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Habitat heterogeneity stabilizes the spatial and temporal interactions between cereal aphids and parasitic wasps

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Abstract

Although it is widely recognized that landscape heterogeneity (LH) can enhance the activity of natural enemies, little is known about the effect of LH on the spatial and temporal stability of pests and their natural enemies. Here, we designed a gradient of LH in agro-ecosystems and examined experimentally the relationship between LH and the spatial and temporal stability of cereal aphids and their parasitic wasps from 2009 to 2012. Stability was measured by the reciprocal of the spatial and temporal coefficients of variation of the population density. Results showed that LH can significantly homogenize the distribution of cereal aphids and their parasitic wasps, thus enhancing the spatial stability of the system. Increasing LH further dampened the fluctuation of the populations of primary parasitoids and hyperparasitoids, thus enhancing the temporal stability of the system. The stability of parasitism and hyperparasitism was also improved with the increase of LH, with the hyperparasitism being more sensitive to the heterogeneity change. Consequently, integrated pest management in agro-ecosystems could be better studied from a multi-trophic food-web perspective.

Zusammenfassung

Während weithin bekannt ist, dass die Landschaftsheterogenität (LH) die Aktivität von natürlichen Feinden steigern kann, ist wenig über den Einfluss der LH auf die räumliche und zeitliche Stabilität von Schadinsekten und ihren Gegenspielern bekannt. Wir entwarfen einen Gradienten der LH in Agrarsystemen und untersuchten experimentell die Beziehung zwischen LH und der räumlichen und zeitlichen Stabilität von Getreideblattläusen und ihren parasitischen Wespen (2009.2012). Die Stabilität wurde gemessen als Kehrwert der räumlichen und zeitlichen Variationskoeffizienten der Populationsdichte. Unsere Ergebnisse

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zeigten, dass LH die Verteilungen der Getreideblattläuse und ihrer Parasitoide signifikant homogenisieren kann, wodurch die räumliche Stabilität des Systems verstärkt wird. Zunehmende LH dämpfte darüber hinaus die Fluktuationen der Populationen von primären Parasitoiden und Hyperparasitoiden, wodurch die zeitliche Stabilität des Systems erhöht wird. Die Stabilität von Parasitierung und Hyperparasitierung wurde ebenfalls mit steigender LH gesteigert, wobei die Hyperparasitierung empfindlicher gegenüber Heterogenitätsänderungen war. Es folgt, dass integriertes Schädlingsmanagement in Agrarökosystemen besser mit einer multitrophischen Nahrungsnetz-Ansatz untersucht werden könnte.

Keywords: Biological control; Food web; Habitat management; Landscape; Parasitism

Introduction

The sustainable management of pests at the landscape scale is important for sustaining the yield in agro-ecosystems, where pests and their natural enemies form the key biotic module (Landis, Wratten, & Gurr 2000; Thies et al. 2011). Understanding how landscape patterns affect species diversity and composition of pests and their natural enemies in agro-ecosystems is a great challenge to sustainable management (Steingrover, Geertsema, & van Wingerden 2010). The loss of natural enemies and the decline of their biocontrol services have been reported in many ecosystems, with landscape changes recognized as one of the most important drivers (Schmidt et al. 2003; Chaplin-Kramer & Kremen 2012; Tscharntke et al. 2012). It is, thus, crucial to elucidate how insect communities that provide multiple ecosystem services respond to landscape changes (Werling & Gratton 2010).

Many studies have examined the relationship between landscape heterogeneity (LH) and the abundance of natural enemies (Cardinale 2012; Jonsson et al. 2012; Martin, Reineking, Seo, & Steffan-Dewenter 2013). Changes in LH can drive the rearrangement and redistribution of habitat patches for insects (Thies et al. 2011). Increasing LH has been found, in most cases, to enhance the abundance of natural enemies and suppress pest populations (Meehan, Werling, Landis, & Gratton 2011; Woltz, Isaacs, & Landis 2012; Zhao et al. 2013a). Because a parasitic wasp (a bio-control agent) needs to search for different food resources in multiple habitats during its life cycle (Gagic et al. 2011; Rand, van Veen, & Tscharntke 2012), the bio-control of pests in agro-ecosystems is likely to be affected by land-use changes. Indeed, such changes can affect the availability of surrounding semi-natural habitats to parasitic wasps as alternative food sources and overwintering refuges (Tscharntke et al. 2008; Woltz et al. 2012).

Habitat management of landscape composition and heterogeneity, at both local and regional scales, has been proposed as an important avenue for optimizing bio-control services from natural enemies (Rosch, Tscharntke, Scherber, & Batary 2013). In particular, increasing LH has been widely recommended in pest management (Batary, Andras, Kleijn, & Tscharntke 2011; Haddad, Crutsinger, Gross, Haarstad, & Tilman 2011). As one way to increase LH, the construction of semi-natural habitats and refuges in agricultural landscapes can be an effective method for boosting the activity and abundance of natural enemies (Steingrover et al. 2010). However, as agricultural pests and their natural enemies are functioning in different modules and at different trophic levels, experiments on how LH affects this agricultural food web warrants investigation.

The diversity of natural enemies in agricultural landscapes is often positively associated with landscape complexity and forms the basis for effective biocontrol (Thies, Steffan-Dewenter, & Tscharntke 2008). However, although diversity is largely positively correlated with community-level metrics such as cumulative abundance, it has a rather versatile relationship with population stability, positive in some cases whilst negative in others (Valone & Hoffman 2003). As the stability of natural enemies can ensure a constant pressure on pests (Tscharntke et al. 2012), biocontrol services and agricultural sustainability can be assured by safeguarding both species diversity and population stability. However, although LH can improve the abundance and diversity of natural enemies by supplying them with abundant food resources and refuges, whether it could also increase the population stability of natural enemies in agroecosystems is largely unknown; consequently its role in the biocontrol of major pests remains unclear (Vollhardt, Tscharntke, Wackers, Bianchi, & Thies 2008; Gagic et al. 2012).

Ecological stability, including both resistance and resilience, can only be assessed in long-term field experiments (Tilman & Downing 1994). Resistance is the tolerance of an ecosystem to disturbance while resilience is a measure of the capability of recovering from a disturbance. A common measure of population stability is the reciprocal of the coefficient of variation, which can be calculated using both the temporal series and spatial distributions of population densities (Haddad et al. 2011). The coefficient of variation (CV) measures the variation in the number of individuals across samples (Hui, Veldtman, & McGeoch 2010) and has been widely used in field studies for reflecting the stability of a focal component in ecosystems (e.g. Tilman, Reich, & Knops 2006). Other stability measures do exist but we chose the inverse CV due to its simplicity and universality for comparison with literature results.