

Environmentally Friendly Farming and Multi-scale Environmental Factors Influence Generalist Predator Community in Rice Paddy Ecosystems of Japan

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Abstract

Generalist predators provide important ecosystem services by suppressing the density of pest insects, thus offering a sustainable solution to trade-offs between agricultural production and biodiversity conservation. There is increasing recognition that landscape factors beyond the field scale are important determinants of the community structure of generalist predators, because surrounding environments serve as alternative habitats when arable fields are unsuitable. In addition, macroscale factors are important drivers of farmland biodiversity at large spatial scales. However, few studies have been done in rice paddies, which constitute a major type of farmland in Asia. Here, we present the results of research that explored how agricultural practices and environmental factors influence community structures of generalist predators in rice paddy ecosystems in Japan.

Keywords: dragonfly, frog, geographic information system, landscape structure, latitudinal variation, spider

1. Introduction

Agricultural intensification is a major threat to biodiversity in agroecosystems. To mitigate this human impact on agro-biodiversity, environmentally friendly (EF) farming, in which the use of agrochemicals and chemical fertilizers is reduced, is being promoted around the world. However, agricultural production in EF-farmed fields can be lower than that in conventionally farmed fields on account of the reduced use of agrochemicals. Therefore, effective techniques for pest management are needed to sustain EF farming (Zehnder et al., 2007).

Generalist predators such as spiders and ground beetles provide effective control of pest insects (Symondson et al., 2002), offering a sustainable solution to the trade-off between food production and biodiversity conservation. In general, the function of generalist predators can be enhanced in EF farming because predator communities within EF fields are generally more diverse and complex than those in conventionally farmed fields (Pfiffner and Luka, 2003; Bengtsson et al., 2005; Hole et al., 2005; Tuck et al., 2014). However, predator communities are influenced by factors beyond the field scale. For example, the surrounding landscape is an important determinant of the community structure of predators, because it provides alternative

habitats for field organisms including both prey and predators when arable fields are unsuitable (Tscharntke et al., 2007). In addition, macroscale factors such as climate and topography are important drivers of farmland biodiversity at large spatial scales (Nyffeler and Sunderland, 2003; Amano et al., 2011). Many studies have explored how multi-scale factors determine the abundance and diversity of generalist predators in upland farmlands (e.g., wheat fields and meadows) in Europe (Bianchi et al., 2006), but few studies have been performed in rice paddies, which constitute a major type of farmland in Asia (Katayama et al., 2015). The influence of multi-spatial scale factors on predator communities in rice paddy ecosystems is likely to differ from that in Europe, because various factors (e.g., environmental conditions within farmland, landscape structure, and climatic zones) differ between Europe and Asia (Miyashita et al., 2015). Here, we present the results of our research that explored how agricultural practices and multi-scale environmental factors influence the abundance and diversity of generalist predators in Japan's rice paddy ecosystems.

2. Effects of Environmentally Friendly Farming

EF farming practices, in which pesticide use is reduced, offer effective ways to enhance the numbers of generalist predators. This effect has been confirmed in many studies in Europe but in few studies in rice paddy ecosystems in Asia (Takada et al., 2014). We tested this effect by comparing the abundances of generalist predators—namely spiders, dragonflies, and frogs (Fig. 1)—between conventional and EF (organically farmed) paddy fields, in which no synthetic agrochemicals and chemical fertilizers were applied, at six locations in Tochigi Prefecture, in the northern part of the Kanto region (Fig. 2). Predators were sampled in accordance with the instructions in a survey and evaluation manual (AFFRC/NIAES/NIAS, 2012).

EF farming practices enhanced the abundance of spiders (Fig. 2; results shown for lycosid spiders only), dragonflies, and frogs and the species richness of spiders. This enhancement might

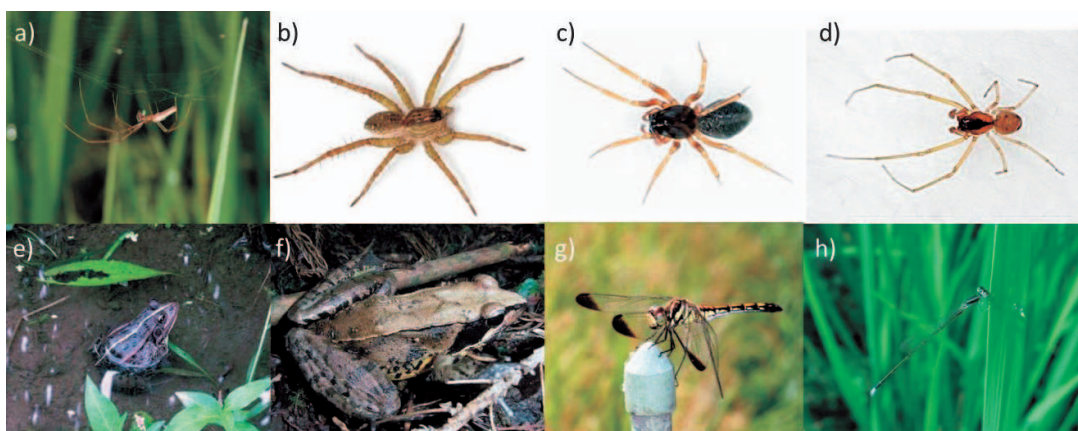


Fig. 1 Generalist predators in Japanese rice paddies. (a) *Tetragnatha* spider, (b) lycosid spider, (c) linyphiid spider, (d) *Pachygnatha* spider, (e) Daruma pond frog, (f) Japanese brown frog, (g) dragonfly, (h) damselfly

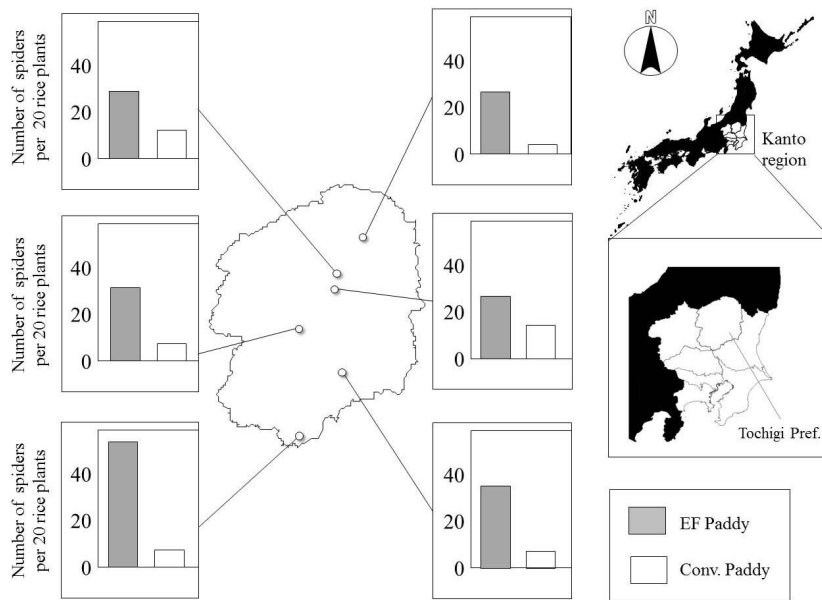


Fig. 2 Comparison of abundances of lycosid spiders between environmentally friendly (EF) and conventional rice paddies at six locations in Tochigi Prefecture. EF, environmentally friendly; Conv., conventional

be attributable to improvement in the survival rates of predators or to increases in the availability of alternative prey such as detritivorous insects (e.g., Takada et al., 2014) on account of the reduced pesticide use. This positive effect of EF practices on predator abundance has been confirmed throughout Japan (AFFRC/NIAES/NIAS, 2012).

3. Effects of Landscape Factors

The surrounding landscape is important in determining the abundance and diversity of generalist predators, because it provides alternative habitat, breeding sites, and overwintering sites when arable fields are unsuitable. The effects of landscape on generalist predators are thought to vary with species ecology and taxonomic group (Schmidt et al., 2008). For example, the requirement of the Japanese brown frog (*Rana japonica*) for both forest habitat and wetlands translates into positive effects of the surrounding forest area on its abundance in rice paddy fields (Kato et al., 2010). In contrast, landscape elements other than farmland can reduce the abundance of organisms that depend strongly on farmland through a decrease in, or fragmentation of, available habitat.

We used a geographic information system (GIS) and a generalized linear model to evaluate land uses and thus analyze the effects of landscape and farming practices on generalist predators. We conducted a field survey in Shioya-cho, in Tochigi Prefecture. The study area features an environmental gradient from forest-rich landscape to farmland-dominated landscape. We

surveyed the abundance of spiders, dragonflies, and frogs in 10 pairs of adjoining conventional and EF paddy fields along a gradient (see Fig. 3 for spider data; data for dragonflies and frogs not shown). Fungicides and herbicides were applied on both types of fields, but insecticides (e.g., fipronil in May; etofenprox or dinotefuran in August) were used only on the conventional fields. In EF farming, the use of inorganic fertilizers was reduced, and organic fertilizers were applied instead. To evaluate the area of each land-use category, we used the GIS to generate buffer zones with a radius of 50 to 200 m around each field and then calculated the areas covered by forests and dwellings in each buffer zone.

Generalist predators responded differently to farming practices and landscape context depending on their taxonomic group. The abundance of two major spider groups—*Tetragnatha* (web-weaving spiders) and lycosids (cursorial spiders)—responded positively to EF farming and increasing forest area within a radius of 200 m around the paddy fields (Fig. 3; data shown for lycosids only). Linyphiid and *Pachygnatha* spiders also responded positively to EF farming, but they responded differently to landscape: linyphiids responded negatively to increasing forest area, and *Pachygnatha* spiders did not respond. Although detail mechanisms were unknown, this inter-taxonomic variability in landscape effect likely reflects the differences in habitat uses

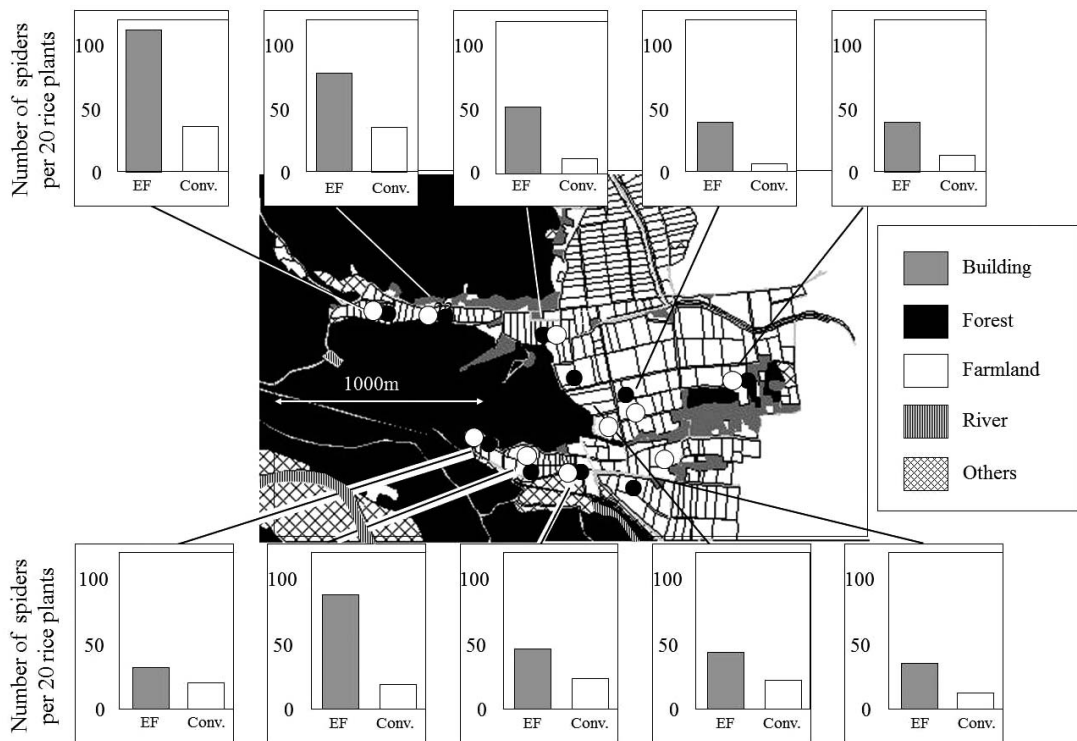


Fig. 3 Spatial patterns of abundance of lycosid spiders along the environmental gradient from forest-rich landscape to paddy-dominated landscape in Shioya-cho, Tochigi Prefecture. White and black circles represent environmentally friendly (EF) and conventional rice paddies, respectively. EF, environmentally friendly paddy; Conv., conventional paddy

among the spider groups.

Two frog species responded differently to both local and landscape factors. Numbers of the Daruma pond frog (*Pelophylax porosus porosus*), which depends strongly on wet habitats, were influenced negatively by the presence of forest areas within a radius of 100 m around the study fields and positively by EF farming. In contrast, the abundance of the Japanese brown frog, which inhabits forests during the non-breeding season, increased with increasing forest area within a radius of 200 m. These results reflect differences in the frogs' habitat use and support the results of other work that different frog species responded differently to spatial scale and landscape composition (Kato et al., 2010).

The abundance of *Sympetrum* dragonflies and various damselflies was affected positively by EF farming but not by landscape factors, because their effective spatial scale seems to be broader than 200 m, reflecting their high dispersal ability. The positive effect of EF farming on abundance was stronger in dragonflies than in damselflies; this may reflect the harmful effects of insecticides such as fipronil on *Sympetrum* (Hayasaka et al., 2013).

Our findings suggest that the effects of landscape context are highly variable, depending on the ecological properties of each taxonomic group, and that this variability results in the formation of various community compositions of natural enemies in rice paddy fields. Although many studies have examined the spatial patterns of abundance and diversity of natural enemies in arable fields in European studies, relatively few have examined the mechanisms underlying these patterns. To elucidate these mechanisms, we will need to investigate the abundance and species composition of generalist predators in surrounding environments (e.g., Pfiffner and Luka, 2000; Schmidt and Tschardt, 2005) and the movement of predators between farmland and surrounding areas.

4. Effects of Macroscale Factors

Topography and climatic variables are key drivers of biodiversity dynamics at large spatial scales. Many studies have investigated the macroscale patterns of abundance, species diversity, and species composition (e.g., Rahbek, 2005), but few have focused on natural enemies in agroecosystems (Nyffeler and Sunderland, 2003). Exploring the patterns of predator communities at large geographic scales can provide useful information for establishing regionally adapted biological control programs. We investigated nationwide patterns of the abundance and species composition of *Tetragnatha* and lycosid spiders, both of which are used as biological indicators in Japanese rice paddy ecosystems (AFFRC/NIAES/NIAS, 2012), by using abundance data obtained from EF-farmed rice paddies in 13 regions from Okinawa to Hokkaido through the research project.

The abundance of *Tetragnatha* spiders was lower in Hokkaido and Okinawa and higher in Honshu and Kyushu. Interestingly, it tended to increase with latitude across Honshu and Kyushu. The abundance of lycosid spiders was similar: lower in Hokkaido and Okinawa and higher in Honshu and Kyushu. However, for these spiders there was no latitudinal increase in abundance across Honshu and Kyushu.

The species composition of *Tetragnatha* spiders, with seven species in total, differed among regions, and species diversity varied accordingly (Fig. 4). On Ishigaki Island, *T. javana* and *T. nitens* dominated, whereas on Kyushu (Kumamoto and Kagoshima), *T. nitens* and *T. maxillosa* dominated, and species diversity was relatively low. In western Honshu (Hiroshima, Shimane, and Hyogo), *T. maxillosa* or *T. vermiformis* dominated. In addition to these species, *Tetragnatha caudicula* and *T. extensa* were emerged in eastern and northern Honshu, resulting in the highest species diversity in the northern part of the Kanto and Tohoku regions. On Hokkaido, *T. extensa* dominated, and species diversity was very low. This pattern suggests that the species diversity of *Tetragnatha* spiders varies widely with changes in species composition along a latitudinal gradient.

Lycosid spiders were represented mainly by *Pirata subpiraticus* (prominent in northeastern

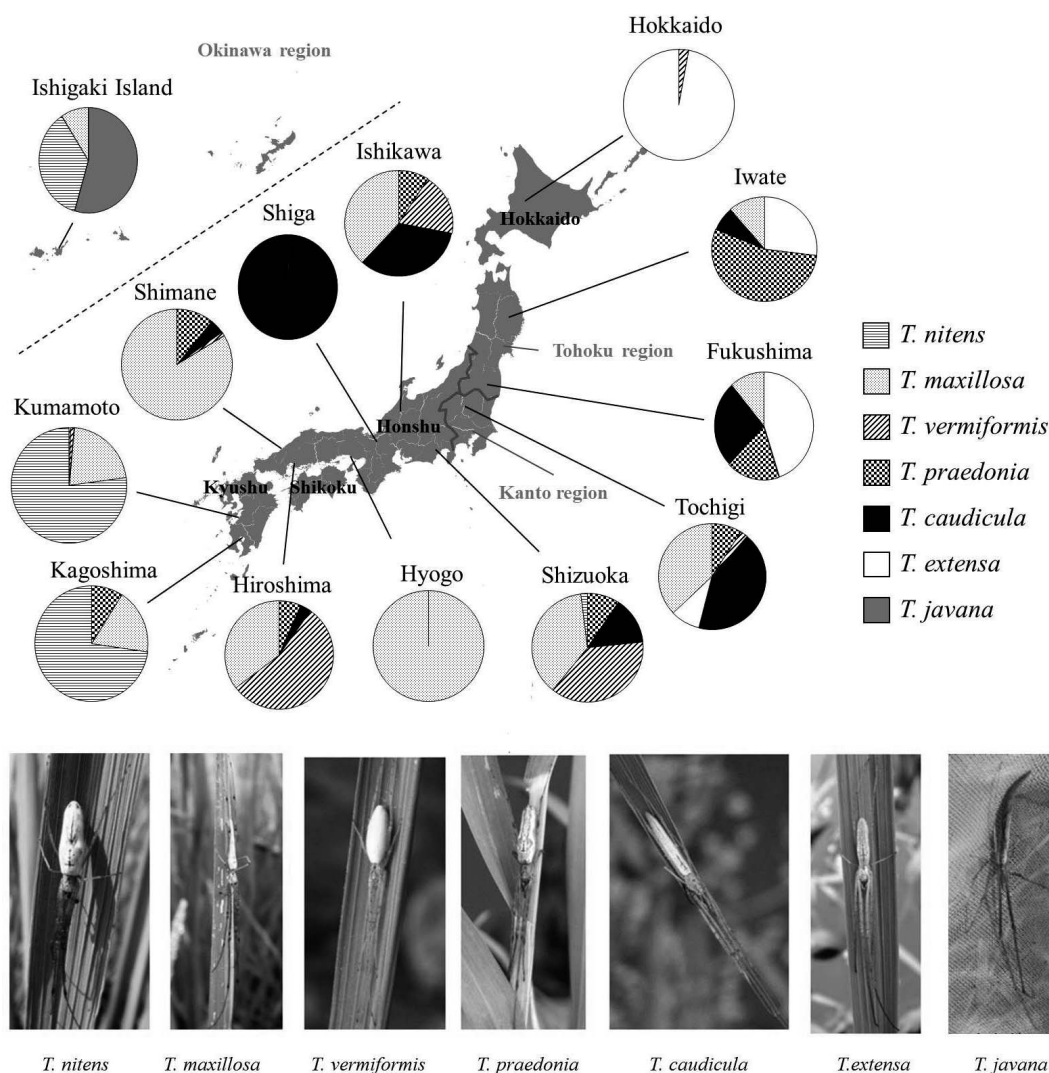


Fig. 4 Geographic variation in species composition of *Tetragnatha* spiders across Japan

Japan) and *Pardosa pseudoannulata* (abundant in southwestern Japan; Fig. 5). This pattern may reflect differences in their preferred climate conditions, but interspecific interaction also seems to be involved, as we found an inverse abundance relationship between these species in Tochigi Prefecture where they occur together, indicating that there is interspecific competition (K. Tanaka and Y. Baba, unpublished data).

In summary, our nationwide survey revealed that spiders living in EF rice paddies showed marked geographic variation in abundance and species composition. These results suggest that the abundance and species composition of natural enemies vary among regions with different climatic conditions, and this variation could affect ecosystem services for pest control. In future studies we will need to clarify the mechanisms behind these complex geographic patterns.

5. Conclusions

Our results demonstrate that factors at various spatial scales drive the structure of generalist predator communities in rice paddy ecosystems and contribute to the formation of diverse communities of these natural enemies at multiple spatial scales. Further investigation of the mechanisms underlying the patterns of abundance and diversity of predators is needed. In addition, we need to clarify the relationship between various community properties of natural enemies and ecosystem functions for pest control.

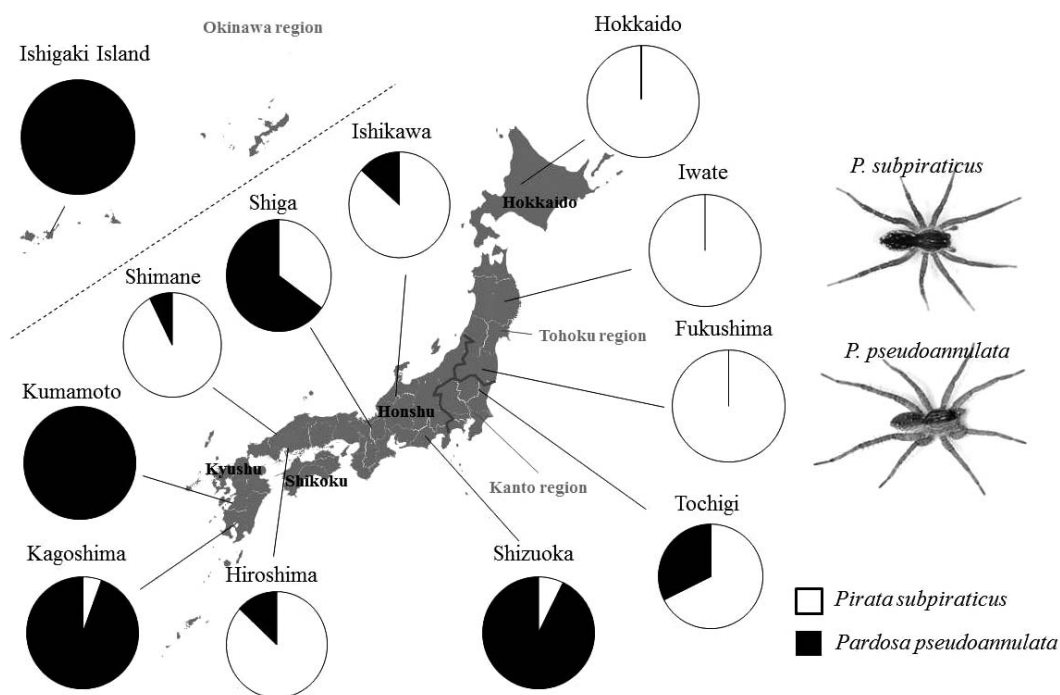


Fig. 5 Geographic variation in species composition of lycosid spiders across Japan

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