Selection of indicator organisms for functional Agrobiodiversity in paddy ecosystems in Japan

Koichi Tanaka
National Institute for Agro-Environmental Sciences,
Kannondai 3-1-3, Tsukuba 305-8604, Japan
Email: tanaka@affrc.go.jp

Abstract

To select indicator organisms that can be used to evaluate the effects of environment-friendly agriculture on conservation and enhancement of biodiversity in agro-ecosystems, a research project “Selection of functional biodiversity indicators and development of assessment methods" has been conducted since 2008 in Japan. This paper outlines this research project and describes the procedure for selecting the candidates for indicator organisms. In paddy landscapes, the web-building spiders and wandering spiders were selected as nationwide-common indicator organisms and other several organisms were selected as regional-common indicators.

Key words: indicator organisms, functional biodiversity, environment-friendly agriculture, natural enemies.

Introduction

Conservation of biodiversity is one of the most important issues in the 21st century. The Convention on Biological Diversity (CBD) was adopted at the United Nations Conference on Environment and Development (UNCET, the Earth Summit) held at Rio de Janeiro, Brazil, in 1992. The tenth Conference of the Parties to CBD (COP10) was held at Nagoya, Japan, in October 2010. For terrestrial ecosystems, the most important direct drivers of change in ecosystem services in the past 50 years have been land cover alteration, particularly conversion to cropland, and the application of new technologies that have contributed to the increased supply of food, timber, and fiber (Millennium Ecosystem Assessment 2005). It is true that if rain forests or grasslands affording high biodiversity are converted to croplands, ecosystems will be altered to a considerable extent and biodiversity will be reduced. Agriculture, however, is the single largest use of land globally, accounting for some 36% of the world's land surface devoted to providing the primary produce (New 2005). Thus, it is not possible to conserve biodiversity or endangered organisms only in protected areas, and it is necessary to use agro-ecosystems to preserve them as well as natural ecosystems.

After the CBD was adopted, the National Biodiversity Strategy of Japan was drafted in 1995 by the Ministry of the Environment. This National Biodiversity Strategy was revised in 2002 and 2007, and its 2010 version was drafted in March 2010 (Ministry of the Environment of Japan 2010). As to biodiversity in agro-ecosystems, according to this strategy it is necessary to develop indicators of biodiversity that can be used to evaluate the effects of agricultural policies on the environment, including biodiversity, and to understand the role of agriculture in the conservation of biodiversity, which will enable people to agree to the promotion of such policies. The Ministry of Agriculture, Forestry and Fisheries also drafted a biodiversity strategy in 2007 containing the same description. The Basic Act on Biological Diversity was enacted in 2008. Policies concerning biodiversity should be implemented according to this act.

Humankind as well as all other organisms depends on ecosystem services and biodiversity contributes the important parts of ecosystem services or functioning (Hillebrand and Mathiessen 2009). We also can practice agriculture, depending on the ecosystem services including those supplied by genetic resources (or genetic diversity) for varieties of crop plants and livestock, soil organisms and microorganisms decomposing dead plants into organic matter, pollinators pollinating fruit trees, and natural enemies controlling outbreaks of crop pests. Biodiversity may play significant role of such specific function in agriculture and functional biodiversity that serves the specific function has attracted attention of agricultural researchers.

To promote sustainable agriculture, environment-friendly or environment- preserving farming systems have been developed and propagated in Japan as well as other countries. Sustainable agriculture is that in which agricultural productivity is compatible with the conservation of biodiversity. However, little is known about the effects of these farming systems on biodiversity in agro-ecosystems. To address this problem, a research project entitled "Selection of functional biodiversity indicators and development of assessment methods" was started in 2008 in Japan. In this paper, I outline this research project, particularly the research selecting indicator organisms in paddy landscapes.

Outline of the project: objectives and period

The objectives of this research project are to select indicator organisms that can be used to evaluate the effects of environment-friendly farming systems on the conservation and enhancement of biodiversity in agro-ecosystems, and to develop methods that can be applied at farms to assess the indicators. The project will be carried out for a period of five years. During the first two years, the 2008 and 2009 fiscal years, we selected candidates for indicator organisms. During the following three years, we have been determining the indicator organisms from their candidates and developing methods to survey them and to evaluate farms by using them.

Target organisms

The main target indicators to be selected are organisms beneficial to agriculture, such as natural enemies of crop pests. Such natural enemies consist mainly of arthropod predators and parasitoids. These functional groups include great numbers of diverse species. For example, predators and parasitoids accounted for 54% (Kobayashi *et al.* 1973) or 64% (Settle *et al.* 1996) of the species in arthropod fauna in paddy fields. In addition, they comprise intermediate trophic levels in a food web in which their populations are supported by diverse prey organisms at a lower trophic level. On the other hand, they sustain populations of a higher trophic level, e.g., vertebrates. Thus, the biodiversity of these functional groups (functional biodiversity) is considered to reflect the biodiversity of lower and higher trophic levels to some extent. In addition, these functional groups are useful for practicing environment-friendly farming, because they may control outbreaks of insect pests of crops, providing ecosystem services as natural pest control in these farms, in which the application of chemical pesticides should be reduced. Although we primarily focus on natural enemies as indicator organisms finally selected, we also survey various arthropods, including neutral organisms as well as crop pests, during our research period.

Composition of research

The project consists of two research groups: a group for the selection of indicator organisms and a group for the development of simple assessment and prediction methods. The former group is much larger than the latter.

Research group for selection of indicator organisms

This research group consists of two sub-groups. Some organisms are vulnerable to management, such as pesticide application, in crop fields. Their populations may be directly affected by the management of each field plot; consequently, their population levels may differ among field plots that are managed differently. Other organisms move among a wide range of fields or use different sites as habitats within a landscape. Their populations may fluctuate at the landscape level. Hence, in this project, biodiversity is analyzed at both crop field and landscape levels, and thus this research group consists of two sub-groups. In this chapter, I describe the outline of the sub-group that analyzes biodiversity at the landscape level. The other sub-group is delineated by Ihara *et al.* (the next chapter).

The locations of the study areas for this sub-group are shown in Fig. 1. The Japanese Islands extend over a long distance in the north-south direction. Consequently, there are wide ranges of fauna and flora. To cover the whole country, this group has carried out case studies in each of six regions, including representative landscapes (mostly paddy field landscapes).

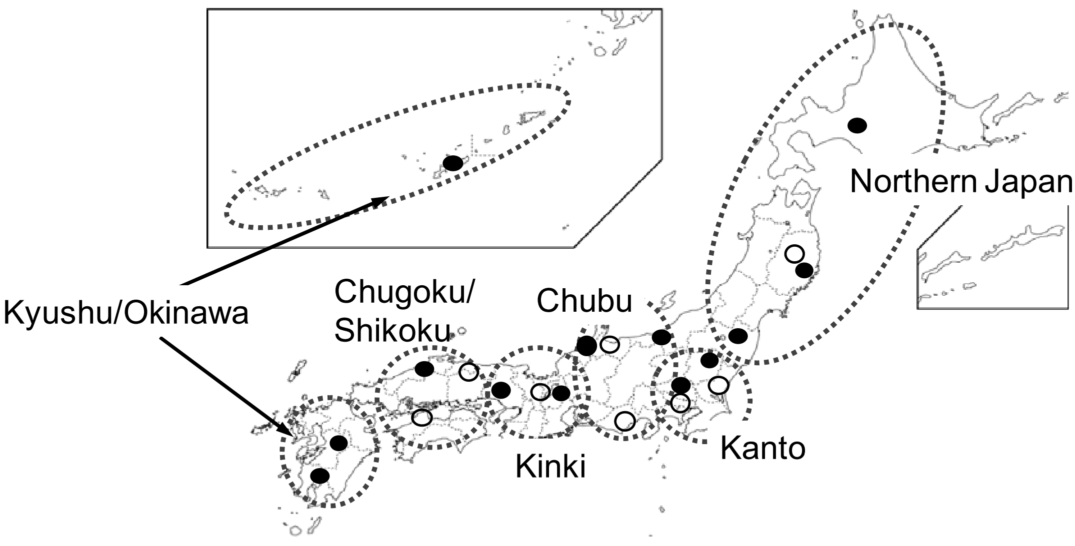

Fig.1. Locations of the study areas for landscape-level research.
●: study areas including representative landscapes in each region,
○: various agricultural study areas including suburban areas, vegetation-managed areas and grasslands.

It has ... eas,

vegetation-managed areas, and grasslands. Vegetation-managed areas are those where vegetation surrounding crop fields or vegetation during fallow periods is managed in different ways, such as by using ground-cover plants.

Methods for selecting indicator organisms

In this research, the basic methods for selecting candidates for indicator organisms were as follows. (1) First, we selected areas where environment-friendly farming was practiced and areas where conventional farming was practiced. (2) Secondly, we surveyed organisms (mainly insects and spiders) in several field plots in the selected areas. (3) We then compared species and the abundance of the organisms between the selected areas. (4) Finally, we selected more-abundant organisms in environment-friendly farming areas as candidates for indicator organisms.

For these surveys of organisms, the same basic census methods were used. For the paddy landscapes, the following census methods were applied: (1) visually observing and counting arthropods on the rice plants, (2) sweeping rice plants with a sweep net, (3) sweeping vegetation surrounding the study fields with a sweep net, (4) beating rice plants so that arthropods fall onto a sticky board or into an insect net, (5) using pitfall traps to collect arthropods wandering on the levees, (6) dipping a D-flame net into paddy water to capture aquatic insects, (7) visually observing and counting frogs on and around the paddy levees, and (8) using a route census to count large insects and frogs by walking along a canal edge, farm road and levee for a total of ca. 1,000 m.

Research group for development of simple assessment and prediction methods

I briefly delineate this research group although I do not discuss the research of this group in this paper. This research group also consists of two sub-groups: a group for developing simple assessment methods and a group for understanding and predicting the functional biodiversity of an entire country. Objectives of the former sub-group are to develop simple methods to (1) identify indicator organisms, (2) survey indicator organisms by establishing efficient monitoring and effective trapping methods, and (3) preserve indicator organisms in the laboratory.

The objectives of the group for understanding and predicting the functional biodiversity of an entire country are to (1) construct a system that efficiently collects and accumulates data obtained in the research group for the selection of indicator organisms, (2) analyze these data at an entire country level, and (3) develop methods to predict changes in biodiversity caused by alteration in agricultural environments, such as agricultural practices and landscape structures.

Data obtained in the project

Here I describe the characteristics of the data obtained by the research group for the selection of indicator organisms. The study areas of this research group cover a wide range of the Japanese Islands, as they include 25 of Japan’s 47 prefectures (Fig. 1 and Fig. 1 of the next chapter). The surveys were carried out basically in cultivated fields, i.e., on farms. Quantitative data on the biodiversity of agro-ecosystems in Japan are lacking (Yamamoto and Kusumoto 2008). Thus, the data obtained in the project are important, representing the present status of arthropod biodiversity in Japanese farmlands. Our research group has, however, investigated organisms primarily within farms, although it has also surveyed around farms, such as vegetation on levees, farm road margins and slope faces surrounding paddy fields, and has carried out route censuses. The management of study field plots, including application of chemical and organic fertilizers and chemical pesticides, was recorded. Thus, the biodiversity and abundance of the surveyed organisms can be analyzed in relation to the management of study fields. The same survey methods were used as a rule to investigate the fields of each crop as described above, which enabled us to compare the data among different areas and regions. During the first two years of the research period, diverse taxa of arthropods were investigated. Beginning in the third year, we have focused on the candidates for indicator organisms. Hence, detailed biodiversity data were obtained during the first two years.

Procedure for selecting candidates for indicator organisms

To select the candidates for indicator organisms, the biodiversity and abundance of organisms were surveyed and analyzed in each study area during the fiscal years 2008 and 2009. A total of more than 2 million individuals (primarily arthropods) were captured and identified in all the study areas in each year.

Two steps in the screening of these organisms were taken to select the indicator candidates. The first step in screening was carried out by the researchers responsible for each study area and the working group consisting mainly of team leaders and sub-team leaders. In the first step, basically (1) the candidates for indicator organisms were considered at the species level of taxa, and (2) they were significantly more abundant in the environment-friendly areas than in the control conventional areas using statistical tests. For the statistical tests, many species were studied; this led to the problem of multiple tests. Thus, the significance level should be corrected. However, there is a paradox or problem where, as one performs a more detailed analysis, such as more statistical tests for larger numbers of species, the probability of finding a significant result declines if correction of significance level, such as the sequential Bonferroni correction, is applied (Moran 2003). At this screening, to adopt rather many species as indicator candidates, each species was tested without correction of the significance level. Examples of such statistical tests are shown in Figs. 2 and 3. This study area was located in Tochigi Prefecture, the Kanto District, eastern Japan, and consisted of four study sites. Each study site involved environment-friendly paddy fields (no pesticides) and conventional paddy fields. Species richness, i.e., the number of species, among spiders (Araneae) was significantly greater in the environment-friendly paddy fields than in conventional paddy fields (Fig. 2).

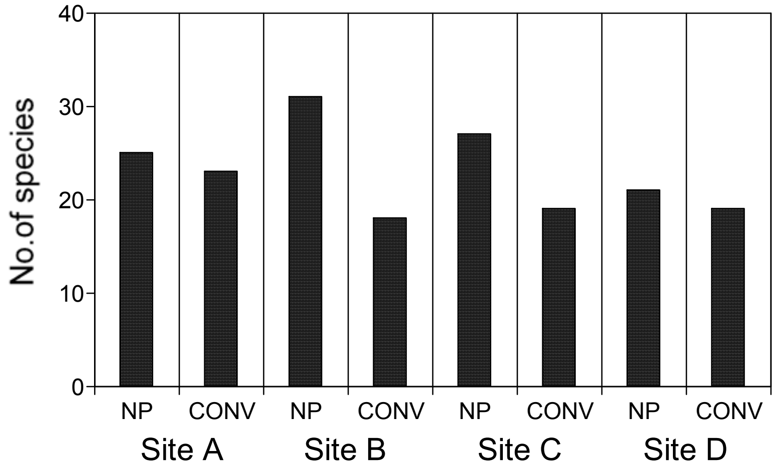

Fig. 2. Example of data on species richness: the mean number of spider species captured by sweeping the rice plants with a sweep net in the environment-friendly (no pesticide: NP) and the conventional (CONV) paddy fields at four study sites in Tochigi Prefecture, the Kanto District. There were significant differences in species richness between farming systems (NP and CONV) ($P<0.001$) but no significant difference among study sites ($P>0.05$) using 2-way ANOVA. (Tanaka *et al.*, unpublished data)

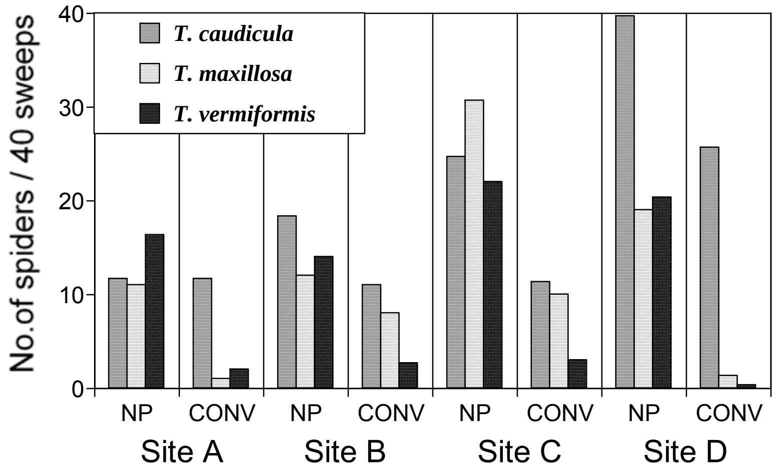

Fig. 3. Example of data on abundance of organisms: the mean number of individuals of *Tetragnatha* spiders captured by sweeping the rice plants with a sweep net. The study sites are the same as Fig. 2. There were significant differences in abundance of each spider species between farming systems ($P<0.01$) and among study sites ($P<0.01$ except *T. vermiformis*) using 2-way ANOVA. (Tanaka *et al.*, unpublished data)

In addition, several spider species were significantly more abundant in the environment-friendly paddy fields than in the conventional ones (Fig. 3) (Tanaka *et al.*, unpublished data). Thus, we concluded that these spiders could be adopted as candidates for indicator organisms. Other organisms also differed significantly in abundance between differently managed paddies in this study area.

The working group performed the second step of screening, in which they considered the suitability of focal organisms as indicators (e.g., beneficial for agriculture and representative of each habitat) by using information from the literature. They also grouped several species at an appropriate taxon higher than species for practical purposes. In addition, the working group selected candidates for the nationwide-common indicators that can be applied to many regions in the entire country and those for the regional-common indicators applied to specific regions (Fig. 4).

Candidates for indicator organisms in paddy landscapes

In paddy landscapes, the selected nationwide-common indicators include the web-building spiders inhabiting the upper parts of rice plants, e.g., *Tetragnatha* spp. (Tetragnathidae), *Neoscona adianta* and *Larinioides cornutus* (Araneidae), and the wandering spiders dwelling on the lower parts of rice plants and water or ground surfaces, e.g., *Pardosa pseudoannulata* and *Pirata subpiraticus* (Lycosidae) (cf. Murata and Tanaka 2004).

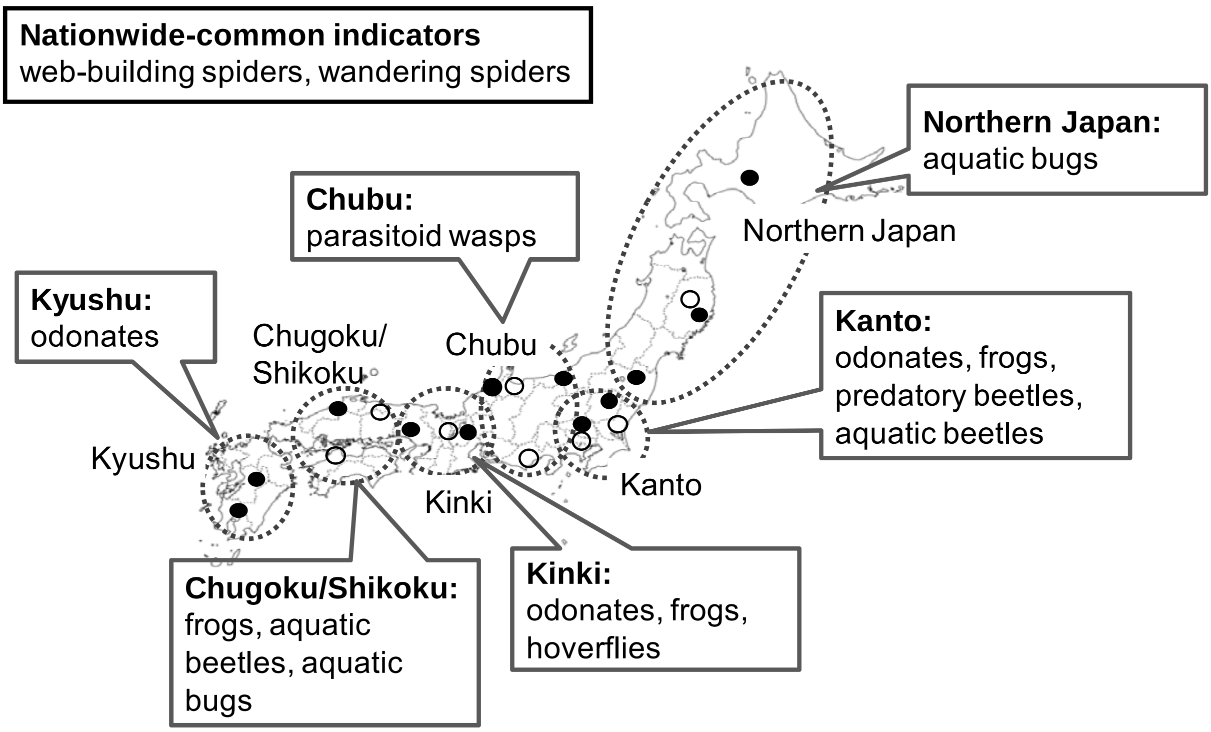

Fig. 4. Candidates for nationwide- and regional-common indicator organisms for paddy landscapes.

The web-building spiders on the upper parts of rice plants were captured by a sweep net, and the wandering spiders on the lower parts were caught by beating the rice plants or found by visually observing rice plants. *Tetragnatha* spiders were especially common, since they were selected as indicator candidates in all 13 study areas of paddy landscapes. These spiders were more susceptible to insecticides than other spiders, e.g., lycosids and linyphiids (Tanaka *et al.* 2000). Thus, they may be vulnerable to insecticide application and consequently to conventional management of paddy fields.

On the other hand, the regional-common indicators are odonates (*Sympetrum* dragonflies and coenagrionid damselflies), frogs (*Rana* and *Hyla*), hoverflies (Syrphidae), aquatic beetles (Dytiscidae and Hydrophilidae) and aquatic bugs (Hemiptera). The abundance of these animals differed among regions or study areas, and hence may be common regionally.

Perspective of utilization of indicator organisms

The candidates for indicator organisms were determined by the two-year research phase as mentioned above. In the third year, our project started the second phase of research. We are focusing on the selected candidates for indicators as target organisms to be investigated and surveying them in more study areas to examine whether or not the candidates can be applied to these areas and are suitable for indicators. That is, we are determining whether or not they exactly represent the effects of environment-friendly farming. In addition, we will develop simple and efficient techniques to survey indicator organisms and standard methods to evaluate farms using the indicators. Finally, we will determine the indicator organisms if they prove to be suitable for indicators, and will establish the methods for surveying and evaluating them. We will also prepare a manual that describes the methods of identifying, surveying and evaluating the indicators.

At present, it is undecided how the indicators will be utilized for any agricultural policy, scheme or program. However, they are expected to be used for several objectives. First, they can be used to assess the effects of agricultural policies or programs that attempt to preserve environments, including the conservation and enhancement of biodiversity in agro-ecosystems. For example, they have been used to assess the effects on biodiversity of an agricultural program, called "the farmland, water and environment preservation and improvement measures", that has been implemented by the Ministry of Agriculture, Forestry and Fisheries of Japan. Several study areas of our project involve areas covered by this program. The candidates for indicator organisms were more abundant in these areas than in their control conventional-farming areas. These results are to be used for assessment of this program.

Secondly, the indicators are expected to be used as criteria for determining subsidies to farmers who practice environment-friendly farming, although there is no such subsidy in Japan now. In the European Union, which implements an agri-environmental scheme, subsidies are given to farmers who practice some options of agricultural activities to conserve and enhance biodiversity in farmlands. Most of the payments are based on measure-oriented options, i.e., those in which farmers apply certain measures that will enhance biodiversity in their farms. In Switzerland (Jeannerett *et al.* 2003) and the German state of Baden-Württemberg (Wittig *et al.* 2006), a few payments are based on result-oriented options in which farmers count indicator organisms in their farms. Other possible utilization of indicator organisms is proposed by Ihara *et al*. (the next chapter).

Acknowledgements

I thank Prof. Nakasuji, the leader of this research project, for his advice, discussions and encouragement throughout the research. This research project was supported by the Grant-in-Aid from the Ministry of Agriculture, Forestry and Fisheries of Japan (Selection of functional biodiversity indicators and development of assessment methods 1211-1271).

References

Hillebrand, H. and B. Mathiessen. 2009. Biodiversity in a complex world: consolidation and progress in functional biodiversity research. *Ecology Letters* 12: 1405-1419.

Jeannerett, P., B. Schupbach, L. Pfiffner, F. Herzog and T. Walter. 2003. The Swiss agri-environmental programme and its effects on selected biodiversity indicators. *Journal for Nature Conservation* 11: 213-220.

Kobayashi, T., Y. Noguchi, T. Hiwada, K. Kanayama and N. Maruoka. 1973. Studies on the arthropod associations in paddy fields, with particular reference to insecticidal effect on them. I. General composition of the arthropod fauna in paddy fields revealed by net-sweeping in Tokushima Prefecture. *Kontyû* 41: 359-373. (in Japanese with English summary).

Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC, U.S.A.

Ministry of the Environment of Japan. 2010. *The National Biodiversity Strategy of Japan 2010*. Ministry of the Environment of Japan, Tokyo, Japan.

Moran, M.D. 2003. Arguments for rejecting the sequential Bonferroni in ecological studies. *Oikos* 100: 403-405.

Murata, K. and K. Tanaka. 2004. Spatial interaction between spiders and prey insects: horizontal and vertical distribution in a paddy field. *Acta Arachnologica* 53: 75-86.

New, T.R. 2005. *Invertebrate Conservation and Agricultural Ecosystems*. Cambridge University Press, Cambridge, U.K.

Settle, W.H., H. Ariawan, E.T. Astuti, W. Cahyana, A.L. Hakim, D. Hindayana, A.S. Lestari, Pajarningshih and Sartanto. 1996. Managing tropical rice pests through conservation of generalist natural enemies and alternative prey. *Ecology* 77: 1975-1988.

Tanaka, K., S. Endo and H. Kazano. 2000. Toxicity of insecticides to predators of rice planthoppers: spiders, the mirid bug and the dryinid wasp. *Applied Entomology and Zoology* 35: 177-187.

Wittig, B., A.R. gen. Kemmermannb and D. Zachariasc. 2006. An indicator species approach for result-orientated subsidies of ecological services in grasslands: a study in Northwestern Germany. *Biological Conservation* 133: 186-197.

Yamamoto, S. and Y. Kusumoto. 2008. Strategy of biodiversity inventory for quantitative assessment of rural environmental change. *Journal of Rural Planning* 27: 26-31. (in Japanese).