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Regional-scale effects override the influence of fine-scale landscape heterogeneity on rice arthropod communities

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ABSTRACT

Irrigated rice croplands are among the most biologically diverse agroecosystems globally; however, intensification and simplification of farmed areas into homogeneous monocultures can lead to biodiversity loss and a reduction of associated ecosystem services such as natural pest regulation. Understanding how landscape heterogeneity affects the diversity of arthropod communities is therefore crucial for the sustainable management of rice agroecosystems. Here, we examine the influence of fine-scale landscape heterogeneity and regional-scale effects on the arthropod communities of three rice-production regions in the Philippines. Our analysis of 213 arthropod morphospecies (37,339 individuals) collected using two sampling methods at 28 field sites indicated that the rice agroecosystems in each study region had unique arthropod assemblages, likely reflecting region-specific environmental and land-use conditions. For all sites together, we found no effect of fine-scale landscape context (classified as rather high or low heterogeneity sites) on assemblage structure (arthropod abundance, species richness or diversity). When assemblages were analyzed separately, significant effects of fine-scale landscape context were only detected in one region and for two functional groups (predators and detritivores). Elevation gradient, used as a proxy for regional-scale effects in the study regions, explained more than 60% of variance in assemblage structure. Total arthropod abundance and rarefied species richness were negatively related to elevation, suggesting that regional-scale effects rather than fine-scale landscape heterogeneity explained the composition of rice-arthropod communities in landscapes. To further disentangle the complex effects of broad-scale environmental drivers versus fine-scale landscape complexity on arthropod communities and biocontrol services, future research in rice agroecosystems should focus on a more detailed quantification of landscape heterogeneity and examine its effect at multiple spatial scales.

1. Introduction

Rice (*Oryza sativa* L.) is the main staple food for nearly half of the world's population (Zeigler and Barclay, 2008) and is among the most important cereal crops in the developing world (Seck et al., 2012). With the World's human population expected to reach 9.2 billion by 2050 (United Nations, 2013), the demand for rice continues to grow, exerting increasing pressure on rice production systems (Ericksen et al., 2009). Rice agroecosystems have been classified as human-made wetlands (Ramsar, 2010). Because of their alternate dry and wet conditions and their largely tropical distribution, rice fields have been associated with high biodiversity (Cohen et al., 1994; Settle et al., 1996). Rice production promotes complex landscape mosaics because contiguous dry land is often interspersed with the flooded rice fields. These landscapes can attract a wide range of aquatic animals and plants. For example, Schoenly et al. (1996) recorded more than 600 macroinvertebrate species in conventional-cropped fields in the Philippines, which surpasses that of most natural temperate systems (Pimentel et al., 1992).

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Such high levels of biodiversity support complex interactions among multiple organisms, which help suppress rice pests and diseases and thus enhance rice production via biological control (Altieri, 1999; Bottrell and Schoenly, 2012; Macfadyen et al., 2015). Although agroecosystems are designed and managed by man to provide provisioning ecosystem services such as food, forage and bioenergy (Kremen, 2005), they strongly depend on regulating ecosystem services such as pollination and biocontrol (Power, 2010). The latter is of particular importance in rice agroecosystems as pest damage is considered a major limiting factor (Pathak and Khan, 1994).

Agronomic intensification tends to reduce diversity in agroecosystems through the expansion of farmed land, the loss of field margin vegetation, and high intensity management on existing cropland (Gerstner et al., 2014; Robinson and Sutherland, 2002; Swift et al., 1996). This further leads to the simplification and homogenization of farmed areas, resulting in considerably fragmented semi-natural habitats (Robinson and Sutherland, 2002; Meehan et al., 2011) and a degradation of biodiversity and ecosystem services (Tscharntke et al., 2005). In most agroecosystems, monocultures are characterized by higher levels of pest damage and smaller populations of natural enemies (Power, 2010; Gardiner et al., 2009), whose abundance and diversity are negatively affected by the lack of potential food resources and habitats (Landis et al., 2000). Therefore, understanding the effects of landscape heterogeneity and other environmental drivers on the diversity of arthropod communities is crucial to sustainably manage rice production systems and the surrounding landscapes with a minimum harm to agro-biodiversity (Ericksen et al., 2009).

High landscape heterogeneity, i.e. the fine-scale composition and configuration of crop and non-crop areas, is generally associated with increases in natural enemy abundance and diversity (Thies and Tscharntke, 1999; Gardiner et al., 2009; Woltz et al., 2012). While the role of arthropod diversity in maintaining natural pest regulation is not yet universally accepted as a basic principle by farmers (Bianchi et al., 2006), the evidence that landscape heterogeneity improves biological control is mounting (Bianchi et al., 2006; Letourneau et al., 2009; Chaplin-Kramer et al., 2011; Settle et al., 1996). Complex landscapes with large amounts of semi-natural habitat may benefit arthropod communities by providing (i) refuge from agricultural disturbances (Coll 2009; Kleijn and Sutherland, 2003; Meek et al., 2002), (ii) alternative hosts and prey or nectar resources, which are essential for many insects (Bugg et al., 1998), and (iii) a moderate microclimate, which can promote the survival of, for example, parasitoids that experience shorter lifespans at temperature extremes (Dyer and Landis, 1996, 1997). Although the positive aspects of landscape heterogeneity have been explored across a range of cropping systems and study regions (O'Rourke, 2010; Chaplin-Kramer et al., 2011), little is known about their effects on arthropod communities in complex rice production systems. For example, Wilby et al. (2006) documented landscape impacts on the processes of community assembly in rice, largely through effects on abundance, but they found only weak and sometimes contradictory patterns concerning the impact of rice cover and landscape heterogeneity on arthropod diversity.

In addition to fine-scale landscape heterogeneity, rice arthropod communities are affected by climate, environmental conditions and other landscape and land use factors operating at a regional scale. Regional-scale drivers, such as elevation gradients, provide "natural experiments" for testing the distribution of insect biodiversity (Körner, 2007; Samways, 2007). Elevation is often used as a surrogate variable for investigating the influence of regional climate conditions (Sanders et al., 2003), because both temperature and precipitation are highly correlated with elevation gradients. Temperature, in particular, plays a major role in the life history processes of arthropods (Sinclair et al., 2003), as it affects, among others, body growth and morphology, the number of instars and generations produced per year and the length of the life cycle (Hodkinson, 2005). In rice agroecosystems, the abundance of arthropods have been shown to decrease with increasing elevation but no significant trends were observed for species richness or diversity (Schoenly et al., 1996, 1998).

Whilst much emphasis has been placed in the past on describing the rice arthropod community itself (Heong et al., 1991, 1992; Schoenly et al., 1996, 1998; Settle et al., 1996), few studies so far have investigated the potential effect of fine-scale landscape heterogeneity or regional-scale effects on these communities. In this study we examine whether fine-scale landscape heterogeneity is positively related to arthropod diversity, particularly the diversity of natural enemies, in tropical rice fields. To do this we examined arthropod community structure at sites with either fine-scale high or low landscape heterogeneity within a 100 m radius and along an elevation gradient in the Philippines. By including sites at different elevations, we could examine the relative contribution of regional-scale effects and fine-scale habitat heterogeneity in structuring the communities. Furthermore, we assessed the utility of two sampling methods for examining aspects of rice arthropod community ecology.

2. Material and methods

2.1. Study sites

The study was conducted in three areas of 15 × 15 km (henceforth 'region') located on the island of Luzon in the Philippines (Fig. 1). These were the focal sites of a larger research project on sustainable rice production (LEGATO: Settele et al., 2015). The first region (PH_1) was situated in Laguna Province, southern Luzon, with study sites ranging in elevation from 25 m to 290 m asl. In these hilly lowlands, irrigated rice is double cropped, such that a standing rice crop including a ratoon crops is present during most of the year. Narrow plains and lightly undulating hills characterize the terrain. There are no remaining natural forests in the region, but agro-forestry is dominated by coconut plantations and other fruit trees. The second region (PH_2) was located in the Nueva Ecija Province of Central Luzon, at an altitude ranging from 45 to 60 m asl. This typical lowland region is characterized by flat relief with large expanses of irrigated rice and only few semi-natural non-crop habitats. Rice is double cropped using comparably high levels of mechanization and agricultural inputs. The third region (PH_3) was located in the mountainous Ifugao Province, at an elevation ranging from 780 to 1300 m asl. The terrain is diverse and characterized by rice terraces that are believed to have existed for up to 2000 years. The region also includes large patches of primary and secondary forest habitats. Traditional rice varieties are cultivated with relatively low mechanization and few agricultural inputs, typically with one crop per year, see Klötzbucher et al. (2015) and Burkhard et al. (2015) for additional details of the study regions and sites.

To examine the influence of fine-scale landscape heterogeneity on arthropod community composition, five pairs of fields (i.e. 10 core sites) were selected within each region (Fig. 1b) according to the composition of the surrounding landscape, resulting in a total of 28 core sites (sampling could not be performed at two of the core sites in PH_2, because vegetables and not rice were grown at the time of sampling). The mean distance between two core sites within each pair was ~369 m and ranged from ~177 m to ~1192 m. The core sites being relatively close to each other, they primarily differed in fine-scale landscape heterogeneity within each region while other potential regional-scale effects were similar for each pair. For each site, landscape surface coverage and the proportion of rice fields within a 100 m radius were visually estimated by the same observer. Each pair of sites consisted of: (a) a rice field surrounded by high heterogeneity (i.e., the proportion of rice surrounding the core site was substantially lower than 50% with dominance of non-rice habitats including other crops, forests or settlements); (b) a rice field surrounded by low heterogeneity (i.e., more that 50% of the surface coverage consisted of rice fields and with little non-rice habitat). Selected within consistent frame conditions, we assume that the low and high fine-scale heterogeneity sites