Functional Biodiversity Indicators and their Evaluation Methods in Japanese Farmlands

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Abstract

To mitigate the detrimental environmental effects of modern agriculture, such as those from chemical fertilizers and pesticides, environmentally friendly farming systems have been developed and propagated. Such farming systems are expected to conserve both the wildlife inhabiting agroecosystems and overall biodiversity. However, actually little is known about the effect of environmentally friendly farming systems on biodiversity in agroecosystems. To address this issue, the research project “Selection of functional biodiversity indicators and development of assessment methods” was conducted in Japan across the 2008–2011 fiscal years. After the conclusion of this project in March 2012, a manual was published that describes indicator animals and explains the survey and evaluation methods used. This paper outlines the research project and describes some examples of the manual’s contents.

Keywords: environmentally friendly farming, indicator animals, manual, parasitoids, predators

1. Introduction

Numerous species have become extinct during the last 100 years, and extinction is occurring at a higher rate than ever before–more than 1000-fold that of the prehistoric mass extinction. Therefore, the 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 (“the Earth Summit”) held at Rio de Janeiro, Brazil, in 1992. The 10th Conference of the Parties to CBD (COP10) was held at Nagoya, Japan, in October 2010. Following this meeting, biodiversity has become a term familiar to the Japanese population. However, Japanese citizens often say that they do not fully understand biodiversity or its usefulness. Indeed, people worldwide benefit from organisms and ecosystems, and these benefits are called ecosystem services. Biodiversity provides various ecosystem services such as food, fiber, and medical substances (together representing provisioning services), as well as climate control, flood control, and water purification (regulation services) (Millennium Ecosystem Assessment, 2005).

After the CBD was adopted, the National Biodiversity Strategy of Japan (NBSJ) was drafted in 1995 by the Ministry of the Environment. The NBSJ was revised in 2002, 2007, and 2010, and the 2012–2020 version was drafted in 2012 (Ministry of the Environment of Japan, 2012). The NBSJ defined four factors that threaten biodiversity and cause its crises: (1) human activities including development; (2) reduced human activities; (3) artificially introduced factors; and (4) changes in the global environment. The second and third crises are particularly relevant to agriculture. Representative of the second crisis is the loss of biodiversity in rural landscapes known as *satoyama,* a loss caused by the abandonment of management of farmlands and surrounding lands. The third crisis concerns invasive alien species and agrochemicals. For the conservation of biodiversity in agroecosystems, the NBSJ states that it is necessary to develop biodiversity indicators that can be used to evaluate the effects of agricultural policies on the environment and to improve our understanding of the role agriculture plays in biodiversity conservation. This will encourage citizens to agree to the promotion of such policies. The Ministry of Agriculture, Forestry and Fisheries also drafted a biodiversity strategy in 2007 and revised it in 2012, which contains the same description.

Agroecosystems have occasionally provided habitats for wildlife, including some endangered species. However, modern agriculture commonly has a detrimental effect on the environment, such as through the use of chemical fertilizers and pesticides. To mitigate such effects, environmentally friendly farming systems have been developed and propagated in Japan, as well as in other countries. These environmentally friendly farming systems are expected to conserve both the wildlife inhabiting agroecosystems and overall biodiversity. However, actually little is known about the effect of these farming systems on biodiversity in agroecosystems. To address this issue, a research project entitled "Selection of functional biodiversity indicators and development of assessment methods" was conducted in Japan. After the conclusion of this project in March 2012, a manual was published that describes indicator animals and explains the survey and evaluation methods used (AFFRC, NIAES and NIAS, 2012). A PDF of the manual is available [in Japanese] at the website of the National Institute for Agro-Environmental Sciences (http://www.niaes.affrc.go.jp/techdoc/shihyo/). In this paper, I outline the research project and describe some examples of the manual's contents. In addition, I discuss the use of the identified indicators.

2. Objectives and Outline of the Research Project

The objectives of the research project were to develop practical methods for evaluating the effects of environmentally friendly farming systems on conservation and enhancement of biodiversity, by identifying key indicator animals.

The main target indicators to be selected are organisms beneficial to agriculture, specifically natural enemies of crop pests. Such natural enemies consist mainly of arthropod predators and parasitoids. These functional groups account for a significant proportion of the species richness recorded; for example, predators and parasitoids accounted for 54% (Kobayashi et al., 1973) or 64% (Settle et al., 1996) of the arthropod species richness in paddy fields. The intermediate trophic levels in the food webs are comprised of these predator/parasitoid functional groups and are supported by a diverse range of prey species at lower trophic levels. Simultaneously, species at higher trophic levels (e.g., vertebrates) are sustained by the abundance and diversity of these same predator/parasitoid functional groups. Thus, the biodiversity of these functional groups (functional biodiversity) is considered to represent the biodiversity of lower and higher trophic levels to some extent, especially lower trophic levels (i.e., prey species). In addition, these functional groups are useful in the practice of environmentally friendly farming, as they provide the ecosystem service of natural pest control, thus reducing the need for the use of chemical pesticides. Although the primary focus on natural enemies was as indicators, various other arthropods were also surveyed during the research period, including neutral species and crop pests.

The research project was carried out for four years, across the 2008–2011 fiscal years. During the first two years, candidate indicator animals were selected. During the final two years, the indicator animals were chosen from these candidates and methods were developed to survey and evaluate farms.

The basic methods of selecting indicator candidates were as follows. First, crop fields covering both environmentally friendly farming and conventional farming practices were selected. Next, animals (mainly insects and spiders) were surveyed in the selected crop fields. The fauna and abundance of the animals were then compared between the selected fields. Finally, animals found in greater abundance within environmentally friendly farming fields than in conventional ones were selected as candidates for indicator animals. During the final two years of the research period, the research team focused on investigating the selected indicator candidates by surveying for them in additional crop fields. We examined the appropriateness of candidate animals as indicators, specifically how well they represent the effects of environmentally friendly farming, the ease of surveying for them in farmlands, and the ease of identification. The team also attempted to establish simple methods for surveying them and appropriate methods for evaluating them.

Seven national institutes, seven universities, and 26 prefectural institutes participated in this research project. The study sites consisted of rice paddy fields, orchards, and vegetable fields located throughout Japan (Fig. 1). The orchards and vegetable fields included citrus groves; orchards (apple, Japanese pear, and peach); tea gardens; and cabbage, eggplant, green onion, and soybean fields. Each study area was located in a major region for the production of each crop in Japan.

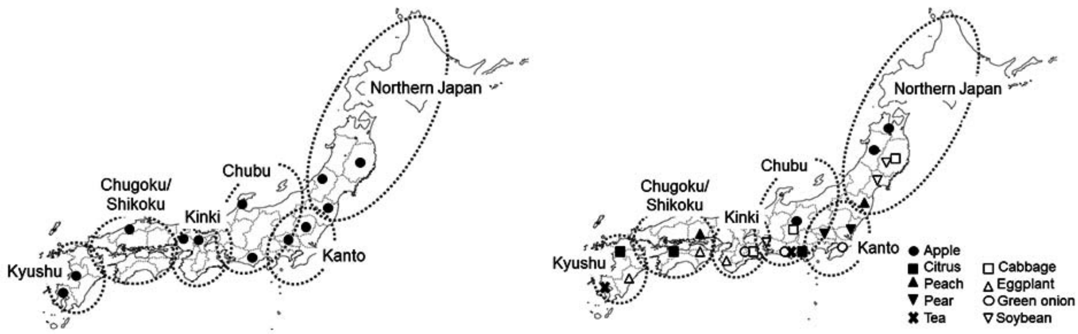

Fig. 1 Locations of the study areas for rice paddy fields (left) and orchards and vegetable fields (right).

3. Indicator Animals and their Evaluation Methods

1) Indicator Animals

Indicator animals were selected for each crop and for each of the six regions of Japan (Table 1). They were grouped by two field types: rice paddy fields and upland crop fields (including orchards and vegetable fields). Most indicator animals are not single species but rather taxonomic or functional groups consisting of several or more species, such as lycosid spiders and predatory lady beetles. The reason for defining them as such groups was to make identification easier. If the indicator were a single species, people who are not experts in taxonomy would not reliably be able to accurately identify it to the species level. Additionally, identification of a single species from many individuals observed or collected in the field will be time-consuming work even for expert researchers. Table 1 shows common animal names that correspond to high-level taxonomic groups and consequently contain many species. Importantly, however, these names do not cover all species included within those groups, but do represent some specific groups corresponding to each region. For example, dragonflies/damselflies (order Odonata) for paddy fields represent several dragonfly species of the genus *Sympetrum* or several damselfly species of the family Coenagrionidae as described below.

The indicator animals were classified into two categories based on the region in which they can be applied. Nationally common indicators can be applied to most regions in Japan, whereas regionally common indicators can be applied only to specific regions in Japan. The Japanese Islands extend a long distance in the north–south direction, thus encompassing regions with

Table 1 Nationally and regionally common indicator animals for paddy fields and orchards/vegetable fields (AFFRC, NIAES and NIAS, 2012)

Region	Paddy fields	Orchards/ Vegetable fields
Nationally common	*Tetragnatha* spiders, lycosid spiders	ground-dwelling beetles, spiders
Northern Japan	dragonflies/damselflies, frogs, aquatic beetles/bugs	parasitoid wasps, predatory lady beetles, hoverflies, ants, predatory mites
Kanto	dragonflies/damselflies, frogs, aquatic beetles/bugs	parasitoid wasps, predatory stinkbugs, predatory mites
Chubu	dragonflies/damselflies, frogs, aquatic beetles	parasitoid wasps, predatory lady beetles, predatory stinkbugs, ants, predatory mites, earwigs
Kinki	damselflies, frogs, aquatic beetles	parasitoid wasps, predatory stinkbugs
Chugoku/Shikoku	frogs, aquatic beetles/bugs	parasitoid wasps, predatory lady beetles, staphylinid beetles, ants, predatory mites
Kyushu	dragonflies/damselflies, aquatic beetles	predatory lady beetles, predatory stinkbugs, staphylinid beetles

substantially different climatic conditions. It is surprising, therefore, that some indicator animals are relevant to most regions in Japan, despite the different climatic conditions across the regions.

In paddy fields, two groups of spiders were selected as the nationally common indicators (Fig. 2). One is the *Tetragnatha* spiders belonging to the genus *Tetragnatha*. Eight species of *Tetragnatha,* including *T. maxillosa, T. caudicula,* and *T. extensa,* are dominant in paddy fields in Japan, with different species compositions depending on regions or climatic conditions (Tanaka and Baba, unpublished data). They are web-building spiders that inhabit the upper parts of rice plants and construct horizontal orb-webs. The other group contains spiders belonging to the family Lycosidae. Two lycosid species, *Pardosa pseudoannulata* and *Pirata subpiraticus,* are dominant in paddy fields in Japan (Tanaka and Baba, unpublished data). They are wandering spiders that dwell on the lower parts of rice plants, as well as on the water surface or ground surface. Both of these groups of spiders are abundant in paddy fields and known as important predators of rice pests (Kiritani et al., 1972; Takada et al., 2012). *Tetragnatha* spiders were especially common, and they were selected as indicator candidates for paddy fields in all study areas. The *Tetragnatha* spiders are more susceptible to insecticides than other spiders (Tanaka et al., 2000), and, consequently, they may be more vulnerable to conventional management of paddy fields.

For orchards and vegetable fields, two groups of arthropods were selected as the nationally common indicators (Fig. 3). The first is ground-dwelling beetles, mostly ground beetles of the family Carabidae such as *Amara chalcites* and *Chlaenius micans.* The second group is spiders that wander on the ground (including some members of the family Lycosidae), construct webs on plants (including Araneidae and Agelenidae), or live directly on plants (including Thomisidae and Salticidae). The selected nationally common indicators are all generalist predators and are abundant in farmlands throughout Japan; they apply to most regions in Japan.

The regionally common indicators in paddy fields include dragonflies/damselflies (Odonata), frogs, aquatic beetles (Coleoptera), and aquatic bugs (Hemiptera). The research team focused primarily on arthropod predators and parasitoids as indicators. However, we did select some frogs as indicators, because several species of frogs are abundant in paddy fields, and they are predators of rice insect pests. In addition, they are paddy-dwelling animals familiar to Japanese people. For the orchards and vegetable fields group, regional indicators include parasitoid wasps,

Fig. 2 Examples of nationally common indicators, the *Tetragnatha* spider (left) and the lycosid spider (right), for paddy fields.

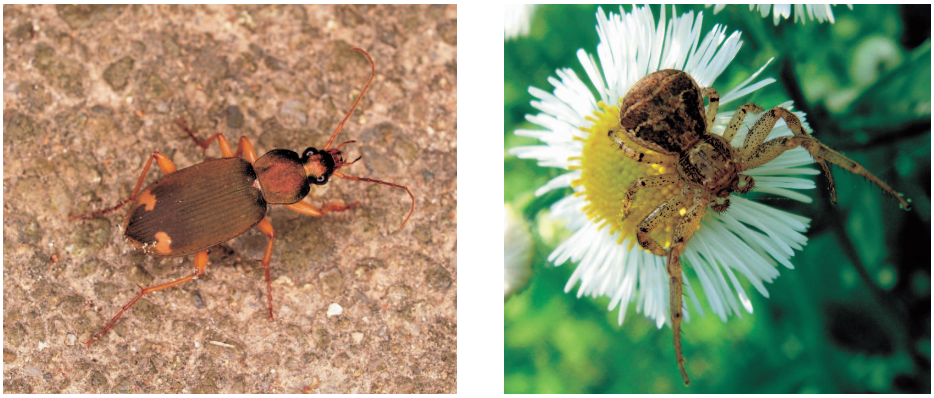

Fig. 3 Examples of nationally common indicators, a ground-dwelling beetle (left) and a spider (right), for orchards and vegetable fields.

predatory lady beetles, predatory stinkbugs, hoverflies, ants, predatory mites, and staphylinid beetles. The abundance of these animals differed between regions, and hence they may be common regionally.

2) Survey and Evaluation Methods

When surveying fields in a region, both the nationally common and the common indicators specific to the region should be used. Next, fields should be surveyed and evaluated according to the methods specified for each indicator, crop, and region. An example applied to the paddy fields in the Kanto region is given in Table 2, which shows the indicator animals, methods of surveying, and methods for scoring based on the survey results. The indicator animals in the example belong to five groups. Two of the groups are nationally common indicators, (1) *Tetragnatha* spiders and (2) lycosid spiders; three are regionally common indicators, (3) *Sympetrum* dragonflies (adults or nymphal exuviae) or coenagrionid damselflies (adults), (4) frogs of the *Pelophylax porosus porosus* or *Rana japonica* species group, and (5) aquatic beetles (Coleoptera) and aquatic bugs (Hemiptera). For (3) odonates and (4) frogs, we have an option to choose between two groups. These options are provided because the abundances of the alternative groups differed between environmentally friendly farms and conventional farms. In some areas, however, the population of either group was small, and in this case there was little difference in its abundance between farms. Providing a choice of a more abundant group from two alternative groups allows us to appropriately evaluate the farms in the area. In addition, for the *Sympetrum* dragonflies, we have an option to choose adults or nymphal exuviae (Fig. 4). The *Sympetrum* adults disperse from the paddy fields after they emerge in early summer. The nymphal exuviae usually remain on rice plants even after their dispersal. Therefore, a count of nymphal exuviae can be more representative of abundance than the number of adults recorded in a field. However, it may be rather difficult for non-experts to find nymphal exuviae; the investigators should choose between the two groups depending on their own abilities. For group (5), aquatic beetles (Coleoptera) and aquatic bugs (Hemiptera), we must survey both groups.

Table 2 Indicator animals, survey methods, and scores to evaluate the surveyed fields applied to paddy fields in the Kanto region (AFFRC, NIAES and NIAS, 2012)

Indicator animals	Survey method	Survey sites in a field plot	Score†		
			0	1	2
(1) *Tetragnatha* spiders	Sweeping rice plants with a sweep net	20 sweeps × 2 sites	<5	5–15	≥15
(2) Lycosid spiders	Visually counting spiders on rice plants	5 rice hills × 4 sites	<3	3–9	≥9
(3) *Sympetrum* dragonflies (adults or nymphal exuviae) or Coenagrionid damselflies (adults)	Visually counting odonates on and around rice plants along a paddy levee	10 m × 4 sites	<1	1–3	≥3
(4) *Pelophylax porosus porosus* or *Rana japonica* species group	Visually counting on and around paddy levees	10 m × 4 sites	<3	3–9	≥9
(5) Aquatic beetles (Coleoptera) and Aquatic bugs (Hemiptera)	Dipping a D-frame net into paddy water along a paddy levee	5 m × 4 sites	<1	1–3	≥3

† Score is given based on the abundance of each animal surveyed.

Fig. 4 An adult (left) and nymphal exuviae (right) of *a Sympetrum* dragonfly.

This is because the combined abundance of both groups more accurately reflects the effects of environmentally friendly farming than does the data from only one of these groups.

Once the indicator animals to be surveyed in the study fields are known, they should be identified from among the animals living there. The manual includes pictures of representative indicators and describes simple keys to identify them. Figure 5 shows an example identification key for *Tetragnatha* spiders. They have a characteristic morphology, that is, long jaws and long/thin body and legs. Thus, they can be easily distinguished from other spiders. Next, investigators should learn the specific techniques to survey for the indicator animals in the fields. Table 2 shows the names of survey methods and the survey sites in a field plot. The manual includes details of necessary equipment and fully explains the survey methods. For example, sweeping rice plants using an insect net should be the method used to collect *Tetragnatha* spiders (Fig. 6), whereas pitfall traps should be used to capture ground-dwelling beetles and spiders (Fig. 7).

After the survey data are obtained, the fields are evaluated by assessing the abundance data collected for the indicator animals. Continuing with the Kanto example (Table 2), we find a score

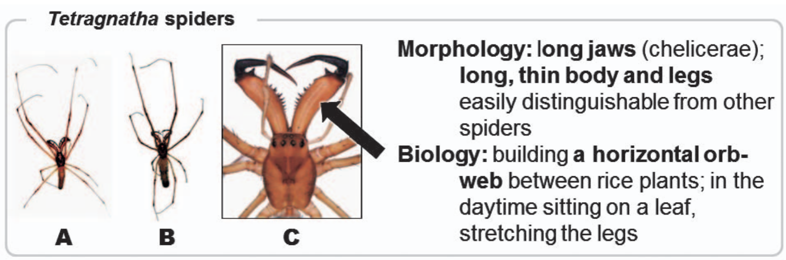

Fig. 5 Simple keys to identify *Tetragnatha* spiders. A: male, B: female, C: cephalothorax. The arrow indicates a long jaw.

Fig. 6 Sweeping rice plants with a sweep net for surveying Tetragnatha spiders in paddy fields.

Fig. 7 A pitfall trap for surveying ground-dwelling beetles and spiders in orchards and vegetable fields. A plastic dish is placed above the trap to prevent rain from falling into it.

for each of the five indicator animals, referring to the abundance data. The score ranges from 0 to 2. This scoring is based on the results of investigations on the candidate indicator animals across many study sites during the last two years of the overall project. We assigned the abundance limit for each candidate that discriminates between environmentally friendly farms and conventional farms. This number was designated as the discriminant abundance. When abundance was within a certain range around the discriminant abundance, a score of 1 is awarded; a score of 2 is awarded for the abundance higher than the range, and 0 for the abundance lower than the range. After the score for each indicator animal is obtained, the scores are summed to obtain the overall score. Finally, the grade of the surveyed fields is calculated based on the overall score, as shown in Table 3. The number of groups of indicator animals to be surveyed depends upon the region and the crops being evaluated (e.g., five groups for paddy fields in the Kanto region). The overall score depends on the number of indicator groups.

Table 3 Grading based on overall score (AFFRC, NIAES and NIAS, 2012)

No. of groups of indicator animals	Grade†			
	S	A	B	C
1	2	1	0	—
2	4	2–3	1	0
3	5–6	3–4	1–2	0
4	7–8	4–6	2–3	0–1
5	8–10	5–7	2–4	0–1
6	10–12	6–9	3–5	0–2
7	11–14	7–10	3–6	0–2
8	13–16	8–12	4–7	0–3
9	14–18	9–13	4–8	0–3
10	16–20	10–15	5–9	0–4
11	17–22	11–16	5–10	0–4

† Each grade shows evaluation and recommendations as follows:
S: Biodiversity is high. Continue efforts to practice environmentally friendly farming.
A: Biodiversity is relatively high. Continue efforts to practice environmentally friendly farming.
B: Biodiversity is relatively low. It is desirable to improve the present farming toward environmentally friendly practices.
C: Biodiversity is low. It is desirable to improve the present farming toward environmentally friendly practices.

4. Perspective on the Use of Indicator Animals

Indicator animals were selected and their evaluation methods were determined based on the survey results from many study sites throughout Japan. For each crop, however, the number of study sites was not sufficient to allow adequate data collection. This meant that some regions were not surveyed for particular crops. Further investigations are required to confirm the validity of the indicators and their evaluation methods in those regions and prefectures that have not yet been surveyed. In addition, animal populations fluctuate yearly and vary regionally depending on local climatic conditions and surrounding landscapes. It is also important to investigate the effects of these factors on abundance of indicator animals and on this evaluation system.

It is expected that the manual and its description of using indicator animals will be utilized for agricultural management, including the creation of policy and providing guidance on the scope and extent of activities and site choice for relevant programs. Indicators can be used to assess the effects of agricultural activities that attempt to preserve environments. For this purpose, we will survey the indicators in areas where such activities are practiced. Indicators can also help us to utilize functional biodiversity efficiently in order to aid environmentally friendly farming. For this purpose, farmers or technical instructors will monitor the indicators and adjust farming practices to conserve and enhance beneficial indicator groups, such as those that comprise natural enemies to crop pests. These practices will enhance existing pest control.

These uses are expected to have several positive effects on the public. Consumers will better understand the positive effects of environmentally friendly farming, increasing the purchase of these crops. Farmers, working with the help of natural enemies to control crop pests, can take more pride in their farming. For example, a group of farmers who were practicing environmentally friendly farming in rice paddy fields surveyed the indicator animals according to the manual. The evaluation of their fields resulted in a grade of A (see Table 3). They created an appropriate label for this grade and labeled their packages of rice accordingly. This rice could be sold at a higher price than standard rice produced by conventional farming. In addition, a subsidy has been provided to the farmers who practice environmentally friendly farming. However, at present, options of farming practice for which the subsidy is paid are still restricted. It is expected that the use of indicators and the resulting effects described here will promote the use of environmentally friendly agriculture.

Acknowledgement

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