Dual Values for Biodiversity Conservation in Agricultural Landscapes

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1. Introduction

One major goal of the "Aichi targets" adopted in CBD (Convention on Biological Diversity) is to increase protected areas until 2020. However, establishing protected areas, including national parks that restrict human activities, is not always realistic due to a great demand for food production. It is also important that not all endangered organisms live in pristine environments, such as primary forests and large wetlands. Human-dominated rural landscapes, often harboring mosaic landscapes due to traditional human land-use activities, have provided suitable habitats for many organisms for thousands of years. However, modern agricultural practices have decreased organisms therein, and not a few of them are now designated as threatened species. Therefore, the management of human-dominated landscapes to conserve these species is an urgent issue.

Environmental-friendly farming may be effective to ameliorate the trade-off between food production and biodiversity conservation, as it enhances habitat quality for wildlife while producing safety foods for human. Environmental-friendly farming is analogous to "land-sharing" [1], especially in developed countries in temperate regions, which is designed to keep mosaic landscapes that could serve as habitats for many organisms, including endangered species. Another possible merit of wildlife-friendly farming is that natural enemies of insect pests and crop pollinators could maintain populations with high densities there, which could provide ecosystem services. It should also be noted that surrounding landscape structures are occasionally important for determining abundance and species richness of natural enemies and pollinators in agricultural landscapes.

With the above background in mind, we would like to show three major issues. First, we show the general processes by which landscape heterogeneity enhances biodiversity in agricultural landscapes. Here we pay particular attention to habitat complementation for various organisms, which emphasizes the importance of linkage between different landscape elements. Second, we show evidence that biodiversity and landscape heterogeneity could provide higher pest control and pollinator services. Third, using spiders as model natural enemies in paddy-dominated landscapes, we explore the possible mechanisms maintaining their populations, focusing on the bottom-up effects from non-pest insects as well as the role of alternative habitat. We propose that mechanisms maintaining generalist predators in paddy-dominated landscapes may be fundamentally different from what was known in dry arable croplands.

2. Traditional agricultural landscapes harbor high species diversity

Rice cultivation in East Asia has traditionally been conducted in heterogeneous landscapes consisting of rice paddies, secondary forests, grasslands, and creeks [2]. This is because of inherent topographic complexities, as well as the need to create mosaic land-use to obtain various resources, including green manure from grasslands, fuel from secondary forests, and water from creeks. When considering biodiversity conservation in paddies, a landscape perspective is essential. Three principal mechanisms operate by which species richness is enhanced in these landscapes. First, the presence of different types of habitats results in a high beta-diversity, which represents the turnover of species composition between different habitats, or between-habitat diversity. This is self-evident because different habitats harbor different species assemblages in response to different environmental conditions. According to fragmentation theory, mosaic landscapes that contain small habitats can represent a double-edged sword for species richness because small habitats impose a higher risk of local extinction for habitat specialists, which results in a low alpha-diversity (within-habitat diversity). However, this negative effect may be overcompensated in terms of total species richness (gamma diversity) by the higher beta diversity in agricultural landscapes [3], and this is likely to be true in Satoyama landscapes. The second mechanism that enhances species diversity in Satoyama landscapes is periodic disturbances by human activities (e.g., mowing of grasses for green manure and livestock food, and coppicing of trees for fuel), which prevents vegetation succession to closed canopy forests, allowing a large number of species to coexist under non-equilibrium ecological conditions [4]. This obviously enhances alpha-diversity. Third, many species of organisms require multiple habitats to complete their life cycles, such as amphibians and aquatic insects. For these species, a combination of different habitats (or niches) can be considered an "emergent niche" [5], which is not divisible for the persistence of these populations. In this sense, landscape heterogeneity creates emergent niches through landscape complementation, enhancing both alpha and gamma diversity.

Although inconclusive, we consider that landscape heterogeneity generally increases species richness, although some species that are specialized on rice field habitats may benefit from landscape homogeneity with regard to widely distributed rice paddies.

3. Biodiversity and landscape heterogeneity enhances pest control- and pollinator services

Despite the naïve recognition that ecosystem services are sustained by biodiversity, there have been limited evidence that biodiversity enhances ecosystem services. Actually, some of the ecosystem services, such as water preservation and timber production, do not seem to require biodiversity *per se*; just a few sets of plant species may provide enough biomass or productivity to fulfil such ecosystem services. Among various types of ecosystem services, pest control- and pollinator services in agriculture appear to need diverse assemblage of species. Recent studies have shown that species richness of wild bees increases pollination success and fruitsets of crops, being independent of the total bee abundance [6]. Diversity of natural enemy species is also shown to decrease pest abundance and thereby increase crop production [7], although in some cases, diversity of natural enemies sometimes fail to suppress insect pests due to intraguild predation [8]. The mechanisms of increasing ecosystem services by increasing species richness is not well demonstrated in the fields, but niche complementation that increases the levels of services and temporal asynchronization of population dynamics among species that stabilizes services in time are the two major mechanisms.

For enhancing pest controlling services, the existence of alternative prey, such as Chironomids and Collemborans, seem to be important, as these insects appear to sustain generalist predators in seasons when insect pests are absent or scares [9]. These prey are called "non-target insects" in Japan [10], and increasing these prey by wildlife-friendly or organic farming may be effective to enhance generalist predators. Therefore, species richness across trophic levels could be important for suppressing insect pests, although such evidence is still limited in the fields.

The extent of pest control- and pollinator services are also known to be landscape dependent. For instance, oil rape damage by herbivores in German is reduced when crop fields are located with a high percentage of non-crop habitats nearby, such as set-aside fields and woodlots, owing to high rate of parasitism of the herbivores [11]. This may be due to spill-over effect of parasitoids from surrounding habitats. Buckwheat production in Japan is enhanced when surrounding forest cover is high, probably because bees utilize forests as nest-sites [12]. However, it is still unknown whether such patterns of landscape dependencies are general, especially for pest control services in paddy dominated landscapes.

4. Mechanisms maintaining populations of generalist predators using web spiders

Previous studies on natural enemies of insect pests in Europe focused on dry croplands, so both croplands and non-croplands are terrestrial habitats that are structurally similar. Here, it seems that source–sink dynamics, which was mediated by spillover of natural enemies from non-crop habitats, are common. In contrast, paddy-dominated landscapes are composed of contrasting habitat types, because rice fields are aquatic habitats while forests and grasslands are terrestrial. As a result, rather than spillover effects, habitat complementation seems to play a major role. Although earlier studies paid less attention to the distinction between spillover effects and habitat complementation [13], this distinction is important to implement appropriate landscape management.

Tetragnatha spiders are one of the commonest predators in rice fields, and they can be an indicator of the effectiveness of organic rice farming [14]. According to our study conducted in Tochigi prefecture, central Japan, the abundance of *Tetragnatha* spiders was greater in paddy fields than in ditches in the rice growing season, but an opposite tendency was found in the non-crop season. This indicates complementary utilization of ditches and paddy fields in different seasons, which appeared to maintain *Tetragnatha* populations in paddy fields. Moreover, the density of flying insects (mainly dipterans) was also increased in paddy fields in rice growing season, and population growth rate of the spiders in paddy fields was correlated positively with the density of flying insects. Therefore, the bottom-up effect of flying insects (non-target insects) emerging from paddy fields may have played a role. It appears that the high primary productivity in paddy fields, in combination with nearby ditches as refuges, sustained the high population density of *Tetragnatha* spiders in paddy-dominated landscapes.

However, is it not clear how other natural enemies in paddy-dominated landscapes shift their habitats with seasons, and the effects of landscape structure on the abundance of natural enemies appear to be species-specific. Furthermore, what types of biodiversity are more important for providing pest control services are totally unclear. Therefore, we should accumulate knowledge on the causal relationship between biodiversity and ecosystem services, by way of large-scale pattern analysis and well-designed manipulative field experiments.

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