Ecological Effects and Prospects of Regional Agricultural Landscapes on Insects: Postprint

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Abstract

Ecological regulation of pests has long been an important frontier scientific and technological field in crop pest and disease prevention and control. Currently, research on ecological pest regulation has expanded from single fields to the spatial scale of regional farmland landscapes. Investigating the effects of pattern characteristics and human activities in regional farmland landscapes on the population dynamics of pests, diseases, and natural enemies is not only of great significance for the practice of biological pest and disease control, but also holds major theoretical importance for revealing the impacts of human activities on biodiversity structure and function, and for elucidating the mechanisms of biodiversity integration and maintenance in regional farmland landscapes. Directed prevention and control of crop pests and diseases—in terms of interspecific information flow and behavior manipulation—ultimately needs to be manifested and implemented within specific geographical regional spatial scales, participating in the processes of food crop production and ecological pest management activities. This article mainly elaborates on the ecological effects of pattern characteristics and human planting activities on insects in regional farmland landscapes, and proposes the construction of a diversified ecological pest regulation system based on regional farmland landscapes.

Full Text

Ecological Effects of Regional Agricultural Landscape on Insects and Its Prospect

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Abstract

Ecological regulation and control of pests have always represented important frontier areas in the science and technology of crop disease and pest management. The research framework for pest ecological regulation has expanded from single agroecosystems to regional agricultural landscape ecosystems. Investigating how landscape pattern characteristics and human activities in regional agricultural landscapes affect the population dynamics of pests and their natural enemies holds significant practical value for biological pest control and offers major theoretical insights into revealing how human activities influence biodiversity structure and function, as well as elucidating the mechanisms underlying biodiversity integration and maintenance in regional agricultural landscapes. Targeted prevention and control of crop diseases and pests—through information flow and behavioral manipulation among organisms—must ultimately be implemented within specific geographic regions and integrated into food crop production and ecological pest management processes. This paper primarily elaborates on the ecological effects of landscape pattern characteristics and human planting activities on insects in regional agricultural landscapes and proposes the construction of a diversified ecological regulation and control system for pests based on regional agricultural landscape heterogeneity.

Keywords: regional agricultural landscape, ecological regulation and control, biologically-diversified landscape ecosystems, landscape pattern characteristics, human activities

Introduction

Ecological regulation of pests has consistently constituted a critical frontier in crop pest prevention and management, aiming to ensure food production security while reducing chemical pesticide use and protecting soil, water, biological resources, and the broader ecological environment. As human understanding of crop pest management has deepened and practical applications have expanded, research on pest ecological regulation has progressed from single-field approaches to encompass regional agricultural landscape scales. A regional agricultural landscape refers to an ecosystem within a specific geographic area composed of cultivated crops, non-crop natural habitats, and non-vegetative land cover elements. In such systems, multiple crops and plants interact and constrain each other with pests and natural enemies, forming an integrated whole. Landscape pattern changes and intensified human planting activities represent significant aspects of global change in regional agricultural landscape systems. Therefore, studying the impacts of landscape patterns and human activities on pest and natural enemy population dynamics not only advances biological control practices but also reveals how human activities affect biodiversity structure and function, clarifying the mechanisms of biodiversity integration and maintenance in regional agricultural landscapes.

Landscape Pattern Effects on Agricultural Insects

Spatial Scale and Landscape Configuration

Spatial scale represents a crucial characteristic of landscape patterns, referring primarily to habitat patch configurations and functional dynamics within landscapes or regions, integrating large-scale static structures with dynamic functions. Advances in geostatistical technologies now enable precise analysis and quantification of agricultural landscape spatial structures and arrangements. Large-scale agricultural landscape patterns directly influence pest and natural enemy distribution and dispersal, potentially blocking pest migration and significantly affecting population dynamics. Agricultural landscape patterns manifest primarily through the spatial configuration of various habitat patches and resources. Strategic spatial arrangements can provide refuges for natural enemies while eliminating pest overwintering sites and blocking their transfer to alternative hosts, thereby preventing large-scale pest outbreaks and enhancing biological control. Various landscape indices now enable quantitative analysis of landscape structural and spatial configuration characteristics.

Contemporary theory on insect ecological regulation based on ecosystem services posits that insect management should encompass not only pest control but also beneficial insects (e.g., pollinators, natural enemies, decomposer insects), extending management from single-field ecosystems to agricultural landscape ecosystems. Crop structure within agricultural landscapes directly affects pest occurrence and damage. For instance, Meisner et al. analyzed ten years of data from California and found that landscape structure increased Lygus hesperus populations in cotton fields, subsequently affecting cotton yield.

Natural Enemies and Biological Control Services

Natural enemies provide crucial ecosystem services for pest control in agricultural landscapes. Recent research demonstrates these effects across multiple scales. At the micro-landscape field scale, stable isotope methods for quantitatively analyzing insect movement have revealed the dispersal patterns of Propylaea japonica between cotton and maize, clarifying how cotton cultivar diversity, crop diversity, landscape diversity, and non-crop habitats affect cotton pest communities and natural enemy control functions, showing that landscape complexity enhances biological control. At the county landscape scale, field surveys and remote sensing analysis in Yucheng City, Shandong Province, documented population dynamics of P. japonica and Harmonia axyridis in farmland and shelterbelts, revealing that tree shelterbelts in North China wheat-cultivated landscapes facilitate natural enemy movement between crop fields and adjacent habitats, thereby enhancing biological control capacity in agroforestry landscapes. At broader scales, quantitatively predicting landscape structure effects on natural enemy control functions and their mechanisms is essential for increasing agricultural sustainability.

Conversely, many studies show that landscape simplification reduces natural enemy richness and diversity. Rusch et al. quantitatively analyzed European and American agricultural ecosystems, finding that agricultural intensification-driven landscape simplification undermines natural enemy biocontrol services, suggesting that protecting and restoring semi-natural habitats represents a fundamental first step for maintaining and enhancing these functions. Additionally, Martina et al.' s field exclusion experiments demonstrated that natural enemy control functions increase with landscape structural complexity, but so does bird predation on natural enemies, hindering their effectiveness. This indicates that large-scale landscape structure changes alter multi-trophic interactions, affecting natural enemy control functions. However, mechanisms underlying how landscape structure enhances natural enemy services remain relatively understudied. Research shows that both natural enemy arrival time in fields and landscape complexity are important for pest control, suggesting that strategic habitat layout in simple landscapes can enhance natural enemy effectiveness. More detailed studies on habitat functions and insect dispersal processes are necessary to better understand insect movement characteristics and their relationship with landscape structure to maximize natural enemy control of major agricultural pests.

In 2016, Ouyang et al. quantitatively assessed how landscape composition types, proportions, and structural configurations affect wheat aphids and their natural enemies. Results showed that landscape pattern factors had minimal impact on aphids (9.81% weight) but substantial effects on parasitoids (25.87% weight) and ladybird predators (47.86% weight). Optimizing crop and non-crop habitat layouts in agricultural landscapes can directly regulate and increase natural enemy species and abundance, effectively controlling wheat aphid populations and enhancing biocontrol services.

Human Planting Activities in Agricultural Landscape Systems

Human planting activities constitute another key characteristic of regional agricultural landscape systems. Insect-resistant crops represent highly effective pest management tools. Over the past two decades, transgenic insect-resistant crops (cotton, maize, soybean), particularly Bt crops, have controlled numerous important pests and reduced insecticide use. Lu et al. demonstrated that Bt cotton fields showed significantly increased natural enemy populations (ladybirds, lacewings, spiders) and decreased aphid pests, reducing insecticide applications while providing additional biological control benefits to neighboring crops (maize, peanut, soybean), indicating that Bt cotton cultivation can reduce insecticide use and enhance biological control effects.

However, the primary threat to sustained Bt crop application is the evolution of Bt resistance in target pests. Tabashnik et al. (2013) analyzed global Bt resistance monitoring data, finding that while most pest populations remained susceptible, five important pest species had developed field resistance, including western corn rootworm (Diabrotica virgifera virgifera) resistance to Bt maize causing economic losses, compared to only one resistant pest population reported before 2005. To delay resistance, countries like the United States and Australia typically plant 20% non-Bt crops near Bt fields as refuges, providing sufficient susceptible pests to dilute resistance genes and delay resistance development. Recently, Carrière et al. proposed new refuge strategies including "pyramids" and mixed planting of transgenic and non-transgenic seeds. Collaborative research by Wu Yidong, Wu Kongming, and Tabashnik demonstrated that in North China cotton regions, Bt resistance allele frequencies in cotton bollworm increased from 0.93% in 2010 to 5.5% in 2013, while modeling showed that without natural refuges, resistance allele frequency would have reached 98% by 2013. This study internationally confirmed that natural refuges effectively delay target pest resistance to Bt crops and directly proved that under diverse Bt resistance inheritance patterns, dominant resistance develops significantly faster than recessive resistance.

Prospects: Constructing a Diversified Pest Ecological Regulation System Based on Regional Agricultural Landscapes

Regional agricultural landscapes exhibit diversified characteristics, encompassing both landscape pattern heterogeneity and diverse human activities. Landscape patterns involve multiple dimensions that can be summarized as four aspects: "quality, quantity, shape, and scale." "Quality" refers to different landscape components—patch types including crop varieties, non-crop species, etc. Composition changes include cultivar diversity (different varieties of the same crop), crop diversity (different crop combinations), plant diversity (multiple plant combinations in non-crop habitats), and landscape diversity (combinations of crops, non-crop habitats, and non-vegetative land cover). "Quantity" reflects patch sizes and area proportions. "Shape" indicates patch configurations and arrangements. "Scale" encompasses temporal and spatial dimensions, reflecting the scope and frequency of landscape pattern changes.

Ecological regulation targets pests, but approaches can be diversified: (1) Designing, planning, or manipulating crop types, non-crop habitat types, and landscape element diversification within regional landscapes can provide food and refuges for pests, delaying resistance to pesticides and transgenic crops or blocking pest migration to regulate pest populations. (2) Designing and manipulating diversified regional landscape patterns can provide nectar resources and habitats for natural enemies, promoting their movement between crop and non-crop habitats to directly regulate and increase natural enemy abundance, effectively controlling pest populations and enhancing biocontrol services. (3) Combining both approaches simultaneously.

From 2000–2010, China' s ecological environment experienced maximum human disturbance. Land use pattern changes and global climate change altered pest occurrence patterns and dynamics, affecting pest impacts on ecosystems and their services. Previous research systematically assessed biological disaster-causing factors across China' s provincial farmland, forest, and grassland ecosystems, analyzing spatial distribution characteristics and trends from 2000–2010, examining response capabilities and control measures in affected areas, and evaluating impacts on human safety, property, and ecosystems. These studies proposed strengthening research on landscape diversity-based pest ecological regulation mechanisms.

Under future conditions of accelerated environmental and human activity changes, we propose constructing a diversified pest ecological regulation system based on regional agricultural landscape heterogeneity for crop pest prevention and management.

Theoretical considerations require further research on how landscape type characteristics, patterns, and diversity affect pest population dynamics and damage levels to reveal ecological regulation mechanisms of landscape factors in biological disasters.

Methodological approaches should integrate pre-disaster forecasting, real-time monitoring during disasters, and post-disaster loss analysis into a unified assessment framework, considering temporal correlations in pest occurrence. Landscape-driven mechanisms of pest disasters should be analyzed across scales from patches to landscapes, regions, and even national levels.

Technical means include utilizing 3S technologies (GIS, RS, GPS), landscape pattern analysis, and mathematical modeling to clarify how different landscape elements affect pests and natural enemies; employing stable isotope and molecular marker techniques to explore interactions among plants (crops and non-crop habitat vegetation), pests, and natural enemies; and combining laboratory experiments, field trials, and mathematical simulations to evaluate the value of diversified landscape-based pest ecological regulation services and propose optimization measures.

Management strategies involve designing and manipulating the temporal and spatial arrangement of various plants (including crops and habitat vegetation) in regional agricultural landscapes to influence pest and natural enemy food sources and habitats, thereby regulating population dynamics and dispersal pathways.

In summary, pest ecological regulation primarily controls pests by regulating plants in agricultural landscapes. This process requires long-term management considerations spanning entire years or multiple years. Spatially, it necessitates defining the maximum spatial boundaries of regional agricultural landscapes, establishing long-term representative monitoring sites within the region to track plant types (both within and outside farmland patches) and pest and natural enemy species and population dynamics. Based on the operability and modifiability of landscape elements, we propose management at three levels: within-field cultivar and crop diversity management, field-edge buffer zone plant diversity management, and external landscape diversity management to maximize regional pest ecological regulation potential.

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Note: Figure translations are in progress. See original paper for figures.