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Crop heterogeneity and non-crop vegetation can enhance avian diversity in a tropical agricultural landscape in southern China

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A B S T R A C T

In agricultural landscapes, the positive role of environmental heterogeneity for biodiversity conservation is often assumed. However, with agricultural intensification, opportunities to maintain or restore semi-natural/natural features that produce environmental heterogeneity may be limited. In such a situation, crop heterogeneity could be a way to balance crop production and biodiversity conservation. Despite growing interest in this possibility, few studies have examined whether crop heterogeneity is a major contributor towards environmental heterogeneity in agricultural landscapes in Asia. We investigated how crop heterogeneity, non-crop heterogeneity, and the amount of non-crop vegetation influenced avian diversity in a tropical agricultural landscape in southern China using a hierarchical multi-species occupancy model. We conducted bird and crop surveys during the winter and summer of 2015–2016. Within a 100 m-radius area, we calculated the total length of edges between fields (configurational heterogeneity of croplands) and two Shannon-Wiener diversity indices representing compositional heterogeneity of crop types and of non-crop features (mostly non-crop vegetation). We calculated the amount (i.e., percent cover) of non-crop vegetation within a 500 m-radius area. Crop and non-crop compositional heterogeneity positively influenced species richness in the winter and in the summer, respectively. The amount of non-crop vegetation within the landscape increased species richness in both seasons. Similarly, the occupancy probability of almost half of the species increased with increasing crop compositional heterogeneity or the amount of non-crop vegetation in the winter, and non-crop compositional heterogeneity in the summer. While crop configurational heterogeneity did not show a consistent effect on species richness in either season, it influenced positively the occupancy probability of several open area species in the winter. Our results suggest that crop compositional heterogeneity can have an impact on avian diversity, although its effect varies seasonally, and that the amount of non-crop vegetation at the landscape scale is important for the conservation of avian diversity in tropical agricultural landscapes.

1. Introduction

With growing human population and demand for food, agricultural land-use has been continuously intensified to increase crop production worldwide in developing countries (Food and Agriculture Organization of the United Nations (FAO), 2016). The expansion of agricultural production is seen as one of the largest threats to biodiversity conservation in this century, especially in the tropics (Tilman et al., 2011; Laurance et al., 2014). The future of agriculture is particularly critical to investigate in China, where there is great pressure on food security due to the country's large population size and economic growth, as well as a decline in the availability of arable lands resulting from rapid urbanization (Grumbine, 2014; Veeck, 2013). Agriculture intensification in China has entailed significant overuse of agrichemicals, raising concerns for food safety and environmental health issues (Lam et al., 2013). While this has spurred research on finding environmentally-friendly agricultural practices (e.g., conservation agriculture) or crop mixtures that reduce agrichemical use without compromising crop production (Wu et al., 2015; Zhang et al., 2013), biodiversity, which is crucial to maintaining ecological resilience and ecosystem services (Millennium Ecosystem Assessment, 2005), has been less considered. Lately, the Chinese government has begun to emphasize biodiversity conservation in agricultural landscapes; however, empirical studies on the biodiversity-environment relationship in agricultural landscapes are as yet insufficient (Liu et al., 2013), resulting in little scientific basis to guide policymakers' decision-making.

One of the key factors in restoring or conserving biodiversity in agricultural landscapes is environmental heterogeneity (also called habitat heterogeneity or landscape heterogeneity depending on the focus of research) at multiple spatial and temporal scales (Benton et al.,

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2003; Fahrig et al., 2011; Tscharntke et al., 2005). In ecological studies, it is often assumed that heterogeneous environments, which consist of diverse semi-natural and natural elements, could provide more complementary/supplementary resources for different species, leading to an increase in biodiversity ("compositional heterogeneity": MacArthur and MacArthur, 1961; Rosenzweig, 1995; Tews et al., 2004). Heterogenous environments may also show a complex pattern of spatial arrangement of these semi-natural and natural elements, in a way that facilitates animal movement and dispersal or increases species' resource accessibility ("configurational heterogeneity": Fahrig et al., 2011). For instance, if semi-natural/natural habitats are interspersed within a landscape, species requiring more than one resource may easily access other complementary resources within the landscape (Ethier and Fahrig, 2011; Fahrig et al., 2015). Overall, environmental heterogeneity, particularly compositional heterogeneity, has been advocated to improve the effectiveness of agri-environmental schemes, which are one of main conservation tools to mitigate biodiversity loss in agricultural landscapes in Europe (Benton et al., 2003; Smith et al., 2010), although the overall effectiveness of the schemes still remains controversial (Batáry et al., 2015; Kleijn et al., 2006). A greater diversity of plants, birds, and arthropods are often observed in heterogeneous agricultural landscapes, compared to homogeneous landscapes (Bassa et al., 2011; Firbank et al., 2008; Lee and Martin, 2017; Molina et al., 2014). The amount of non-crop vegetation, i.e., semi-natural/natural vegetation (trees, shrubs, and herbaceous plants) in the landscape and the characteristics of field margins also affect biodiversity (Billeter et al., 2008; Vickery et al., 2009).

Environmental heterogeneity in agricultural landscapes is traditionally assessed based on different types of non-crop vegetation and other non-crop features (e.g., open water). Recently, however, ecologists have started paying attention to whether crop or cropland heterogeneity (composition and configuration of different croplands in a landscape) can be a part of environmental heterogeneity and whether it influences biodiversity positively, as we assume due to the biodiversity-environmental heterogeneity relationship (Fahrig et al., 2011; Monck-Whipp et al., 2018; Vasseur et al., 2013). Agricultural intensification often creates landscapes dominated by a few crop types planted in large scale monocultures (Kareiva et al., 2007; Malezieux et al., 2009). Cropland heterogeneity may be particularly important in situations where patches of semi-natural/natural vegetation are lost or too small to support viable populations of native species. The number and type of croplands or crops are also a component of the agricultural landscape that can be shaped by policy. It has been argued that planting mixed species in cropping systems may be beneficial to local economics and the environment (Malezieux et al., 2009). One recent study also indicates that crop diversification can potentially increase ecosystem services such as pest control and reduce insecticide uses without diminishing crop yields (Gurr et al., 2016). Hence, increasing crop heterogeneity may be a way to positively affect both crop production, and thus farmers' livelihoods, and biodiversity conservation.

However, the effects of crop heterogeneity on biodiversity could be strongly influenced by many external factors. Farmers use different practices for different crops: agrichemical usage (e.g., application rate and type of agrichemicals), field margin management (e.g., timing and frequency of weed removal), cultivation method, and crop rotation change spatially and temporally with crop types (Vasseur et al., 2013). Even the same crop can be managed in different ways. For instance, in the rice-wheat system in south Asia, no-tillage of wheat has been often adopted as a kind of conservation agriculture, because it can increase agricultural production as well as minimize soil disturbance (Hobbs et al., 2008). These different practices can modify vegetation structure, alter available food resources, and affect nesting and reproductive success of animals such as birds, which in turn impact species diversity and population dynamics (Berg et al., 1992; Butler et al., 2007; Vickery et al., 2001). Landscape features (e.g., characteristics of the matrix in which the cropland is embedded) and dominant crop types also influence biodiversity (Molina et al., 2014; Poggio et al., 2013). The effect of crop heterogeneity may be indirect or confounded with the effects of other environmental characteristics. All these factors might explain why the findings of previous studies are inconsistent and vary by taxa and the component (compositional or configurational) of crop heterogeneity, making it difficult to generalize the biodiversity-crop heterogeneity relationship (Bertrand et al., 2016; Collins and Fahrig, 2017; Fahrig et al., 2015; Hiron et al., 2015; Monck-Whipp et al., 2018). The relationship is also rarely explored in tropical agricultural landscapes where biodiversity is relatively high and particularly in Asia where smallholders are common.

In China, small farms (e.g., < 0.5 ha) are predominant, compromising almost 90% of farms in the country (Zhang et al., 2013). While staple food crops (e.g., rice, maize, and wheat) are often the main crops planted on these farms, they also contain a variety of vegetables and create a mosaic of heterogeneous croplands. Such an agricultural landscape is quite different from those usually used in investigations of cropland heterogeneity, which are largely conducted in temperate regions where croplands consist mainly of non-vegetable crops such as maize, wheat, or other grains, orchard, and forage crops (hay/pasture), and large scale farms are dominant (Fahrig et al., 2015; Hiron et al., 2015). Such landscapes provide good opportunities to examine whether crop heterogeneity can play a role to enhance biodiversity in tropical agricultural landscapes. Indeed, these could be important components of conservation in some biodiverse regions of China, such as southern Guangxi Province, which belongs to Indo-Burma biodiversity hotspot (Myers et al., 2000).

Our study aimed to investigate the relationship between avian diversity, crop heterogeneity, non-crop heterogeneity, and the amount of non-crop vegetation in agricultural landscapes in tropical regions of southern China, by focusing on species richness and occupancy through hierarchical multi-species occupancy modeling with a Bayesian approach. We selected birds as a target taxon because they are one of the major ecosystem service providers (e.g., pest consumption; Sekercioglu, 2006), survey techniques are well established, and they are commonly used for environmental monitoring (Koshimies, 1989; Whelan et al., 2008). We expected that, similar to the positive biodiversity-environmental heterogeneity relationship, species richness and the occupancy probability of many bird species would be positively associated with compositional heterogeneity of crop types (crop compositional heterogeneity) and of non-crop features (non-crop compositional heterogeneity or non-crop heterogeneity). The amount of non-crop vegetation that may be used as shelter, foraging, or nesting by birds would also have a positive effect on species richness. We expected the positive influence of the total length of edges (borders or boundaries) between fields (i.e., crop configurational heterogeneity) because it may increase resource accessibility (Fahrig et al., 2011), or because those edges are often covered with grassy and other herbaceous vegetation; however, a negative impact is also possible for species preferring tree or shrub vegetation.

2. Methods

2.1. Study region

This study was performed at 75 sample points located in agricultural lands, in a 47 km × 55 km area (22°56′–22°95′N, 108°13′–108°62′E), surrounding the city of Nanning, Guangxi Zhuang Autonomous Region, China (Fig. 1). All sample points were located approximately 12–35 km from the city center. The study region has a hot and humid summer and a warm and wet winter, with a mean annual temperature of 21.8 °C. Guangxi is the largest sugarcane supplier in China, contributing over 60% of sugar production in China in 2013/2014 (Li and Yang, 2015), as well as being an important rice cultivation center, with the ability to harvest rice crops twice a year.

To establish sample points, we first visited agricultural areas within