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Editorial overview: Current investigations of environmental drivers and community interactions that influence biological control

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Mary M Gardiner is an Associate Professor in the Department of Entomology at The Ohio State University. Her laboratory examines how the design, management, history, and landscape context of urban greenspaces influence food web structure and related ecosystem functions and services. She is also engaged in outreach related to enhancing home landscapes, greenspaces and small-scale farms as habitats for beneficial arthropods.

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The discipline of biological control has long recognized the inherent complexity in measuring, predicting and promoting this ecosystem service. To predict biological control activity, it is necessary to understand how a complex set of large-scale and localized environmental variables influence the abundance, richness and composition of natural enemies present within a managed habitat. This field of research has focused extensively on evaluating how broad-scale landscape context and localized farmscape habitat management influence natural enemy communities (Figure 1). These studies demonstrate that increasing landscape complexity and the local establishment of floral resource patches can enhance natural enemy abundance, richness and community composition within managed habitats [1,2]. However, this has not consistently translated into enhanced pest suppression [3,4]. We argue that predicting biological control service based solely on the proximity and quantity of source habitats fails to consider key environmental variables including habitat quality and change as well as abiotic conditions that structure natural enemy guilds and mediate the strength of trophic interactions. Global climate change, agricultural intensification, urbanization, and species invasions can influence the quality of source habitats for natural enemies. The resulting distribution of taxonomic and functional trait richness and evenness within a species pool will influence a complex set of local interactions that can strengthen or disrupt pest suppression. In this special issue, we focus on emerging research documenting how these large-scale drivers and resulting local interactions influence the efficiency of biological control services (Figure 2).

Measuring environmental drivers

Expansion and intensification of agricultural production and urbanization of the environment are key drivers of biodiversity loss [5,6] and can influence the provision of many ecosystem services including biological control. Cohen and Crowder [7] highlight the necessity to increase the intricacy of landscape analyses, suggesting moving beyond simple binary designations of 'agricultural/developed land' versus 'semi-natural/natural habitat' and the calculation solely of the percentage of each present. This binary approach obscures the importance of particular habitat types and/or the arrangement or connectivity of source patches within a landscape for the supply and maintenance of natural enemy populations. Further, Cohen and Crowder [7] introduce temporal landscape heterogeneity as an important and understudied variable. Temporal changes in landscape structure occur both gradually through the movement of natural areas into cultivated land and seasonally via crop rotation schemes. To examine how these temporal changes influence biological control, they argue for longer-duration research

James D Harwood was an Associate Professor of Entomology at the University of Kentucky and is a Jinshan Scholar in the Institute of Applied Ecology and Fujian Agricultural and Forestry University. His research interests seek to understand mechanisms of foraging by generalist predators and identify their role in biological control through the integration of molecular techniques, behavioral studies mathematical approaches and field experiments. These approaches have been used, in combination, to delineate trophic connectivity and measure the intensity of specific predator–prey interactions. Understanding the forces that regulate the abundance of these important natural enemies can ultimately provide information that discerns the role of prey biodiversity and habitat management on predation dynamics.

coupled with more frequent collection of satellite imagery and more intensive ground-based surveillance to accurately verify habitat characteristics.

Quantifying landscape quality can also involve documenting the presence of pollutants within source habitats. Understanding how contact with heavy metals influences the activity of agriculturally-relevant arthropods is an emerging field given the rapid growth in urban farming worldwide [8,9]. The process of urbanization results in concentrated transportation networks, residential development, industrial activities and waste disposal that contribute to environmental pollution including the soil deposition of heavy metals. Gardiner and Harwood [10] investigate how a legacy of heavy metal contamination could influence the potential of an urban landscape to support biological control. They report that exposure to heavy metals can have reproductive, developmental, immunological and behavioral impacts on predators and parasitoids. In general, exposed natural enemies are developmentally delayed, have a reduced life span, and produce fewer viable offspring.

Changing abiotic conditions also influence the habitat value of a landscape for natural enemies. Global climate change may influence the composition of natural enemy communities occupying a region, the spread of invasive natural enemies and interactions among guilds of natural enemies and their prey that influence biological control. Furlong and Zalucki [11] reviewed the thermal performance of parasitoids developing in their hosts, revealing that optimal developmental rates (as a surrogate for fitness or performance) were lower for parasitoids than their hosts. This suggests that parasitoids may be more susceptible to elevated temperatures associated with climate change; such a phenomenon could decouple parasitoid–host relationships within some regions where effective biological control is currently attained. Jonsson *et al*. [12] also examine evidence that temperature alters predation rates via influencing complementarity among species within a natural enemy guild while Honek *et al*. [13] focus on how increasing temperatures influence the regional distribution of natural enemies. Honek *et al*. [13] propose that warming temperatures may result in asynchrony between host plants, prey and coccinellid species resulting in shortened temporal availability of key food resources. This is expected to have the greatest impact on large aphidophagous species and is especially pertinent in relation to the decline of native coccinellid populations. Invasion patterns of the large polyphagous multicolored Asian ladybeetle, *Harmonia axyridis*, provide support for this hypothesis. This species has established in temperate regions of North and South America and Europe but is limited in tropical regions [14], potentially due to a lack of sufficient prey resources and is worthy of further study.

Quantifying food–web interactions

Conservation biological control research has long recognized that local interactions within natural enemy guilds can have negative, neutral or positive impacts on the provision of biological control. A complex set of interactions including intraguild predation, functional redundancy, niche partitioning and facilitation drive these alternative biological control outcomes [15]. However, the aggregate impact of these interactions on biological control remain difficult to predict in complex field environments.

Jonsson *et al*. [12] review a significant shift in how communities are studied, with important implications for predicting the strength of natural enemy guild interactions. Increasing natural enemy diversity is more likely to positively impact biological control when high taxonomic distinctiveness exists [4]. Functional traits are more likely to vary among distantly related