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Monitoring of Arthropod Diversity in Agroecosystem

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ABSTRACT

Biodiversity is important for ecosystem functioning and services. It in recent decades has been seen as an indicator of ecosystem quality and become a general conservation value. For agroecosystems, there have been growing encouragements on enhancing biodiversity through incorporating into natural ecosystem characteristics as well as reducing human inputs. Monitoring of biodiversity provides information about ecosystem integrity and its changes in space or in time, thus is helpful to the management decisions. Arthropod diversity plays an important role in pest regulation and crop production, and is considered an important biological factor to be monitored. In Taiwan, two long-term ecological research (LTER) stations have been established at Chi-Ko Farm of Chiayi Agricultural Experiment Branch, TARI, and Yuinlin Branch Station, Tainan DARES since 2005 for studying the impacts of cultivation practices on the sustainability of agroecosystems. During the last 3-year period, baseline information on in-field climate, hydrology, soil characteristics and fertility, nutrient cycling, crop productivity, disease incidence, and the arthropod and soil biota populations have been regularly monitored and established. The data files were established using Ecological Metadata Language developed by the American Knowledge Network for Biocomplexity, and managed with the Morpho (Client)—Metacat (Server) system, so that information can be shared worldwide. This report introduces the role of arthropods in biodiversity assessments and the monitoring of arthropod diversity in the above mentioned LTER stations. We further suggest a thorough survey of the above-ground arthropod species composition and diversity at the LTER stations. Inventory obtained from this investigation can be used to establish a comprehensive documentation on the aboveground arthropod species composition associated with the rice agroecosystem in Taiwan, provide

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baseline information for comparisons of arthropod diversity among rice fields with different cultivation practices, and evaluate the applicability of using coccinellids as indicator species to assess the overall arthropod diversity. Besides, the study would also help shed light on the impacts of arthropod diversity on pest management in agricultural systems.

Key words: Biodiversity, Long-term ecological research, Biodiversity indicator, Coccinellids, Sustainable agriculture

Introduction

Biodiversity denotes the sum total of all living organisms on Earth; their genetic and phenotypic variation; and the communities and ecosystems of which they are a part (Rozensweig, 1995). The report of Naeem *et al.* (1999) gave an explicit explanation about ecosystem functioning and services. The organisms living, growing, reproducing, and interacting within ecosystems reflect flows of energy and materials. Energy flow refers to the capture of solar energy by plant or algal photosynthesis and its transfer as chemical energy through the food web to plant or alga feeders, predators and parasites, and eventually decomposers. The flow of materials involves the recycling of carbon, nitrogen, phosphorus and other elements between living organisms and the air, water, and soil. These biologically mediated energy and material flows contribute to many ecological or life support services that benefit human welfare such as greenhouse gas regulation, water treatment, erosion control, soil quality control, and plant growth.

Ecosystem services are carried out through various organisms and interactions within ecosystems, therefore their persistence depends on maintenance of biodiversity. Species diversity can influence ecosystem processes through directly mediating energy and material fluxes or altering abiotic conditions that regulate the processes (Chapin *et al.*, 2000). It was demonstrated that less variability in ecosystem processes in communities with greater species richness (Naeem and Li, 1997). This may be because the larger the number of functionally similar species in a community, the greater the probability that they are able to replace or compensate for one another, thus maintain the current functions of the ecosystem (Chaptin, 1985). In this paper, we introduce the role of arthropods in biodiversity assessments and the long-term agroecosystem research program in Taiwan and its monitoring of the arthropod diversity.

Biodiversity in agroecosystem

Modern agriculture is built to pursue maximization of production and profit, however, makes the system depart significantly from the natural ecosystems. In natural ecosystems, energy comes from plants capturing solar energy. Nutrients are taken up by plants from atmosphere or from the soil, and most of them are recycled within the system that ensures the system not limiting for further development and growth. Organism populations through various types of interactions with each other and with the environment are more likely to be maintained in a dynamic equilibrium. With the ecosystems' complexity and species diversity, the systems are more capable of resisting disturbance, as well as recovering from disturbance once it happens.

This is important for agroecosystem since it helps the system sustained despite the regular harvest, tillage, and replanting. Agroecosystems, on the other hand, are open systems where considerable energy is directed out of the system at the time of each harvest. Recycling of nutrients is minimal and considerable quantities are lost from the system with the harvest or as a result of leaching or erosion. The system therefore has to rely heavily on fertilizer inputs to replace those losses. Biological diversity in modern agricultural systems (monocultures) is reduced, trophic structures tend to become simplified, and many niches are left unoccupied (Gliessman, 2007). These lead to high danger of catastrophic pest or disease outbreak regardless of human control efforts.

Modern agriculture systems are simplified ecosystems. With intensive human intervention, the biodiversity (both aboveground and belowground) is even reduced further. This impairs the natural ecosystem functions, and is thought to put the future productivity at risk. There have been increased encouragements on incorporating natural ecosystem characteristics into the agricultural farming systems. Studies have suggested that diversity can be enhanced in time though crop rotations and sequences, and in space in the form of cover crops, intercropping, agroforestry, crop/livestock mixtures, and lower inputs of pesticides and fertilizer, etc (Altieri, 1999). The biodiversification would facilitate pest regulation through natural control of insect pests, diseases and nematodes, and helps optimal energy flow and nutrient cycling, thus promotes agricultural sustainability.

Arthropods and biodiversity monitoring

Monitoring of biodiversity can provide information about changes in ecosystem quality in space or in time, and guide management decisions (Duelli, 1997). Ecosystem diversity can be seen as a function of a particular set of organisms involved. Therefore, biodiversity monitoring usually consists of repeatedly sampling and measuring species over time. A good monitoring program need to be effective, cost-efficient, easy to operate, and well detecting the functional diversity with careful consideration about trap type, sample size, collecting periods, and counted taxa (Obrist and Duelli, 2010).

Arthropods make up for the largest proportion of species richness at any landscape types (Hammond, 1992), constituting about 64% of all known global biodiversity (Wilson, 1987). In agricultural farming systems, arthropods are important biotic factors providing ecosystem services in pollination, pest control, and preventing invasions (Loreau, 2000; Hooper *et al.*, 2000, 2005; Cardinale *et al.*, 2003; Kremen, 2005; Kremen *et al.*, 2007; Moonen and Barberi, 2008), further influence crop production. Arthropod diversity correlates well to overall biodiversity of an ecosystem, and gives important information for assessing ecosystem characteristics (Andersen, 1990; Kremen, 1992; Paoletti and Bressan, 1996; Brown, 1997; Van Straalen, 1997; Van Straalen and Verhoef, 1997; Lawton *et al.*, 1998; Kimberling *et al.*, 2001; Platen *et al.*, 2001). In addition, they respond quickly to environmental changes (Kremen *et al.*, 1993). These make arthropods good candidates for a quantitative biodiversity evaluation. However, use of arthropods in monitoring programs can be challenging since the number of arthropod species is large, and taxonomic studies are insufficient or even lacking in many species (Whitehead, 1990; Noss, 1996). Any attempt to use them for quantifying biodiversity has to start with a standardized reduction in sample size.

There have been several proposed protocols for reducing sample size for monitoring arthropod diversity. The Australian researchers were the first to use 'morphospecies' instead of species to

monitor species richness (Cranston and Hillman, 1992; Oliver and Beattie, 1993, 1996). Bolger *et al.* (2000) and Kerr *et al.* (2000) used 'parataxonomic units' for assessing species diversity in selected arthropod groups. Both approaches do not describe species names, but simply count arthropod groups those differ in some morphological characters from each other. Recently, Obrist and Duelli (2010) reported a rapid biodiversity assessment (RBA) monitoring program conducted in Switzerland that is standardized with respect to reliable trapping devices, optimum sampling period, and an adapted morphospecies approach. For any given sampling location, the weekly catches were sorted into 14 distinct taxonomic groups (orders). Each taxonomic group was then counted for morphospecies separately. With the RBA approach, it resulted in an average of 256 (ranging from 69 to 522) morphospecies per trap station per year, and was demonstrated to correlate well with the overall local species diversity and sustainability of related ecosystem services. Besides of morphospecies and parataxonomic units, approaches with surrogates or correlates such as Hymenoptera, Lepidoptera, Heteroptera, carabid beetles, staphylinid beetles, spiders, and ants (Gaston, 1996; Oliver and Beattie, 1996a; Duelli, 1997; Duelli and Obrist, 1998), or use of higher taxonomic units such as genera or families (Gaston and Williams, 1993; Williams and Gaston, 1994) were also proposed to quantify biodiversity at a particular site. These approaches allow assessments of biodiversity with reasonable efforts and costs.

Trapping devices for sampling arthropods

Several trapping devices are commonly used to sample arthropods in monitoring programs. Pitfall traps are the most often used inventory method in agroecosystems to sample ground-dwelling species (Margules and Usher, 1981; Mossakowski and Paje, 1985; Eyre and Rushton, 1989). The traps are usually placed with the lip of the trap flush with the ground surface. Pitfall traps can be simple containers sunk into the substrate or they can be more elaborate devices with funnels directing catches into the trap. A plastic roof is often set on wooden poles to provide protection from rain for the trap. Traps are usually filled with a conservative solution such as 2% formaldehyde in water, and with soap to decrease surface tension. Flight interception traps randomly collect insects on the wing. The best known flight traps for biodiversity evaluations in open landscapes are window traps (Chapman and Kinghorn, 1955; Juillet, 1963). The window traps usually consist of a wooden framework, holding a glass pane with a sealed plastic container underneath on each side for receiving the catches. Efficacy of window traps can be increased by treating the interception panel with a contact insecticide. Flooding of the trap can be lessened by putting drainage holes near the lips of the trap containers. Pan traps provide a simple inexpensive sampling technique. The traps are shallow, bowl-shaped containers that are placed on or sunk into the ground. Water is placed in the trap, and liquid detergent is added as a surfactant to break the surface tension of the water, thus causing the insects to sink and drown. Certain preservative such as formaldehyde or salt is also added. Drainage holes can be made near the lip of the trap to prevent fluid overflow during a rain. Pan traps sample arthropods that fall or fly into the container and drown in water. Collection may be accidental or the insects may be attracted to the color of the pan or to the fluid surface. Pan traps sunk into the substrate take a wider variety of taxa and larger numbers of catches (Disney *et al.*, 1982). Besides, different taxa are attracted to different trap colors (Finch, 1991). Yellow is the most widely

used color and is especially attractive to various groups of Homoptera and Hymenoptera, while white is more attractive to some Diptera (Disney *et al.*, 1982). Pan traps sample more arthropods than pitfall traps, mainly because of their larger perimeters, and the attractiveness of specific colors to the day-active arthropod species. The above mentioned trapping devices are used as passive methods to be established in the field to collect samples at given intervals. On the other hand, various types of suction samplers and standard sweepnets are used to actively collect all the organisms present within a given unit of habitat (Dietrick, 1961; Henderson and Whitaker, 1977).

Long-term agroecosystem research and monitoring in Taiwan

An organized long-term ecological research (LTER) for agroecosystem in Taiwan has been in operation since 2005. This project is supported by both the National Science Council and the Council of Agriculture, and involves over 10 scientists in 5 research institutes. Two LTER research stations have been established at Chi-Ko Farm of Chiayi Agricultural Experiment Branch, TARI, and Yuinlin Branch Station, Tainan DARES. Crops cultivated in both farms include the rice, peanut, and sweet potato those belong to the economically important crops in the region. Fields for each crop type are divided into two categories with each category adopting either the conventional practice or the modified (sustainable) practice. Modified practices include reduced inputs of fertilizer, insecticides, acaricides, and herbicides. In addition, reduced tillage and crop rotation are also applied as the modified practice. Baseline information of in-field climate (temperature (ambient and soil), photoperiod, light intensity, wind, precipitation, etc) and hydrology, soil physical and chemical characteristics, soil fertility, nutrient cycling, crop productivity, disease incidence, and the arthropod and soil biota species composition have been regularly monitored and recorded. The data files are established using Ecological Metadata Language developed by the American Knowledge Network for Biocomplexity, and managed with the Morpho (Client) – Metacat (Server) system, so that information can be shared worldwide.

Arthropod diversity in the LTER stations, following consultations with the collaborators at Michigan State University, was monitored using ladybird beetles as indicator species. The determination was based on that ladybirds are easy to collect and make specimens, and we have taxonomic specialist available for their identification. In addition, ladybirds often serve as important biological control agents in agricultural farming systems including rice paddies (Coderre, 1988; Wise *et al.*, 1995; Lin, K. S. 2003). They reside at the higher trophic level in food chains requiring more trophic links to support. Therefore, their occurrence may relate to a greater species diversity in the ecosystem, and their use as bioindicators for ecosystem assessments has been reported (Andersen, 1999; Iperti & Paoletti, 1999; Zahoor *et al.*, 2003).

A yellow sticky board (33 × 28 cm) hung on a T-shaped stand (1.5 m high) stuck into the ground was used as the trapping device for sample collection (Fig. 1). Two sets of the trapping device were used in each 0.5- to 0.8-hectare field; totally 26 and 28 trapping sets were established at the Chi-Ko and Yuinlin study fields, respectively. The yellow sticky boards were replaced with new ones at fortnightly intervals. Old yellow boards were brought back to the laboratory, coccinellid catches were examined and identified, and the number of individuals in each species were counted. The monitoring has been regularly carried out during the growing



Fig. 1. Setup of the yellow sticky trap in rice fields at the Chi-Ko and Yuinlin farms.

seasons since 2008. A total of 13 species of coccinellids were found, namely *Cheilomenes sexmaculata* (Fabricius), *Micraspis discolor* (Fabricius), *Coccinella septempunctata* Linnaeus, *Propylea japonica* (Thunberg), *Illeis koebelie* Timberlake, *Oenopia formasana* (Miyatake), *Lemnia biplagiata* (Swartz), *C. transversalis* Fabricius, *Lemnia saucia* Mulsant, *Harmonia octomaculata* (Fabricius), *Synonycha grandis* (Thunberg), *Cryptolaemus montrouzieri* Mulsant, and *L. circumsta* (Mulsant) (Figs. 2 and 3). Among these species, *S. grandis*, *C. montrouzieri*, and *L. circumsta* occurred exclusively in fields at the Yuinlin station. *Cheilomenes sexmaculata* was the predominant species that accounted for about 80% of the total trapped ladybirds at both stations, followed by *M. discolor* (at Chi-Ko station) or *C. septempunctata* (at Yuinlin station). There were no significant differences in ladybird diversity between fields treated with different cultivation practices. This may be due to that only one application of insecticide was conducted in the fields adopting conventional practices.

Conclusions

Biodiversity has become an important conservation value in recent decades. Monitoring of biodiversity helps detect changes in ecosystem integrity for relative decision making. The components of species diversity include the identity of species (species composition), the number of species (species richness), species relative abundances (species evenness), and the temporal and spatial variation in these species properties. Diversity of all living organisms in a given landscape is usually too complex to be measured thoroughly. For most cases, only selected surrogates or correlates can be quantified, and decisions are often governed by the available funding and systematics support. There have been studies indicated that a number of monitoring programs failed in providing information that correlated well to the overall biodiversity or the desired ecosystem functioning (Oliver and Beattie, 1996b; Duelli and Obrist, 1998). We used

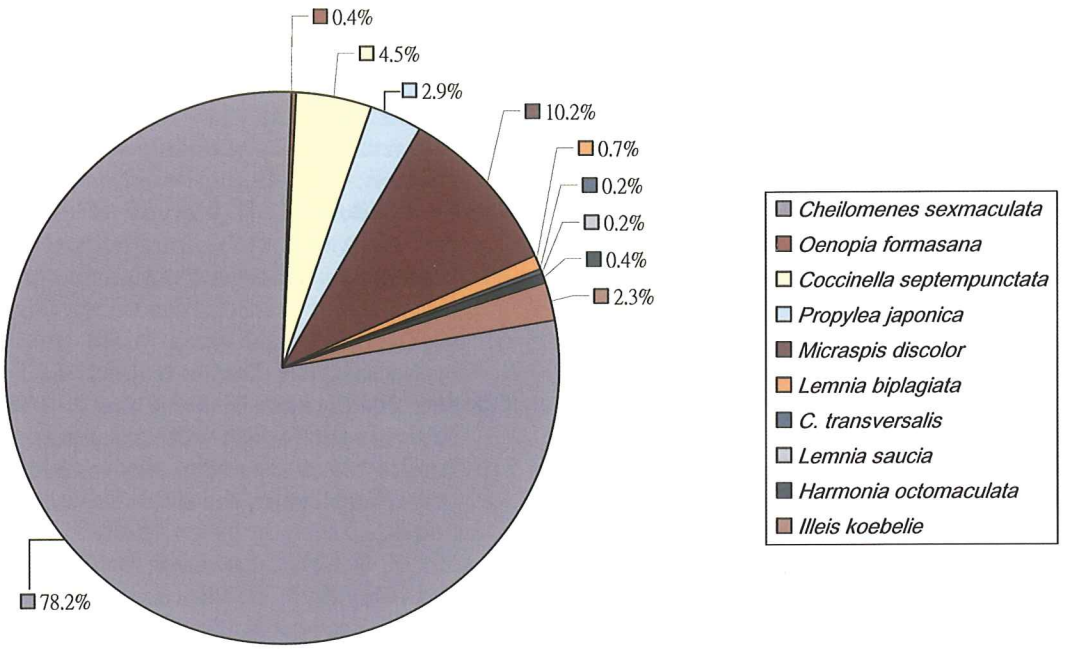


Fig. 2. Coccinellid species composition and their proportions at Chi-Ko farm based on the investigations during 2008-2009.

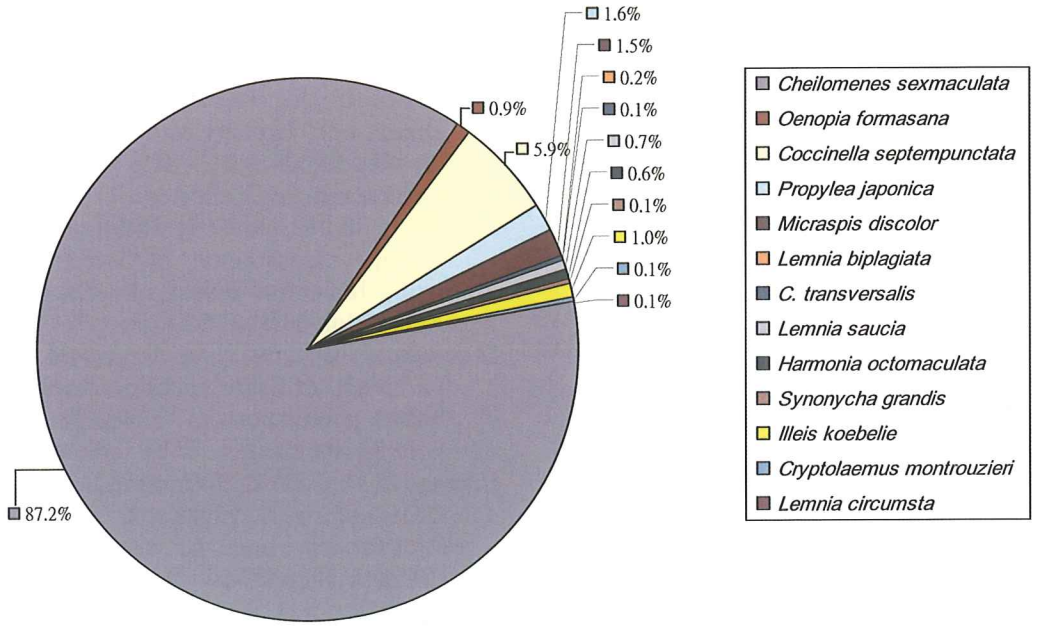


Fig. 3. Coccinellid species composition and their proportions at Yuinlin farm based on the investigations during 2008-2009.

coccinellids as the indicator species for monitoring the arthropod diversity at our LTER stations. However, how coccinellid diversity relates to the overall arthropod diversity and the pest control needs further investigations. The International Rice Research Institute in Philippines houses the world's largest reference collection of rice-associated arthropods (insects, spiders, mites); in addition, a number of taxonomic specialists are serving in the institute. We suggest taking this advantage to conduct a thorough survey of the above-ground arthropod species composition and diversity at our LTER stations. Inventory obtained from this investigation can be used to establish a comprehensive documentation on the aboveground arthropod species composition associated with the rice agroecosystem in Taiwan, provide baseline information for comparisons of arthropod diversity among rice fields with different cultivation practices, and evaluate the applicability of using coccinellids as indicator species to assess the overall arthropod diversity. Besides, the study would also help shed light on the impacts of arthropod diversity on pest management in agricultural systems.

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農業生態系之節肢動物多樣性監測

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摘　要

生物多樣性在生態系統功能及生態系統服務上扮演極重要的角色，近年來生物多樣性已被視為反映生態系統品質的指標，並成為生態保育重要的一環。在農業生態系方面，學者建議可藉由導入自然生態系的特性，同時降低人為投入，以增進生物多樣性。生物多樣性監測有助於我們了解生態系統的健全性，並偵測生態系中各項組成因子於不同時間與空間的變化，可提供農業生產相關決策之重要依據。節肢動物為農業生態系中重要生物因子，其多樣性與害蟲族群的調節以及作物的生產息息相關，因此極具監測重要性。台灣自 2005 年起即在農委會和國科會的支持下，藉由與美國密西根州立大學 Kellogg Biological Station 長期生態研究人員的合作，於農業試驗所嘉義分所溪口農場與台南改良場雲林分場分別設立兩個農業長期生態研究站。本計畫至今，研究人員已分別收集了研究站及站內農田的各項基線資料，包括站內氣象、水文、土壤理化性質與肥力、養分循環、作物生產力、病害發生率、以及地上部節肢動物與土壤生物之族群動態。這些資料皆以美國 Knowledge Network for Biocomplexity 所發展的 Ecological Metadata Language 整理建檔，並以 Morpho (Client)－Metacat (Server) 系統作為資訊管理，可與世界各國生態研究站進行資訊交流。本報告介紹節肢動物在生物多樣性監測上之應用以及臺灣農業長期生態研究站內節肢動物多樣性的監測作業。我們並進一步建議於研究站內進行完整性地上部節肢動物之種的組成、各種類豐度、與種類多樣性的調查，研究結果可供作：(1) 建立台灣水稻生態系節肢動物組成的完整資料，(2) 未來研究各種農事操作對農業生態系生物多樣性影響的基線資料，(3) 評估利用瓢蟲作為指標以監測節肢動物多樣性的適用性。另外，此研究也有助於我們深入了解節肢動物多樣性對蟲害管理的影響與作用機制。

關鍵詞：生物多樣性、長期生態研究、生物多樣性指標、瓢蟲、永續農業。

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