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Editorial overview: Arthropod population dynamics at regional scales: Novel approaches and emerging insights

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The study of population dynamics at regional scales was not widely attempted half a century ago. Since then, however, greater availability of spatially referenced data, analytical methods, and computational resources have helped drive increasing attention to population-dynamic patterns and processes at regional scales. These advances have occurred against a backdrop of accelerating climate change and have helped document impacts on range shifts and spatiotemporal patterns of outbreaks. In many systems, archives of annual insect outbreak maps have been digitized and are a boon to the field of population ecology. Analyses of such data have facilitated quantification of synchronous population fluctuations and exploration of hypotheses regarding the role of regional stochasticity in weather and/or dispersal of insect or natural enemies as drivers of population synchrony. Likewise, outbreak data can elucidate drivers of spatially variable dynamics such as local heterogeneity in resources, natural enemies, and environmental conditions. Greater understanding of insect population dynamics at regional scales has been critical to developing effective strategies for management of issues such as the spread of invasive species and management of recurrent widespread pest outbreaks.

Climate-change effects are a recent focus in the study of population dynamics of insects and other arthropods at regional scales. One of the chief such effects highlighted in recent literature is range expansion of pest species. Johnson and Haynes [1] underscore the high frequency with which range shifts have been attributed to climate change and highlight examples of northward range expansion in several pest species. Wimms et al. [2] explain that climate change has likely contributed to both range expansion of disease vectoring ticks in the Central Plains of North America and phenological changes that promote disease transmission. Jepsen et al. [3] describe how range expansions of pest species outbreaks driven by climate change can have important, often unexpected, ramifications for ecosystems. One of the studies [4] they highlight demonstrates how climate change led to the first known cross-biome range expansion of a forest geometrid and high rates of mortality of the herbivore's host plants in the newly inhabited biome.

Forest insect pests have been important models of the impacts of climate change on the spatiotemporal population dynamics of insects within their existing ranges. Haynes and Walter [5] point out that little is known about the impacts of climate change on the spatial population synchrony of insects and they emphasize the need to address this knowledge gap given the

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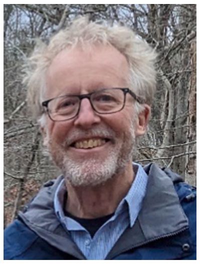

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effects of synchrony in population dynamics on increasing regional-scale damage by pest species and extinction risk of rare species. Overall, climate change appears to be increasing the frequency of outbreaks of forest insect pests, particularly those of bark beetles and other insects that exploit host plants with compromised defenses, but the effects on outbreak dynamics are complex, species specific, and more subtle in other groups such as forest defoliating insects. Johnson and Haynes [1] explain that increases in the frequency and extent of outbreaks of some bark beetles can be explained by increasing susceptibility of host trees due to increasing drought in combination with increasing temperatures and wind damage. Lantschner and Corley [6] elaborate on the role of environmental perturbations in allowing bark beetles to exceed critical threshold densities, allowing them to successfully attack host trees. Some species, categorized as aggressive, are capable of sustained epidemic status even after these environmental perturbations have ended, while semi-aggressive species decline below the critical threshold after the environmental perturbation has ended. They point out, however, that climate change may allow more species to become aggressive.

Another focus in this special issue is regional-scale management of pest insect outbreaks [7] and invasive spread [8] and the importance of forecasting outbreaks in management decision-making. Piou and Marescot [9] highlight progress made in forecasting the catastrophic damage to crops that can be caused by outbreaks of locusts. They describe advances in the development of models for forecasting locust outbreaks and impacts on agriculture that integrate field monitoring and remote sensing, while pointing out a lack of operational systems for forecasting gregarization sites within the short time frames needed to mobilize effective control. Piou and Marescot [9] highlight an implementation of a multistate dynamic occupancy model [10] that may be a particularly promising modeling framework for forecasting locust outbreaks because, as a hybrid between process-driven models and data-driven models, it avoids some of the pitfalls of these disparate approaches. Similarly, Jepsen et al. [3] call for greater emphasis on near-term forecasting of pest insect outbreaks, underscoring that there are few published examples of near-term forecasting for outbreaks of forest insect pests despite clear benefits for management decision-making. They suggest that phenomenological approaches such as machine learning could be used for near-term forecasting in systems for which there is no prior mechanistic understanding of population dynamics. Furthermore, identification of environmental variables that improve predictive ability can, in turn, point to avenues of research that can lead to greater mechanistic understanding and ultimately the development of process-based forecasting.

Recent advances in mechanistic understanding of regional population dynamics often involve new forms of data derived from emerging technologies, interdisciplinary approaches that integrate data from existing population monitoring programs with spatial data on other environmental or biological variables, or the development of novel data-analytical approaches that improve or expand causal inferences. Sturtevant et al. [11] discuss the potential for remote-sensing technologies to carry out regional-scale monitoring of forest insect pests. For example, they highlighted a recent study [12] in which an approach was developed that uses thermal sensors to remotely detect tree stress and explain how this advance could facilitate early detection of rising densities of insect pests. Sturtevant et al. [11] also explain that the study of spatial structure in the population genetics of pest species (or their natural enemies) in relation to variation in factors such as landscape structure and host plants is beginning to improve understanding of the drivers of patterns of spatiotemporal population dynamics. Johnson and Haynes [1] described how greater understanding of the effects of regional variation in temperature, and potentially climate change, on population growth of a forest pest has been achieved through study of direct physiological and developmental direct responses of insects to temperature variation. Haynes and Walter [5] highlight a recent expansion in understanding of the rich complexities in patterns of population spatial synchrony and their drivers that has been gained through application of novel analytical methods to spatiotemporal population data. The strength of population spatial synchrony varies geographically and across timescales, for example, and methods have been developed to evaluate the drivers of this variation.

Currently, we are experiencing rapid increases in the availability of environmental and ecological data as well as accelerating climate change. Much of what we learn about regional dynamics, impacts of insects in the future, and the influences of climate change will be determined by the types, amount, and quality of data that can be gathered. Progress in some systems is still limited by the amount of data collected. For example, under-surveillance limits our ability to track expansion of ticks and the diseases they spread [2]. In some forest insect systems, the quantity of data is immense, but the quality still limits our ability to move beyond pattern analysis to elucidating the processes underlying regional patterns of population dynamics. There are growing calls, including by authors in this special issue, to increasingly leverage available data and integrate different types of data, for example, physiological, for a more mechanistic approach to near-term forecasting of damaging outbreaks of insect pests. Preventive management of outbreaks and damage informed by forecasts has the potential to substantially improve decision-making and outcomes. In recent years, modeling approaches such as machine learning have been used successfully to predict the locations and timing of future outbreaks of pest insects, but forecasting models have been developed for only a small fraction of pests. There are many challenges and costs involved in operationalizing systems of preventative management, but the potential benefits may often outweigh such costs.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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