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Review

Multiscale approach to pest insect monitoring: Random walks, pattern formation, synchronization, and networks

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Abstract

Pest insects pose a significant threat to food production worldwide resulting in annual losses worth hundreds of billions of dollars. Pest control attempts to prevent pest outbreaks that could otherwise destroy a sward. It is good practice in integrated pest management to recommend control actions (usually pesticides application) only when the pest density exceeds a certain threshold. Accurate estimation of pest population density in ecosystems, especially in agro-ecosystems, is therefore very important, and this is the overall goal of the pest insect monitoring. However, this is a complex and challenging task; providing accurate information about pest abundance is hardly possible without taking into account the complexity of ecosystems' dynamics, in particular, the existence of multiple scales. In the case of pest insects, monitoring has three different spatial scales, each of them having their own scale-specific goal and their own approaches to data collection and interpretation. In this paper, we review recent progress in mathematical models and methods applied at each of these scales and show how it helps to improve the accuracy and robustness of pest population density estimation.

Keywords: Insect monitoring; Trapping; Diffusion; Levy walk; Numerical integration; Dispersal

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1. Introduction

The structure and functioning of ecosystems have long been paradigms of complexity [26,86]. In particular, it has been increasingly recognized that ecosystem properties arise as a result of coupling between processes going on different spatial scales [61,75,84,169]. The notion of multiple scales applies to virtually all aspects of ecosystem functioning and to ecosystem monitoring, in particular, to pest insect monitoring. Pest monitoring is an issue of huge practical importance, especially in agricultural ecosystems or 'agro-ecosystems'. Indeed, pests are a sustained and significant problem in the production of food across the globe. Crops are vulnerable to attack from pests both during the growing process and after they have been harvested. Estimates of the annual worldwide loss due to pests at the pre-harvest stage lie between 35 and 42% [106,133]. In particular, the pre-harvest loss of 14–15% of the world's crops has been attributed to harmful insects [136,134].

Effective and reliable ecological monitoring is required in order to provide detailed and timely information about pest species. In agro-ecosystems, monitoring is usually a part of the integrated pest management (IPM) [28,82]. The basic principle of the IPM is that a control action is only used if and when it is necessary. The decision of whether or not to implement a control action is made by comparing the abundance of pests against some threshold level, i.e. the limit at which intervening becomes worth the effort and expense. Such threshold values can be decided upon by taking a variety of factors into consideration. Economic thresholds are most commonly used [162] as the overriding concern is that the pest management program is financially viable (e.g. see [63]).

Once the pest abundance exceeds the threshold, the IPM decision is to intervene and implement a control action, usually application of chemical pesticides. However, use of chemical pesticides has many drawbacks. The first of these is the damage caused to the environment. It has been estimated that around $3 \cdot 10^9$ kg are used across the globe per year [134]. As a result, pesticides significantly contribute to air, soil and water pollution, and there is growing evidence linking their use to human illnesses [4,135]. Note that the per capita efficiency of chemical pesticides is estimated to be quite low as, on average, less than 0.1% of them reach their targeted pest [132].

Secondly, use of chemical pesticides results in significant additional costs added to the agricultural product. Indeed, it is estimated that around $40 billion per year is spent on pesticides [134]. Hence a reduction in the amount of pesticides used would be clearly desirable from the economic perspective.

Finally, indiscriminate or preemptive use of pesticides can make them less efficient. For instance, regular use of pesticides can result in the pest becoming resistant, thus making future management a more difficult task [8]. Another unwanted side effect is that the pesticide can have lethal or sub-lethal effects on natural enemies [157] which can cause a resurgence in the pest population or a secondary pest to emerge.

Thus, accurate monitoring is key to the decision process [28,92]. There is an urgent need for reliable methods to estimate the pest population size in order to avoid unjustified pesticides application and yet to prevent pest outbreaks. In this paper, we review some of the recent research in pest monitoring models and methods applied on different spatial scales.

Two essential components of monitoring are data collection and data processing and/or interpretation. These are not independent as a reliable estimate of the population density resulting from data processing can only be obtained if the collected data contain sufficient information. The latter can be achieved if the spatial arrangement of the data is made consistent with the spatial structure of the agro-ecosystem as given by the self-organized spatiotemporal patterns in the pest species distribution and by the environmental forcing through heterogeneous landscape and weather patterns.

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