Bigger is Better? A Review on the Relationship Between Body Size and Crop Pest Predator Efficiency

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Abstract
Body size represents a key morphological trait that indicates how biotic communities respond to environmental changes and shape ecosystems processes. In agriculture, many carnivorous arthropods, such as arachnids and beetles, represent valued crop pest predators that are used as a sustainable alternative to pesticide use. The scope of this review is to highlight how the body size of arthropod pest predators is influenced by various agricultural practices and, conversely, how it influences the predation efficiency of these organisms and their overall capacity to provide the ecological service they are valued for. We synthesize existing knowledge on the topic and discuss the ways through which body size shapes the resistance, behaviours and hunting efficiency of pest predators. We emphasis the advantages that larger body size offers, such as, increased prey consumption, feeding range and fecundity, while also accounting for potential disadvantages such as reductions of desiccation resistance, predator evasion capacity and the increased risk of toxic compound bioaccumulation. To conclude, we highlight knowledge gaps and propose future research directions which may serve to further enhance and popularize the use of natural pest predators as one of the means towards efficient ecosystem management and sustainable agriculture.
Keywords: arthropods, body size, functional traits, pest predators, predatory efficiency.

1. Introduction

The current human population of the world and the predicted rates of its expansion [1] pose the need for food security if we are to safely and sustainably live on our planet [2]. In this context, the role of agriculture is extremely important both in terms of production, as well as impact [3]. Though vital for food production, agricultural landscapes also provide habitat for multiple insect species, many which contribute to provide invaluable ecosystem services such as pollination [4] and pest control [5]. Predatory arthropods such as spiders (order *Araneae*) and ground beetles (family *Carabidae*) represent validated biological control agents that have the potential to reduce the use of pesticides for suppressing pest populations [6,7].

Land use changes, associated among other with agriculture, represent a dominant driver of worldwide ecosystem change and service loss [8]. Decline of ecosystem services such a pollination and pest control pose a capital threat for agriculture, biodiversity and human society [9]. Efficient ecosystem management and sustainable practices such as increase of non-crop habitats and organic crops and reduction of intensive tillage and pesticide use hold promise to reduce and eventually reverse the biodiversity decline of agricultural landscapes [10]. In order to reach such difficult goals, it is important to increase our understanding of how land use, biodiversity and ecosystem services interact from a functional standpoint [11].
Functional traits represent measurable individual features that shape the fitness and role of organisms within their habitats [12]. Given their cross-taxonomic nature and link to ecosystem performance, these metrics hold great promise to explain mechanistic processes that intertwine

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biodiversity and ecosystem functions and consequently to help in sustainable agriculture [13,14].

Among the functional traits of crop pest predators, body size received much interest, based mainly, on its importance to shape predator-prey trophic interactions within agricultural landscapes and particularly in crops [15]. This morphological trait of spiders and ground beetles has been also addressed with regard to its importance for the dynamic of such communities in varied contexts, such as habitat colonization and survival to harsher environmental conditions [16,17]. For example, large body size variations within predatory communities have the potential to generate intraguild predation in certain contexts [18].

Aside from its role in trophic interactions and adaptation to environment, body size can also be used as a reliable indicator of environmental impact [19]. Body size and other morphometric characteristics of arthropods have become increasingly popular for bioindication and bioassessment of habitats, particularly in studies addressing pollution and toxicity [20]. Research addressing body size variations generally highlights community weighted variations of this trait in response to all types of habitat disturbances, tendencies of which shall be further discussed throughout this paper along with other relevant findings.

Though research on this topic seems to become more popular, the need to structure and interpret existing information should not be overlooked. Consequently, this review aims to synthesize the current state of knowledge with regard to the body size of arthropod pest predators and to highlight existing tendencies, inconsistencies and knowledge gaps. By doing so, we hope to provide a clearer understanding of the topic and to consolidate part of the research needed to support a more sustainable agriculture and ecosystem management.

2. Materials and methods

Our review proposes a synthetic and analytical analysis of the scientific research related to the body size of arthropod pest predators (i.e. spiders and ground beetles).

Relevant scholarly articles were obtained by two complementary search methods, namely a Web of Science query (Table 1) and by the additional use of the snowball method. A total of 71 articles was used for the synthesis of our review, all dating from 2000 onwards. While we acknowledge the possibility that some bibliographic sources were not found, we consider that we have gathered sufficient references to be able to draw clear and realistic conclusions with regard to the tendencies and findings reported in the literature concerning to our topic.

Table 1. Web of Science Boolean search string

TOPIC: arthropod* OR spider* OR "ground beetle*" OR carabid* OR arachnid* "pest predator*"
AND
TOPIC: "body size" OR morphology OR biomass OR "bodied" OR trait*
AND
TOPIC: agriculture* OR crop* OR farm* OR agroecosystem* OR agrarian

Results were structured based on drivers that influence the body size of the studied taxa and on the effects that variations of this trait have on the pest control ecosystem service.

3. Effects of land use and intensity of agricultural practices on arthropod pest predator body size

Most of the screened literature addressed the effect of environmental parameters on the body size of crop pest predators as opposed to the effect that community weighted mean (CWM) values of this trait have on the provisioning of pest control. This disparity emphasizes, on one hand the concern of researchers and stakeholder with regard to the effects of land use, habitat integrity and agricultural schemes and, on the other, the need for more studies to address the effect of CWM body size of natural enemies on their role as pest suppressors.

General patterns of body size dynamics

The majority of the screened literature indicates a clear and consistent pattern in the response of mean body size within the communities of arthropod pest predators. Land use intensification and generally lead to strong reductions of the CWM body size of both spiders and ground beetles (Table 2). Unsustainable agricultural practices such as increased tillage, strong pesticide use and monocultures act as selective pressures that favour smaller species and exclude larger bodied taxa from the impacted communities [65,74].

Table 2. Drivers and trends of body size variation among crop pest predators

Driver	Action	Action tendency	Body size general tendency	References
Land use	Non crop habitat	Increase	Increase	21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34
	Landscape simplification and fragmentation		Decrease	35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64
Agricultural practice	Land management intensity	Increase	Decrease	65, 66, 67, 68, 69, 70, 71, 72, 73, 74
	Pesticide use			75, 76, 77, 78
	Sustainable land management		Increase	79, 80, 81, 82

Such outcomes are consistent across most type of agricultural habitats and crops. Studies in grasslands highlighted how arthropod communities from such habitats were impacted by land use intensification, leading to the dominance of smaller and more mobile species [62,64]. The abundance of smaller sized arthropod predators was also observed in vineyards, cereal and oilseed rape fields [28,59,73].

Conversely, reduced intensity of land use and the implementation of sustainable measures such as organic farming, reduced tillage and maintenance of diverse landscapes supported a greater number of larger bodied arthropods as well as a more diverse community in terms of body size classes [67,75]. Such findings show that agricultural practices act as filters of arthropod pest predator communities based on body size and that sustainable practices can alleviate the impact within the studied communities.

The trends in the relationship between habitat disturbance and body size of arthropod pest predators seem to be consistent both for intra and inter specific levels. Smaller bodied individuals are found in most disturbed habitats. Species with reduced body size are favoured in impacted habitats most due their increased dispersal capacity, shorter lifespan and reduced requirements which lead to communities with lower CWM body size with increasing impact level [25,42,45]. This constant and clear relationship between body size and level of habitat impact seems to constitute a central pattern of pest predator ecology. However, more recently, few exceptions have been reported, all showing the opposite trend and addressing tropical agricultural habitats [83,84]. We consider these few results to be scientifically very important since they indicate that arthropod body size seems to increase along with agricultural impact in the tropics. Additionally, research in the aforementioned habitats is still scarce and growing more important in the context of increased forest conversion to agricultural habitats in the tropics.

Pesticide pollution represents another key driver that has been associated with the body size decrease of crop pest predators. Though not as abundantly addressed as habitat conversion, research on the effect of pesticide pollution on our communities of interest showcase and unequivocally decrease of body size for spiders, as well as ground beetles [34, 75, 76]. Furthermore, pesticide toxicity has been documented to reduce the fecundity of crop pest predators, exacerbate sexual dimorphism and in certain instances to stronger impact females [75,76,77]. We consider such findings to highlight the danger that increased pesticide use poses to non-target taxa such as predatory arthropods. Aside from the direct effects such as body size reduction or mortality, increased pesticide use further impacts the capacity of crop pest predators to efficiently reproduce and hunt through body size asynchrony between sexes, reduced fecundity and behavioural changes related to hunting and thermoregulation.

Driving mechanism of body size responses to environmental changes

Mechanism that determines body size change in arthropod pest predators relate to the intrinsic characteristics of the species present as well as to the characteristics of agricultural landscapes and habitats where they dwell. In order to better understand community changes, one must examine multiple traits of the comprising species.

Larger species are generally filtered due to the life history constraint they possess. More than often, these individuals have lower reproductive output, slower development rates and higher requirement of resources, all of which make them prone to reduction or extinction in intensely agriculturally impacted habitats [13,33].

The dispersal ability of predatory ground beetles and carabids is very closely linked to their body size and ability to withstand unfavourable environmental conditions. It is common among smaller species of predatory arthropods to possess highly developed dispersal traits, ballooning capacity for spiders and functional wings for carabids, which enable them to evade certain disturbances, as well as to hastily recolonize available habitats [62,64].

Habitat characteristic and landscape configuration influence arthropod pest predators through multiple mechanisms such as availability of food, microhabitat conditions and shelter availability. Structurally complex landscapes, such as the ones with non-crop habitats (flower strips, riparian buffers and forest patches) support communities with a wider range of body size classes and favour larger predators [28,59,73]. Additionally, research indicates that larger predators, such as the active hunting spiders of the genus *Pardosa*, exhibit higher fecundity in crops connected to forested habitats, thus promoting the increase of CWM body size within their respective communities [59].

Research gaps and possible research directions concerning the response of arthropod pest predator body size to environmental drivers

Despite the available and growing knowledge, multiple questions remain unanswered in regard to the relationship between environmental drivers and the body size of arthropod crop pest predators. The scarcity of long-term research is a prevalent issue in ecology in general and subsequently in the case of our topic. The few studies that we found highlight two crucial aspects to be considered by researchers and stakeholders alike.

Given the snapshot nature of the research, it is probable that at least some of the characteristics of agriculturally impacted communities have been influenced by historic pressures [35]. Given such a hypothesis, there is a real risk that research addressing environmental impact might amplify the impact of certain pressures, lack to observe their real effects and misunderstand the mechanisms through which environmental changes shape biotic communities, their traits and functions.

The effect of sustainable measures take time to showcase community changes. Even in the case of fast reproducing communities such as arthropods. As such, it is important to undertake long term studies that highlight the time lapse necessary for beneficial measures to improve the condition of natural predators and their capacity for pest control [35,56].

Research in tropical agricultural landscapes should constitute a priority in the context of increased land conversion form forests to agricultural land in such landscapes. Existing research suggest that different trends exist in the relationship between pest predator body size and environmental pressures [83,84]. More research in this direction is needed in order to verify the observed trend and to better understand underlying mechanisms related to habitat and landscape structure or trophic interactions.

Other potential research directions we could identify based on the scarcity of available research and on the needs of this scientific area include the development of trait-based models and their application in sustainable agriculture practices, the study of the effects of climate change and invasive species on the body size and other traits of natural enemies and the exploration of laboratory and mesocosm protocols for the rearing of efficient crop pest predators.

4. The Influence of predator body size on the efficiency of pest predation

Body size represents perhaps the most important functional trait that determines the ecological interactions of arthropod crop pest predators and their capacity to provide the ecosystem service they are valued for. It is generally considered that larger predators possess a broader feeding spectrum and an increased capacity for more abundant and larger prey consumption [85]. These factors serve to enhance pest regulation services, yet, their effect appears to be species and context dependent.

The relationship between body size and predation capacity

Generally, a strong and positive relationship is observed throughout the available literature with regard to the increase in predator body size and prey consumption. The trend is consistent across taxa, with both larger spiders and carabids shown to be able to consume a wider range of prey and to feed at higher rates than their smaller counterparts [86,87,88]. In field and other types of experimental studies shown that larger spiders can consume a higher range of prey sizes, in many cases being the dominant force of the trophic interactions within the arthropod communities that include them [89,90]. Similarly, larger carabids have been shown to exhibit similar trends, consuming larger amounts of food, either weed seeds or invertebrate pests and usually of larger sizes as their body size grew [27, 88].

Larger arthropod cop pest predators seem to exert top-down control more effectively and consistently across heterogenous and well-connected agricultural landscapes [87]. Research that addressed the benefits of organic farming also showed that less disturbed and unpolluted treatments supported predatory arthropod communities with larger individuals that generated more efficient pest suppression, especially when located in structurally complex habitats and landscapes [86, 87].

Trait Interactions and Compensatory Mechanisms

Predator body size represents an efficient indicator of predation efficiency. However, it is clear that it does not shape pest suppression solely on its own, but rather in interaction with other functional traits of the predator and of the prey. Functional traits such as activity period, hunting strategy along with foraging behaviours, such as aggression, determine, along with habitat affinity, the efficacity of predation and pest suppression [86,87,]. An interesting body of research showed that smaller spiders exhibited stronger foraging aggressivity that enabled them to compete and even surpass larger predators in certain contexts [90,91]. Such compensatory effects serve to highlight that body size is not alone in predicting predation efficiency and that behaviours can serve as buffers against morphological limitations [90,91], thus emphasizing the importance of ethological aspects in the study of arthropod crop pest predators.

It is important to mention that the aforementioned type of compensations has been documented preponderantly for active hunting taxa (i.e. wolf spiders), where movement patterns and aggression can serve as dominant factors of predatory efficiency [90,91]. It is possible that the same type of mechanisms may not apply for taxa with different hunting strategy, such as web building spiders and ambush predators, in the case of which more research is needed.

Functional Diversity and Complementarity

Variations of body size within predatory arthropod communities can enhance the efficiency of the pest predation service through niche complementarity. More functionally diverse predator communities are able to target different sized pests and more diverse pests, thus guaranteeing a more complete and time continuous pest control service [27,89,90]. For example, carabid communities with more diversified body size classes were found to be more efficient overall for pest regulation by consuming an increased number of prey species, in various life stages and within multiple habitat and microhabitat types [89].

The trait and the functional diversity that characterize pest communities are, evidently, also highly relevant for the efficiency of the pest control service, yet rarely addressed by the existing research. The size, mobility, defence mechanism and behaviour of the prey are clearly factors that determine the efficiency of the pest control service.

Based on such concepts, it is possible to assume that larger and less mobile predators may prove ineffective in consuming highly agile or defensive pests, while smaller, more mobile predators, could access smaller, cryptic and concealed pest prey. As in the case of predators, the traits, functional diversity and behaviour of prey is often context dependent and associated with habitat and landscape characteristics. For example, simplified landscapes support a higher number of small predators that may not access larger prey classes and impact larger predators which may suffer from the reduced availability of accessible prey and exposure to harsh elements and higher trophic predators [86].

Research gaps and possible research directions concerning the relationship between predator body size and pest control efficiency

Despite the general consensus that predator body size strongly influences predation efficiency and prey accessibility, some inconsistencies and areas with little research still exist.

The idea that behaviour may be more important than body size deserves more research given the existence of instances where it was prevalent over body size [90,91]. However, we consider worth to mention that this compensatory mechanism seems to be species and context specific. Research in this direction would benefit from the study of the most used predator species, first standalone and then in community, keeping in mind that trophic interactions may produce different outcomes compared to monospecific experiments.

Another potentially rewarding research direction is related to the mechanisms that govern intraguild predation. In unfavourable contexts, mixed size predatory arthropod communities shown increased intraguild predation and other antagonistic interactions that ultimately decreased the pest control service [35].

5. Conclusions

The body size of arthropod pest predators represents one of the key traits that structure the capacity of these communities to provide the pest control service that they are valued for. Research focused mainly on how land use and intensive agricultural practices shaped the body size of our studied taxa and to a lesser degree on how variations of this trait influence the role of crop pest predators in ecosystems. It is generally observed that any type of agricultural pressures reduces the body size of spiders and ground beetles and their capacity to suppress crop pests. Based on the scare existing research, the relationship between impact and body size seems to be exactly opposite in the tropics, direction which should be better studied in the future.

Body size seldom acts alone to determine predation efficiency. It is often associated with other traits or, in certain instances, compensated by behaviour. Additionally, without accounting for the functional traits of pests, it is likely that predictions of predator efficacy remain incomplete. Future research should explore predator and prey traits conjointly, further address behavioural and ecological compensations, and prioritize standardized and longer-termed approaches which are rarely encountered. A better understanding of the functional ecology of pest predators represents a perquisite of sustainable agriculture and ecosystem management and most likely a challenging and promising research area.

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