of a living being, then it is a negative action and is to be avoided. As Martha Nussbaum wrote, “there is waste and tragedy when a living creature has the innate, or basic capability for some functions that are evaluated as important and good, but never gets the opportunity to perform those functions” (78, p. 305). Notably, this argument does not require that the subject be aware that a certain action harms it.

Research on conservation mostly deals with vertebrates (120). This is peculiar because invertebrates are much more numerous, by abundance as well as species richness, than vertebrates. Although our understanding of global species richness is very fragmentary, we already know that most of the multicellular species living on Earth today are invertebrates—mostly arthropods, within which insects, and within insects, beetles, are the most species rich (111). Arthropods also deserve attention for the services that they provide for humans (98).

While none of these arguments justify the protection of all arthropod species, taken together, they should lead to a focus on scientific practices based on the premise that not only do arthropod species and their services for humans matter, but so do individual arthropods. In this context, it is worth specifying that species are abstract entities, and harm to an arthropod species occurs through harm to individuals of that species (79).

Recently, attention has been called to the application of the three Rs principle, i.e., reduce, replace, refine (33), and animal welfare considerations have been widened to include invertebrates (70). While there is no universal nonlethal sampling protocol, researchers should consider whether they could perform their intended study using some of the methods described below.

2. A SURVEY OF EXISTING NONLETHAL METHODS

A recent summary of current entomological practice, with special reference to the use of lethal versus nonlethal methods in journals devoted to conservation or, more specifically, to the conservation of insects, shows that the majority of these articles still use lethal study methods (62). Only when studying a few groups, including Lepidoptera, Odonata, and Orthoptera, do scientists employ or prefer nonlethal study methods. Individuals of these groups happen to be colorful and pleasing to the human eye, as is the case for butterflies or dragonflies (101, 126). Overall, even among studies aimed at protecting arthropods, up to 60% used destructive methods (62).

In spite of this, entomology is not inseparably wedded to the use of lethal methods. In this section, we survey the ways in which entomologists could reduce the damage that they cause to the arthropod world while studying it.

2.1. Use of Already-Dead Arthropods

An indirect way of reducing research-related mortality to arthropods is by using specimens that have already been killed, either on purpose or inadvertently as bycatch. This is an application of the reuse principle, which can be added to the three Rs.

2.1.1. Use of arthropods not killed by entomologists. Arthropods are numerous and occur in many environments. Dead arthropods can be found in different situations, and they can provide useful study material.

In archaeological excavations, one can find subfossil material—chironomids, carabids—that can be identified by traditional taxonomy. Desender et al. (23) analyzed carabids found in wells of an excavated village in Belgium and were able to reconstruct the composition of carabid assemblages that existed centuries earlier.

Caves may contain many deposits of various types, and they are commonly used in archaeozoology. We are not aware of studies specifically devoted to arthropods that have fallen into crevices or sinkholes, probably because such animals can easily escape. However, remains of larger animals that perished through such accidents may provide data about their food, and this can help in mapping past distribution areas. In addition, pellets produced by raptors or bats allow the identification of prey insects from fragments based on their morphology (7, 31) or using metabarcoding (94), although soft-bodied prey such as insect larvae are probably underestimated by this method.

Cars are certainly agents of destruction for flying arthropods, and arthropods smashed on car license plates (119) and windscreens (71) have been used to provide data about arthropod abundance trends. Roadkill can be used to describe flying arthropod communities of butterflies (105) or dragonflies (86), although dead arthropods are consumed quickly by scavengers, which limits the use of this method (104).

Ants make up the most abundant group of insects (43), and many species prey on other arthropods. Occasionally, these are not consumed where ants kill them, but instead are carried to the nest. One could base a biodiversity survey on examining prey that ants carry to their nest (13, 113). It is not known, however, how these ants select their prey, and whether food-collecting workers show any preference or sampling bias.

2.1.2. Use of bycatch. There are several widespread and widely used collecting methods that catch and kill individuals that are not the intended targets of collection. Pitfall traps can catch any organism that walks on the soil surface, irrespective of its ecological role, size, protected status, etc. Some of this material is not even collected—the catch can be sorted in the field, and unwanted catch is locally discarded. This catch can include vertebrates, such as small mammals, amphibians, or reptiles. However, invertebrate bycatch is even more common and abundant. A study concentrating on carabids, if using pitfall traps, will still collect isopods, springtails, other beetles, spiders, ants, etc. (11). For example, although they are used to study mainly Lepidoptera, Diptera, and Hymenoptera, light traps and Malaise traps collect large numbers of other taxa (46, 106). This bycatch is frequently kept but often neglected and, after deteriorating due to this neglect, thrown out. If this were not the case, we would be able to gain new knowledge without causing additional destruction, as has been suggested by several authors (28, 109). Nevertheless, we are unaware of any monitoring programs that are based on bycatch data, nor of national or transnational regulations that enforce preservation and analysis of bycatch. Similarly, funding agencies do not typically question applicants about the future use of collected specimens.

Entomological collections are a great source of data on the past presence and distribution of species (73, 112). Digitalization is making these historical data more accessible (100). Moreover, if properly stored, such collections can be used for DNA analysis using fragments of body parts. For example, DNA can be obtained from the ethanol in which samples are stored or by treating the samples with lysis buffer or grinding them to extract DNA (56). However, obtaining DNA from the storing liquid does not provide as good a sample as either treating the samples with a lysis buffer or extracting DNA from the arthropods themselves (56). DNA can also be extracted from dried, pinned specimens (128).

Isotopic signatures can be used to identify the trophic position of (47) or even food consumed by various organisms (84). These isotopic signatures are formed during the individual's lifetime and change little after its death; thus, museum specimens or bycatch can be analyzed to obtain such information.

2.2. Truly Nondestructive Methods

When using nondestructive methods, the necessary information can be collected from the study organism without killing it. These methods may still involve harming or disturbing the individuals.

They fit into a continuum ranging from mutilation to nondisturbance. Three subgroups can be established: (a) methods that do bodily damage to the individual, (b) methods causing stress, and (c) noninvasive study methods.

2.2.1. Nonlethal methods causing bodily harm. Methods that cause bodily harm, while they do not kill the individual study subject, arguably reduce its fitness.

Elytral marks can be etched into the exoskeleton of various arthropods and serve as a means of individual identification (97). Such codes etched into the body of the protected large carabid *Carabus hungaricus* in a field-based capture-recapture study over several years apparently did not reduce the life span of marked beetles (30). Marking can be performed using techniques that are not physically damaging, such as by using acrylic paints (39), adhesive dots (130), or even laser marking (38). Marking can also be performed using radioactive isotopes (80) or trace elements (41). However, radioactive-isotope marking may reduce the life span of the marked individuals, although we have very few data on their longevity.

Mutilation has been used to extract genetic material from individual insects (54, 81) and as a marking method (130). Some species can regenerate the clipped parts (83) but may still be more vulnerable to predators during this time.

2.2.2. Methods causing stress or discomfort. The distinction between the methods above and methods that cause stress or discomfort is not clear-cut. One can argue that attaching transponders will hinder escape movements, in terms of both speed and ease of directional changes (4). Wing tags on butterflies may change their flight patterns, as wing mass may influence flight ability (115). Therefore, while such methods do not cause bodily harm, there is arguably a fitness cost to the marked individual.

Strictly speaking, several of these methods are not interference free; for example, light traps connected with artificial intelligence (AI) recognition leave the arthropods intact, and the record is generated by the natural behavior of the study subject—yet their behavior was modified by the artificial light source. Carabids, even nonflying species, are attracted to light (49, 51, 136), and it is debatable whether this is merely evolutionary baggage inherited from their flying relatives or whether they react this way because the light concentrates their potential prey. Using such an experimental design can still result in unintended harm because predators of arthropods such as bats also visit the light source; thus, light traps create an increased predation risk for potential prey arthropods.

Arthropods can be marked with fluorescent dust, which makes them easy to track, even at night. This method has been used for beetles and, more recently, for whiteflies (40). The behavior of marked individuals is supposed to be unaffected, but we are not aware of any test of this assumption. The increased visibility makes the individual noticeable and likely more vulnerable to visually hunting predators. Protein-based markers have also been used that prevent this disadvantage but require additional laboratory equipment to process (9).

Free-moving arthropods can be tracked by radar and lidar, based on radio and optical waves, respectively. Originally motivated by the aspiration of tracking locust migrations, the use of radar has a long history and was eventually extended to other flying arthropods (27). Radar and lidar can provide quantitative data on the absolute size of the arthropod and on flying height, speed, and direction (12), enabling monitoring at altitudes that would be difficult to reach otherwise and expanding our understanding of flying patterns (27). The main limitation of these technologies remains their high cost.

Arthropods moving at lower altitudes or on the ground can be tracked by harmonic radar. In this case, a passive transponder is fixed on the individual, and a hand-held device generates the

impulse that triggers a response from the transponder. The advantage of this method is that these transponders are inexpensive to use; the disadvantage is that this tracking method is labor intensive, and the signal is nonspecific. Harmonic radar has been used to track small-scale movement of carabid beetles in New Zealand (64), ladybirds in Canada (6), and bumble bees in the United Kingdom (67, 82), among others.

Methods of tracking free-moving animals have undergone an astonishingly rapid development. Originally, the energy source required for signaling was a serious obstacle due to the relative size of the transmitter and the animal to be tracked, but technical developments now allow tagging of large and medium-sized arthropods. Thus, small-scale movements, as well as migrations, can be studied either at the local scale or at larger scales. The Motus tracking network (118) has now been refined to study flying arthropods, such as migrating monarch butterflies (*Danaus plexippus*) (57). Further miniaturization will no doubt widen the range of arthropods that can potentially be studied using such methods.

2.2.3. Nonlethal sampling of trophic relations. An important subfield of entomology deals with trophic relations of arthropods: What do they eat, and what eats them? The food of predatory arthropods has traditionally been studied by dissecting them to identify fragments of their food (114) or prey proteins (63). These methods routinely required homogenates of the whole arthropods themselves or of their intestinal tract. With the increased sensitivity of DNA-based identification methods, smaller samples are sufficient. For example, the feces of predators may provide enough of a sample to identify prey. When handled, carabids often regurgitate their crop content, from which prey can be identified (103, 131). After such sampling, the study object can be released.

The traditional pitfall trap, without preserving fluid, can be used to collect live individuals (110). This method may distort the perceived structure of the sampled arthropod assemblage because different species have different probabilities of escaping from the trap. To reduce predation, intraguild predation, or cannibalism, such live traps have to contain suitable hiding places for the smaller or more vulnerable arthropods (122). Furthermore, such traps need covers to protect the trapped arthropods and need to be frequently checked.

Arguably, all commonly used traps could be used without preserving and killing agents, and one can use the trapped insects to take photographs or body clippings or to look at intestinal content.

Valuable information about the nutritional status of various predators can be obtained in non-invasive, short-term laboratory experiments following the method developed by Toft et al. (121). Live-captured arthropod predators are taken to the laboratory, where their hunger level and nutritional status can be checked by feeding them various kinds of food of known composition and quantity (121). The predators are kept individually for a few days and are tested and measured repeatedly, but no additional invasive methods are used. At the end of the manipulative study, the subjects are released back into the wild.

2.2.4. Noninterfering methods. Finally, there are methods that allow the study subjects to behave normally, i.e., using these methods does not directly modify their behavior.

Trunk refuges do not damage arthropods and are often used to study bark-dwelling spider species (58), but such traps are equally suitable for several other taxa (95). Refugia can range from simple artificial structures, such as cardboard cylinders (42), that allow animals to escape unfavorable abiotic conditions or predators to more complex structures that mimic the typical habitat or nests of a species.

Trapping individuals is not always necessary. As far as one can correctly identify the species, visual surveys along standardized transects are a useful technique with a long tradition of use and are

suitable to estimate densities of mainly day-flying species, such as butterflies (52), dragonflies (2), and bumble bees (77); this approach has also been used to census beetles (93) and night-active spiders (99).

Acoustic surveys are among the most common and reliable methods to study grasshoppers, crickets (14), and cicadas (37), but they can also be used to monitor other arthropods (68), including pollinators (34) and saproxylic insects (1). They can be undertaken without equipment (66), but many of the digital technologies that have been developed to monitor animals in the past decades are suitable for studying arthropods.

Camera trapping has traditionally been used in vertebrate research, but this method is becoming increasingly affordable and useful for arthropod studies (137). Small cameras can be placed in strategic positions in the field and can either be set to take a record at preset intervals or be equipped with motion sensors that trigger a recording (50, 72).

2.2.5. Entomological monitoring through citizen science. Similar to video recording, photographs can also be used to identify arthropods and expand our knowledge of species distribution (48). Such collective databases are particularly useful in citizen science programs where participants can use web platforms such as iNaturalist (18, 133) and, for flagship arthropod groups such as butterflies, may even be comparable to or more effective than traditional sampling in detecting species (85).

2.2.6. The use of artificial intelligence. AI has undergone very rapid development, and its use is being considered in more and more areas. Although the proponents of the use of AI in entomology currently display remarkable techno-optimism and do not mention ethical concerns (45), AI does have the potential to be usefully combined with nonlethal methods.

An optical sensor connected to an AI-based recognition system for monitoring soil-living arthropods, in its current version (19), collects soil-active arthropods into alcohol-filled containers. The same device, once properly calibrated, can possibly be combined with live traps from which arthropods can be released.

Video equipment can be combined with AI that can help identify the arthropods recorded. Such video surveillance can be set up at flowering plants to record flower-visiting arthropods (15) or at prey decoys to identify the most active predators (137) but can also be combined with light traps (5) or pheromone traps to identify species attracted to such cues.

2.2.7. Monitoring the outcomes of arthropod activity. In contrast with sampling techniques and trapping systems that capture individual organisms, indirect estimations of densities or activity may also be used in entomological research.

Arthropods can be identified, and their density estimated, by detecting traces of their presence or activity. Counting exuviae is common for dragonflies (25, 35), and caterpillar frass (i.e., excrement) can be used to estimate herbivore densities (107). Lepidoptera pupal cases or exuviae can be used for DNA analysis of vulnerable species (83). However, such organic debris is fragile and short lived.

Genetic material can also be extracted from the environment, and using metabarcoding, it is possible to rapidly identify species in different habitats, although the method does not provide precise estimates of abundance (116, 124). Environmental DNA samples have been extracted from soil (55), groundwater (124) and other water bodies (88), air (90), and vegetation (123).

Ecosystems provide numerous benefits for humans, and such ecosystem services are intensively studied. Arthropods are very important ecosystem service providers, and the scope of research on their effects is often to quantify the level of various ecosystem services emerging from their activity. The intensity of several ecological processes resulting in ecosystem services (or disservices)

is frequently evaluated by tracking the presence or density of the animals that are involved in those processes. For example, fluctuations in predation pressure are indicated by changes in the number of predators (74). However, in many cases, the process of interest can be monitored directly, for example, by using sentinels (32). Predator activity can be measured, and predators can be broadly identified (although rarely to species level), using sentinel prey (for a review, see 61). Predators attacking sentinel prey made of plasticine can be identified by the attack marks (65) or by analyzing DNA traces left during the attack (92). Similar sentinel methods exist for tracking other functions, including seed predation (19), herbivory (32), detritivory (91), dung removal (75), scavenging (117), and pollination (134).

3. ADVANTAGES AND DISADVANTAGES OF THE USE OF NONLETHAL METHODS

The advantages of using nonlethal methods include: (a) Interference is minimized, and species can continue performing their activities within ecosystems; (b) there is no moral burden for the researcher; and (c) several of these methods allow the public to be engaged in scientific research and appreciate the value of arthropods.

These methods, of course, are not able to completely replace the traditional entomological methods, nor are they free of disadvantages and limitations (**Table 1**). One of the major limitations of using nonlethal monitoring methods is that it is not possible to identify many insect species to the species level without careful examination of a pinned specimen, often by a taxonomic expert. There may be concerns that studies that do not identify arthropods to the species level will not be considered sufficiently rigorous for scientific publication or will miss some important species-specific information.

Additionally, these methods may be more expensive or labor intensive. Developing a functional, field-stable, computer vision–assisted AI system is not trivial and requires significant time and effort for each species and context. Similarly, visual observations are personnel intensive, and repeated sampling to achieve temporal information requires significant travel (and CO₂ emissions). Nonlethal methods often require extra work to sort the arthropods captured and to release the ones that are not the focus of the study (e.g., in dry pitfall traps and refugia). In general, nonlethal alternatives have never received much attention, and thus there are currently few alternatives to replace the traditional destructive techniques. If funding agencies and journals required justification for the use of lethal methods, then this would provide an incentive to search for and develop less damaging alternatives.

4. FUTURE RESEARCH DIRECTIONS AND RECOMMENDATIONS

AI, particularly machine learning, has become an increasingly valuable tool for entomologists, helping with the automatic identification of arthropods based on photographs or acoustic records and with understanding arthropod functional traits (45, 125, 135). By relying on neural networks that emulate the structure of the brain, computers can learn without the help of a human when they are repeatedly exposed to new data (i.e., deep learning). The potential of this technology for monitoring is clearly great, and there is consensus that this new approach will become more prominent in future entomological studies (45, 129). AI will continue to develop and may greatly simplify the task of monitoring species that are taxonomically well known and for which there are abundant digital records (photographs or acoustic records) with which to create complete training data sets. A critical test for these systems will be whether they can become effective monitoring tools for difficult-to-identify species, as validating records of these species can be problematic. In certain contexts where a few focal species need to be routinely monitored, such as specific pests

Table 1 Examples of nonlethal methods and their advantages and disadvantages

Study focus	Move from collecting specimens to...	Advantages	Disadvantages	Reference(s)
Genetic analyses	Mutilation and release	Suitable for DNA analyses	Can reduce the fitness of the individual	54, 83
Distribution	Obtaining data from historical records (e.g., museum collections)	Saves time and sampling effort	Data may be difficult to obtain and not always digitalized and can be limited to certain geographical areas	73, 112
	Citizen science–based data (e.g., iNaturalist)	Saves time and sampling effort	Data mostly based on fortuitous observations; not all species can be reliably identified	18, 133
Presence and density	Visual surveys	No interference with natural behavior	Labor intensive; not all species can be reliably identified	53, 77
	Camera traps	Provides information about daily activity and behavior	Not all species can be reliably identified; high costs	137
	Acoustic records	No interference with natural behavior	Suitable only for species that produce sound	14, 37
	Citizen science–based data (e.g., iNaturalist)	Saves time and sampling effort	Data mostly based on fortuitous observations; not all species can be reliably identified	18, 133
	Environmental DNA	Reliable data on distribution and spread; suitable for freshwater invertebrates	Imprecise measures of abundance or biomass; no single standardized protocol	116
	Refuges	Suitable to study arthropods that overwinter or use refuges	None	8, 58, 95
	Dry pitfall traps	Large reduction of bycatch	More labor intensive; higher travel costs	110
	Traces (e.g., exuviae, frass, pupal cases)	Suitable to determine hidden presences and densities	Rarely suitable to determine species identity; ephemeral	25, 35, 107
Movements, dispersion	Marking using nondamaging techniques (e.g., paints)	Suitable to estimate population size and movement patterns	Labor intensive; may affect individual behavior	39
	Radar and lidar	Quantitative data on arthropod size, flying height, speed, and direction	High costs	12, 27
Trophic relations	Collecting other DNA sources (regurgitates, feces)	Can identify prey without killing the individual predator	None	103, 131
	Laboratory experiment and release	Can provide information on nutritional status	None	121
	Fecal pellets	Suitable to study insect prey of raptors and bats	Underestimates soft-bodied prey; ephemeral	7, 31
Ecosystem services	Use of sentinels	Provides quantitative, comparable data between habitats	Species identity may remain unknown	32, 69, 96

in crop fields (60), the application of AI may be relatively easy. In other cases, the combination of AI with DNA barcoding techniques looks promising (45).

Several of these methods (semiautomatic collection of samples, environmental DNA-based analysis of species, identification using AI, etc.) can save individuals, but they may also reduce direct experience in the field. Such extinction of experience is emerging as a possible problem in

nature–human relationships (108). In contrast, AI-based applications such as iNaturalist may allow nonexperts to enjoy nature and learn about species and can potentially improve citizen science projects.

Even if the argument holds that entomology as a science brings more benefit than the harm caused by killing while studying, our overall recommendation is to promote, use, and further develop nondestructive methods for two reasons. First, it would be beneficial to foster a change in attitudes toward studying nature on the part of entomologists. Arguing that the damage that they cause is minimal or much smaller than natural mortality, or that the resulting benefits outweigh the damage, is ethically not defensible. Second, such an attitude of respect is as useful as it is necessary, especially to the public at large, because it sets an example that living beings are to be respected. This will contribute to a public image of the field of entomology as a science that advances and promotes an altered, less anthropocentric attitude to nature. That we need such a shift in human behavior is increasingly clear.

Additionally, the question emerges: Should consideration of ethical principles prompt reconsideration of the research questions to be asked? For example, it could be argued that one should refrain from sampling a small, remnant population of an insect to obtain its DNA, especially if this would imply a lethal method. Ethics is not a rulebook that can provide a correct answer, yet ethical considerations should influence the research questions that we ask and the problems that we study, even in entomology. After reflection, researchers may decide that seeking answers to certain questions should not be pursued (16).

5. CONCLUSION

In conclusion, there is a need for a methodological revolution in entomology. Mass killing of arthropods, even in the name of science, is no longer acceptable. Even if the ethical foundations continue to be disputed—as they will, because ethics is not a rulebook but a continued dialogue—the currently dominant approach conforms to a worldview placing humans above all other living beings. The consequence of this worldview is that estimated extinction rates are increased by orders of magnitudes above background ones (76), and the sixth mass extinction is looming. Humankind needs to change many things—and we entomologists need a close, hard look at our practice and to change our ways of working to better suit the changed circumstances.

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Errata

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