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Factors affecting abundance and species composition of generalist predators (*Tetragnatha* spiders) in agricultural ditches adjacent to rice paddy fields

Yuki G. Baba *, Koichi Tanaka

Institute for Agro-Environmental Sciences, NARO, 3-1-3 Kannondai, Tsukuba, Ibaraki 305-8604, Japan

HIGHLIGHTS

- Abundance and species composition of *Tetragnatha* spiders in ditches were examined.
- *Tetragnatha extensa* and *T. maxillosa* accounted for 95% of the total abundance.
- The abundances of the two species differently responded to environmental factors.
- Species composition varied depending on vegetation height and distance to forest.

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ABSTRACT

Agricultural ditches adjacent to paddy fields are expected to provide an alternative habitat to the fields for *Tetragnatha* spiders, a major component of the natural enemies of crop pests in rice paddy ecosystems. To better understand the spatial distribution of these spiders in agroecosystems, it is essential to evaluate their abundance and species composition in such alternative habitats. Here, we examined the factors determining abundance and species composition of *Tetragnatha* spiders in agricultural ditches around rice paddy fields. Field surveys were conducted in transects set along 43 concrete ditches in the northern Kanto region, Japan, prior to the rice growing season when spiders are absent in paddy fields. Four species of *Tetragnatha* spiders were found, with two species (*T. maxillosa* and *T. extensa*) accounting for 95% of the total abundance. These two species showed different responses to local and landscape factors. The abundance of *T. maxillosa* increased with ditch width, whereas that of *T. extensa* was highest at intermediate width. Vegetation height had a positive effect on the abundance of *T. maxillosa* but a negative one on that of *T. extensa*. Distance to the nearest forest had no effect on *T. extensa*, but negatively influenced *T. maxillosa*, indicating that forest environments are beneficial to the latter. Reflecting these differences, the proportions of the two species in overall *Tetragnatha* abundance varied depending on vegetation height and distance to forest. Our findings indicate that the potential for immigration of *Tetragnatha* spiders from ditches to fields depends on local conditions and the positional relationship to forest.

1. Introduction

The pest control provided by generalist predators, which account for the majority of natural enemies, represents a regulating ecosystem service in agroecosystems (Marc et al., 1999; Symondson et al., 2002). The importance of such pest control is increasing as environmentally friendly agricultural practices (Jonsson et al., 2008)—in which the use of agrochemicals and chemical fertilizers is reduced—are being promoted around the world (Willer et al., 2010). The environment surrounding arable fields plays an essential role in maintaining generalist predator communities in farmlands as well as in field-plot management, because it provides alternative habitat and overwintering sites for predators during periods when arable fields are ill-suited to their survival (Schmidt and Tscharntke, 2005b; Schmidt et al., 2005, 2008; Pluess et al., 2010; Tscharntke et al., 2012). Surveying the composition and abundance of generalist predators in alternative habitats such as forest and grassland is essential for understanding their spatial distribution in agroecosystems. Several studies have examined species composition of predatory arthro-

* Corresponding author at: 3-1-3 Kannondai, Tsukuba-shi, Ibaraki Pref. 305-8604, Japan.
E-mail addresses: ybaba@affrc.go.jp (Y.G. Baba), tanaka@affrc.go.jp (K. Tanaka).

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pods in semi-natural grasslands around upland fields in Europe (e.g., Schmidt and Tscharntke, 2005a), but few such studies have been conducted in Asian countries, where rice paddy fields represent the major type of farmland.

Tetragnatha spider (Araneae: Tetragnathidae) is one of the predominant generalist predators in Asian rice paddy ecosystems (Okuma et al., 1978; Murata, 1995; Pei and Nakamura, 2012). One to five species of *Tetragnatha* are found in rice paddies on the main islands of Japan (Baba and Tanaka, 2016). These spiders prefer damp habitats such as river and stream banks and paddy fields, and build horizontal orb-webs among plants (Yoshida, 1981). They serve both as a natural enemy of the mirid bug, *Stenotus rubrovittatus*, which is a serious pest of rice plants (Kobayashi et al., 2011; Takada et al., 2012, 2013), and as a biological indicator reflecting the effects of environmentally friendly agricultural practices (Amano et al., 2011; AFFRC, 2012; Tanaka, 2016).

Tetragnatha spiders are abundant in paddy fields during the rice growing season, but their abundance dramatically decreases during the fallow period because paddy fields are dry, and there are no plants to serve as substrates for web construction. These spiders certainly inhabit alternative habitats during the fallow period, and after the rice planting, they immigrate into the paddy fields. After the harvest, they emigrate from the paddy fields and inhabit alternative habitats. However, there is little information about their habitats during the fallow period. The agricultural ditches near rice paddy fields seem to be a potential alternative habitat for them, because these ditches contain water in seasons other than winter. Indeed, Okuma (1977) reported that the density of *Tetragnatha* spiders was higher in ditches than in farmland during the post-harvest season. Recently, Tsutsui et al. (2016) indicated that *Tetragnatha* spider populations were maintained by complementary utilization of paddy fields and ditches through the seasons.

On the other hand, spider abundance and species composition in agricultural ditches are expected to vary depending on environmental factors at both the local and landscape scales. For example, local factors such as ditch size and the presence of vegetation growing along ditches seem to limit the space available for web construction. Additionally, aquatic emergence, which acts as an alternative food resource, is also known to be important determinant of local distribution and abundance of riparian spiders (Kato et al., 2003; Iwata, 2007). As for landscape factors, adjacent forest is known to influence the abundance of *Tetragnatha* spiders by providing food resources or alternative habitat (Amano et al., 2011; Miyashita et al., 2014). In addition, *Tetragnatha* spiders showed divergent habitat use among species (Yoshida, 1981; Aiken and Coyle, 2000), which suggests that the response to environmental factors may differ among species, such that dominant species would change spatially. Thus, in order to assess the immigration potential of *Tetragnatha* spiders from agricultural ditches to rice paddy fields, it is essential to clarify their relationship with specific environmental factors. However, there have been almost no studies have drawn attention to the importance of artificial structures as potential habitat for natural enemies.

In this study, we examined the effect of local and landscape environmental factors on *Tetragnatha* spiders inhabiting agricultural ditches adjacent to rice paddy fields in Japan prior to the rice growing season. First, we assessed the species composition of *Tetragnatha* spiders found in agricultural ditches, and then specified the dominant species. Next, we examined how local and landscape factors affect the dominant species by analyzing spatial variation of their abundance levels and composition. We hypothesize that the response of spider abundance to environmental factors differs among species, reflecting their divergent habitat use, and thus we expect that dominant species will vary spatially across heterogeneous environments.

2. Material and methods

2.1. Study area and spider counts

We conducted the field survey at Shioya-cho, Tochigi Prefecture, in the Kanto region of central Japan (Fig. 1) between 17 and 19 May 2011. In the study area, rice plants were transplanted during early to late May. Thus, in the study period, the rice plants were low and small, which could not sufficiently support spider webs. Consequently, there were very few *Tetragnatha* spiders within paddy fields, indicating that the most *Tetragnatha* spiders inhabited alternative habitats other than arable fields. The most prevalent *Tetragnatha* species found in paddy fields of the Kanto region are *T. caudicula*, *T. extensa*, *T. maxillosa*, *T. praedonia*, and *T. vermiformis*. Other than *T. extensa*, these species are broadly distributed across the main islands of Japan. *Tetragnatha extensa* is only distributed in the northeastern Honshu and Hokkaido (Baba and Tanaka, 2016), although it is distributed all over the Holarctic part of the world (World Spider Catalog ver 17.5)

We selected 43 concrete ditches around paddy fields that were about 500 m away from each other (Fig. 1). We set a 10-m transect along each concrete ditch and recorded the number, body length, and species of *Tetragnatha* spiders occurring within each transect during the day time (08:00–17:00 h). Body length is investigated to confirm whether ditches can serve as a stable habitat for *Tetragnatha* spiders at any development stage. Because *Tetragnatha* spiders are active at night or in dim light (Kiritani et al., 1972), most of them were sheltering within foliage or dead branches during the survey, so we carefully sought them by pushing aside the plants. Adult and medium/large-size juvenile spiders were identified to species in the field based on the key morphological characteristics for their identification such as body shape and markings on ventral side of abdomen (Chikuni, 1989), whereas small juveniles, those were difficult to be identified in the field, were sampled by hand-collecting with grass vials filled with 75% ethanol, and carefully identified with a binocular stereo microscope in the laboratory by comparing them to the reference specimens of each *Tetragnatha* species.

2.2. Environmental factors

Although both or either habitat structure or food availability are known to be important local factors for determining spider abundance (Greenstone, 1984), we mainly focus on habitat structure here, because we found no significant relationship between aquatic emergence and abundance of *Tetragnatha* spiders in ditches (Tsutsui et al., 2016). For the micro-habitat of *Tetragnatha* spiders constructing the horizontal orb-webs, substrates such as ditch wall and vegetation supporting the webs and space occupied by the web are probably important. Therefore, we selected the ditch width and the height of plants growing along the ditch edges as local environmental factors. All the ditches were made of concrete and filled with water. Ditch depth may affect web construction of the *Tetragnatha* spiders. However, the ditch depth was strongly correlated with ditch width ($r = 0.95$, $p < 0.001$), so we did not use it in our analysis. Vegetation height was measured at 10 points selected randomly along each transect by using a metal tape measure, and the mean height was used for the analysis. Water depth was not considered because this variable changes over time and showed a very weak effect on spider abundance in the preliminary analyses.

As the main landscape factor, we focused on distance to the nearest forest patch, which has been shown to have a positive effect on density of *Tetragnatha* spiders (Amano et al., 2011; Miyashita et al., 2012; Miyashita et al., 2014). We calculated the