

Bioindicators of Biodiversity and Farming Practice in Rice Paddies

Takatoshi Ueno

Abstract—Rice paddies occupy the largest cultivated area in agricultural land of Asia and create the habitats for many organisms, sustaining high biodiversity. Natural enemies inhabiting rice paddies have an important function for rice production as agents of ‘ecosystem services’ because they suppress rice pests. Such natural enemies can be a good index reflecting the ‘healthiness’ of agro-ecosystem services in rice paddies. The present study evaluates whether natural enemies could be good biological indicators for biodiversity and agricultural practice. First, the concept of ideal bio-indicators was summarized. Then, the results based on a field survey were given to show the usefulness of natural enemies. Field studies demonstrated that reduction of chemical inputs led to an increase in species richness of natural enemies. The abundance of several species of natural enemies did respond both to pesticide use and to general arthropod biodiversity. Thus, natural enemies can be suitable as bio-indicators. Usefulness of indicator species in rice paddies is discussed in the context of ecologically sound agriculture.

Keywords—Pest Management, Environmentally Sound Agriculture, Indicator Species, Ecosystem Service.

I. INTRODUCTION

RICE paddies, together with the associated irrigation ponds, ditches and ridge, often constitute the traditional landscape in rural environments and are a key ecosystem of Asia. Rice paddies provide the habitats for diverse organisms that differ in their functions [1, 2]. This means that rice paddies support, at least in part, biodiversity in the area or region. Recently, biodiversity in agricultural land has received growing attention because it plays a significant role in agro-ecosystem function [3, 4]. For example, beneficial organisms like natural enemies serve agro-ecosystem function regulating pest populations [5—7]. In agricultural fields, crop production commonly depends on natural control provided by natural enemies. Indiscriminate use of agro-chemicals such as insecticides causes the loss of biodiversity of such beneficial organisms, and leads to the resurgence of pests [8, 9].

In Japan, being ‘ecological’ or ‘environmental’ is on strong demand in agriculture nowadays. Sustainable management of rice paddies is also an increasing concern in the country. However, so-called environmentally sound farming is desired in terms of the production of safe food for humans, and its

impact on biodiversity is often overlooked. Use of indicator organisms can provide the public concern to reconsider what is truly ‘ecological’ and the so-called eco-friendly farming from the viewpoint of biodiversity conservation.

Because the biodiversity of beneficial natural enemies is a key resource to promote the productivity and sustainability in rice paddies, conservation of natural enemies should be an important approach for sustainable rice production [10, 11]. However, conserving the diversity of natural enemies and other organisms may be a formidable challenge. Use of insecticides dramatically reduces the incidence of rice pests and the yield loss, and herbicides allow reducing labor required for weed control [8, 9]. While the intensification of rice farming systems make the yield higher and the price of rice lower, it should cause rice paddies poor in biodiversity. In contrast, biodiversity conservation through reduction of agrochemical use would decrease labor productivity of rice. Nevertheless, biodiversity conservation can help sustainable use of rice paddies and can reduce the incidence of pest outbreaks [12—14]. Importantly, recent studies have demonstrated that the presence of diverse species of natural enemies can enhance the control of pest populations through their complementary function [12—14].

Use of biological indicators or indicator organisms is ideal for biodiversity conservation in rice paddies. Biodiversity in rice paddies is rich; more than 5000 species are recorded from rice paddy ecosystems in Japan [2]. In addition, there are many species that are difficult to identify to the species or group level. Thus, indicators that can reflect biological diversity is required because the evaluation of biodiversity in its entirety is not be practical [15, 16]. Indicator organisms are useful for linking between biodiversity and environmentally sound practices because indicator organisms allow the quantitative assessment of environmental soundness of agricultural practices. Also, such indicators are useful for: (1) linking between farmers and biodiversity and (2) linking between farmers and consumers, if they are usable for everyone.

In the present study, I investigated the diversity of natural enemies in rice paddies to explore candidates of indicator organisms from natural enemies inhabiting rice paddies, and to assess whether indicator natural enemies can be use for conservation planning in rice paddies. Although biodiversity refers to all species including plants, animals, insects and microorganisms occurring within an ecosystem, I mainly focused on arthropod diversity because they occupy the vast majority of the number of individuals and species detected in

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rice paddies at above-ground level [1, 10].

II. FIELD SURVEY

Field survey was conducted on relatively small-scale farms between 2008 and 2009. Study sites are located at Nijyo-machi Town, Fukouoka Prefecture, a lowland area in northern Kyushu main island of Japan. Rice variety chosen for the survey was Hinohikari, the most popular variety in the region. In the study region, rice was an annual crop, and Hinohikari was transplanted from late June to early July. Harvest was mostly in early to middle October. Rice paddies selected for the present survey included both organic farming fields and conventional farmer's fields. In conventional fields, farmers exclusively used Imidacloprid, a systemic insecticide, during the seeding stage before transplanting as the chemical control tool to manage insect pests. In many fields, herbicides were applied once after transplanting rice. Around the flowering stage of rice, farmers applied Dinotefuran (a systemic insecticide) once or twice to control leafhoppers, planthoppers and green bugs but not all farmers applied such insecticides. Thus, rice paddies studied were placed in three types: (1) organic fields, and (2) fields with insecticides only once during the seeding stage or (3) three times (once in seedling and twice during growing stages).

Sampling of arthropod natural enemies was made in 40 farmer's fields between September and October when more than 2 weeks had been passed since the final application of pesticides, allowing the analysis of cumulative effects of farming in the growing season. In 2008 and 2009, general survey was first made to know the species composition of natural enemies in the area of Nijyo-machi Town. Sweeping with an insect net and visual collection were performed to obtain specimens, and the list of natural enemies was prepared. In 2009, data for analyzing biodiversity and exploring candidate organism were also obtained by inspecting the entire plant while walking 5 m along 3 lows of rice plants. Each field was sampled at two sites, and sampling was repeated twice in different days for each field. The numbers of natural enemies were counted, and the species were recorded. When necessary, specimens were collected for exact identification to species level.

The data were analyzed with the aid of JMP (SAS 2008). Here, the diversity of natural enemies was estimated by Shannon's Index (= Shannon-Wiener Index), which allows the measurement of biodiversity. This index is commonly used because it has an advantage to take into account the number of species and the evenness of the species, both of which are important concept of biodiversity.

III. RESULTS AND DISCUSSION

A. Biodiversity of natural enemies and insecticide use

The effect of insecticide applications on species richness of natural enemies was examined. Natural enemies were divided into two main categories based on their basic function, i.e.,

parasitoids and predators. The relationship between insecticide use and diversity index of natural enemies was then assessed with a generalized linear model (=GLM). Insecticide use significantly influenced the species richness (GLM; link function for poisson; $df = 3$, $\chi^2 = 18.5$, $P = 0.0004$ for parasitoids; $df = 3$, $\chi^2 = 21.8$, $P < 0.0001$ for predators). As expected, the highest levels of species richness for parasitoids (Fig. 1a) and predators (Fig. 1b) were observed in rice paddies where no insecticides had been applied.

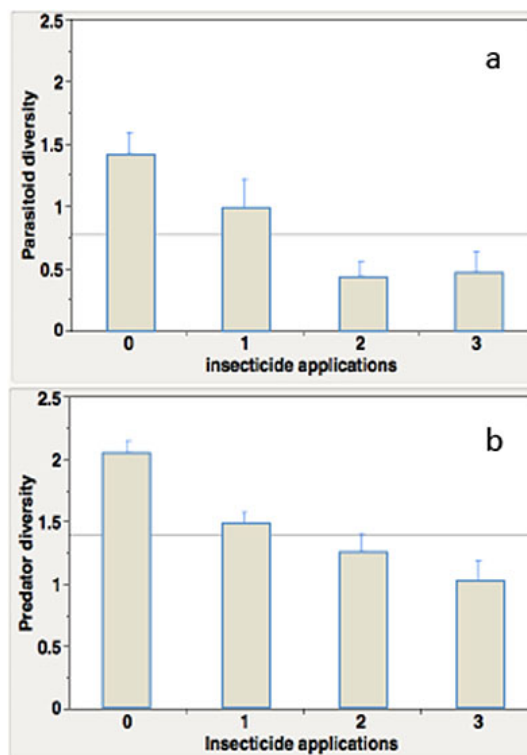


Fig. 1. Relationship between insecticide use (total number of applications during the growing season) and diversity of natural enemies measured with Shannon's index (above: parasitoids, below: predators).

It is well known that rice paddies provide habitats for many organisms, including beneficial natural enemies that are important resources for natural control of pest organisms [1, 2, 10]. However, a number of practices used in modern rice production systems can harm such beneficial species, weakening the function of natural biological control. The present study has demonstrated that insecticide use decrease the diversity of natural enemies in commercial rice paddies.

B. An ichneumonid wasp as a bioindicator

Feasibility of natural enemies as indicator organisms was examined. Here, *Itopectis naranyae* Ashmead (Hymenoptera: Ichneumonidae) was chosen for the following assessment as a potential candidate. *Itopectis naranyae* is a solitary parasitoid wasp with a wide biogeographic range in Asia [17, 18]. This parasitoid attacks pupae of lepidopteran pests of rice, including the rice leaf folder *Cnaphalocrocis medinalis* Guenée [18, 19]; the percentage of parasitism by *I. naranyae*

occasionally exceeds 50% of pupae of the rice leaf folder in autumn. *Itoplectis naranyae* therefore is an important natural enemy of the rice leaf folder. *I. naranyae* is readily recognized because of its size and body color and is easily mass-reared in the laboratory [20, 21]. Taken together, this parasitoid wasp can be a good candidate of indicator organisms among natural enemies.

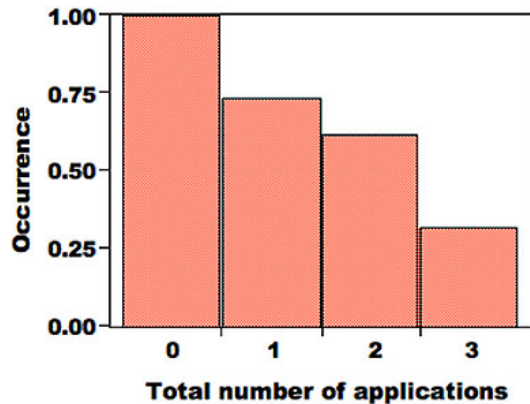


Fig. 2. Relationship between insecticide use and the occurrence of *Itoplectis naranyae* in farmers' rice paddies.

I. naranyae was detected in 28 out of 40 rice paddies (70.0%). The probability of its incidence was significantly related to pesticide use (Fig. 2; chi-squared test; $P = 0.032$); it was 100% in organic fields while only 33% of paddy fields with 3 times insecticide-applications supported the parasitoid. The abundance of *I. naranyae* differed significantly among rice paddies differing in insecticide applications (Fig. 3; GLM, $P = 0.018$). Rice leafroller *C. medinalis* was detected in all 40 rice fields, indicating that this pest widely occurred in the study area.

Rice leafroller *C. medinalis* is a major pest of rice in many Asian countries [21, 22]. It is ideal if the parasitoid complex of *C. medinalis* can play a significant role in suppressing this pest [21]. *I. naranyae* occurs widely and is very common in rice paddies (Fig. 2), suggesting the importance of the parasitoid as a natural enemy of rice leafroller. Farmers may benefit from protecting *I. naranyae* by reducing insecticide applications. Although reduction of insecticide use increases the density of rice leaf roller, the presence of parasitoids can keep the pest density to the below-economically injurious level (though the overall density of the pest will increase).

The density of *I. naranyae* was related to insecticide inputs (Fig. 3), indicating that *I. naranyae* was sensitive to chemical use. Alternatively, such a relationship may arise because its host *C. medinalis* is fewer in rice fields with higher inputs of insecticides. In any case, *I. naranyae* can reflect the extent of insecticide use, a major measure for environmental soundness of farming practice.

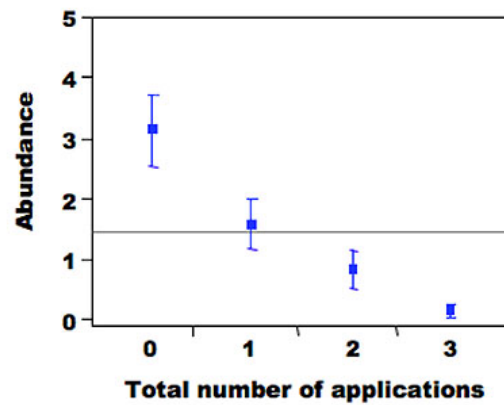


Fig. 3. Relationship between insecticide use and density of *Itoplectis naranyae* in farmers' rice paddies.

Itoplectis naranyae is readily recognized because it is relatively size and has a conspicuous body color; this species is one of the easiest parasitoids to recognize and identify among parasitoids recorded from rice paddies [21]. My unpublished data also have demonstrated that *I. naranyae* reflected overall arthropod diversity. Taken together, *I. naranyae* is a good ecological indicator of the environment of rice paddies and may be used as a bioindicator to examine whether natural enemies are preserved in rice paddies or to assess whether pesticide use is minimized.

C. Usefulness of bioindicator in rice paddies

In recent years, use of agro-chemicals has been largely reduced in rice paddies of Japan; in fact, the count of pesticide use was only three times at maximum in the study area. Nevertheless, the present results have given evidence that pesticide use harms beneficial natural enemies like *I. naranyae*. Inappropriate use of insecticides can increase the incidence of outbreak of some pests due to a combination of development of insecticide resistance and loss of natural control given by natural enemies [8, 9]. Reduction of insecticide use as possible would help conserving the community of natural enemies, allowing the avoidance of disruption of native ecosystems and agro-ecosystems. However, in the future study, we need to examine what extent we can reduce agrochemical use by considering the balance between rice production and biodiversity conservation.

Environmentally sound agriculture, which is often desired in terms of the production of safe food for humans, should be linked to the conservation of biodiversity by minimizing use of agrochemicals and other practices potentially harming the environments. The present study has demonstrated that natural enemies can be useful to assess what extent a given practice is friendly to the environment, on the basis of the diversity of natural enemies and the abundance of particular natural enemy species. Because biodiversity monitoring is time and labor consuming, it is desired to find indicator species that reflect both the level of biodiversity and environmentally sound practices. Natural enemies can be suitable for indicator species [10, 11] as shown in the present study with *I. naranyae*.

There are a number of subjects that should be focused in the future study. For example, it is crucial to highlight the importance of the surrounding environment such as ridge and vegetation areas around rice paddies. The enhancement of biodiversity in rice paddies would depend on biodiversity of the surrounding environment; after transplanting rice, many organisms including pests, natural enemies and neutral species immigrate to colonize rice paddies from the surrounding environment. The extension of urbanized areas causes a rapid change of rural areas, resulting in a decrease of vegetation around the areas. Also, urbanization causes fragmentation of the habitats. Habitat fragmentation and loss of vegetation area are both important factors leading to a decrease of biodiversity and a reduction of the power of natural control [12, 13]. Thus, focusing the importance of the environment around rice paddies together with the effect of farming practices is needed. This subject would be highlighted in future research.

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