Arthropod Communities Inhabiting Organic Rice Agro-ecosystem

Pisit Poolprasert, and Touchkanin Jongjitvimol

Abstract—All insect pests and natural enemies in organic rice agro-ecosystem and species diversity were examined. A total of 34 species of insects and spiders representing 11 orders and 28 families; these included 11 pest (PT) species, 17 predator (PD) species and 6 parasite (PR) species. The species diversity (*H'*) for all insects and spiders of all rice stages was considered relatively high. Moreover, (*H'*) obtained from the pooled data set of this survey was 2.54. Significant differences in insect and spider species diversity indices of eight rice planting stages were detected ($P < 0.05$) in all comparisons. The distribution of insects and spiders was aggregated for all rice growth stages, as indicated by the values of variance to mean ratio ($S^2/\bar{x}$) and the index of aggregation ($I\delta$).

Keywords—species composition, rice pest, natural enemies, rice agro-ecosystem.

I. Introduction

THE most important of all cereals, rice (*Oryza satia* L.) has contributed to the economic development of several nations. Rice is a good source of protein as well as a stable food in many parts of the world. As the main byproducts, rice milling provides rice hulls or husks, rice bran and brewer's rice [1]–[3]. Rice cultivation has grown to nearly 158 million ha worldwide, with approximately 90% of the production in developing countries [4]. China was the largest rice producer (202.6 million tons) in 2011, followed by India (155.7 million tons) and Indonesia (65.7 million tons) whereas Thailand was the sixth largest rice producer of the world with 34 million tons [5]. According to the USDA report, India was the world's largest exporter of rice with 9.75 million tons. Whereas, Thailand is considered as being the third largest rice exporter (6.5 million tons) of world [6]. Recently, total planting areas and rice production in Thailand has been decreasing slightly [7]. A main constraint of profitable rice production is insect pests. Most crop loss caused by insects can be attributed to the major pest complex. Seventy insects are considered rice pests but only 20 species were of crucial importance. Those insect pest species – monophagous (restricted to rice) – infest all the rice plant parts at all developing stages. Some are vectors such as leafhoppers and planthoppers, which caused to direct damage as well as transmitted viral diseases, stem borers and a defoliator species group [8]–[11]. As a result of heavy insect pressure, the control of rice pests has relied heavily on insecticides [12]. Rice yield has improved but overuse and misuse of these insecticides have led to increasing problems of insecticide resistance, resurgence of pests and introduction of new pests, as well as beneficial insects' destruction [10].

Natural control of insect pests is one of the tactics of the integrated pest management concept (IPM), which has been used in this country since the early 1970s [13]. It has played a vital role in controlling most potential pests of rice [14]. Many species of insect pests and natural enemies (predators & parasites) have been surveyed and reported in Thailand [15]–[17]. Species diversity regarding to abundance and species richness is a quantitative parameter of community structure [18], [19]. The right kind of species diversity is basic to modern pest control. Understanding of the species present and their role in the ecosystem could be significant in deciding whether or not to apply pesticides [20]. Generally, species diversity and complexity of association among species are important to the stability of the community. It is necessary to provide the essential data about species richness and abundance of rice pests and their natural enemies as a partially taxonomic aspect in rice protection in Thailand. Information on distribution patterns of insect pests is used for data analysis to determine appropriate sampling plan and sample size, and to construct sequential sampling programs. Reliable sampling plans are necessary for periodic screening of pest-population densities where timely pest management decisions are essential [21]. Whereas the number of samples could vary with the distribution pattern of the pest, it is significant to determine the distribution pattern of rice key pests for specific areas and different seasons [22]. The data acquired are still insufficient to form a foundation and for developing an integrated pest management system in Thailand. The purpose of this current study was to simulate species composition, together with determining the distribution pattern of arthropods (insects and spiders) that act as pests, predators or parasites in an organic rice paddy field.

II. Materials and Methods

The experimental area is located at an organic rice paddy field of Neon Kum sub-district, Bang Krathum district, Phitsanulok province, Thailand. The Khao Dawk Mali 105, a

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rice variety/line, was selected and cultivated in this study. Samplings were conducted during August to November 2013. Five plots (100 m × 100 m each) were randomized at each time of the sampling. Rice insect pests and natural enemies, predators and parasites, were gathered from each plot of rice paddy field every 14 days after planting through harvesting; The period of time was based on simple random technique using sweeping net at 20 times/sampling surveyed spot. Each surveyed line in each rice plot was walked as a diagonal. All insects and spiders collected were preserved in 70% alcohol and then all samples were identified by using a manual of Pathak and Khan [10], Maloney et al. [23], Rouyaree [24] and Shepard et al. [25].

For analysis of the insects and spiders, the assemblage data from organic rice paddy filed were classified into eight main rice growth stages (14, 28, 42, 56, 70, 84, 98 and 112 days after planting). All assemblage parameters in this study were calculated based on average density of each arthropod species in each level. The Shannon-Wiener index (*H'*) [19], [26], Pielou's evenness index (*J'*) [27] and Simpson's diversity function (D) [28] were used to determine the diversity among insects and spiders in each level of rice growth. High numbers on *H'* signify high diversity, whereas low values on D indicate high diversity. For species composition or relative abundance of different arthropods found, the similarity in species composition among rice developing stages was determined by a cluster analysis with Sorensen distance measurement [29], [30].

Inspections of insects and spiders per rice plot fitted to distributions, which would be expected if arthropods are randomly spread (Poisson distribution) or aggregated (negative binomial distribution). The distribution pattern of arthropods was statistically classified by calculating the Variance–to–mean ratio ($S^2/\bar{x}$) and Morisita's Index (I_δ) [31], [32]. For the distribution pattern, the value is higher than 1.0 (> 1.0) shows aggregated form, the values is equal to 1.0 (= 1.0) indicates random form whereas the value is lower than 1.0 (< 1.0) it means regular pattern of arthropods.

Statistical tests were conducted using SPSS program [33]. Cluster analysis was carried out using PC-ORD 5.10 software [34]. A rarefaction model was used to compare arthropod diversity among these stages of rice growth. Rarefaction value and its 95% confidence interval were computed by EcoSim version 7.72 software [35]. Afterwards, the values of every stage groups were plotted as a function of sampling effort. With this plot, significant difference in species diversity is indicated by an absence of overlap in the confidence interval of rarefaction curves among eight different rice growth stages at maximum sampling effort [36].

III. Results and Discussion

A list of the collected insects and spiders as pests and natural enemies from eight different rice growing stages is summarized in Table I. A total of 1,928 individuals -- representing 27 orders, 11 families and 34 species -- were collected by sweeping method during eight different stage of rice growth (14, 28, 42, 56, 70, 84, 98, and 112 days after planting). Of all 34 species, 11 rice pest species, 17 predacious species and six species of parasites were found during this time. The total of arthropod species in each rice growing stage, from the lowest to the highest was: 14 days (7 species); 112 days (10 species); 98 days (12 species); 42 days (15 species); 28 days (16 species); 70 days (17 species); 84 days (19 species) and 56 days (20 species), respectively, as shown in Table II. These finding corresponds to Sorapongpaisal et al. [37]. The three common arthropod groups as pests, predators and parasites found were 1) pests: (rice whorl maggots, *Hydrellia* sp.), (brown planthoppers, *Nilaparvata lugens*) and (rice thrips, *Stenchaetothrips biformis*), 2) predators: (lady beetles, *Micraspis crocea*), (pigmy dartlets, *Agriocnemis pygmaea*) and (long-jawed spiders, *Teteagnatha maxillosa*n and 3) parasites: (small ant-like bethylid wasps, *Goniozus nr. triangulifer*), (ichneumonid wasps, *Amauromorpha accepta metathoracica*) and (ichneumonid wasps, *Trichomma cnaphalocrosis*).

About 20 insect species are considered pests in the rice paddy fields of Thailand [38]. Furthermore, over 800 species of insect in rice fields have been reported worldwide. Of these, about 100 species attack rice and the rest are friendly insects [9]. However, due to more than 100 predacious and parasitoid insect species –natural enemies- in the rice field, only 5-6 insect pests were found. This indicated that the ability of natural enemies could suppress insect pests to be under the economic threshold level (ETL) or economic injury level (EIL) in the organic rice paddy field [38].

TABLE I
ORDER, FAMILY, SPECIES TOTAL NUMBER RECOVERED AND STATUS OF INSECT AND SPIDER GROUP PRESENTED IN EACH AGE OF RICE AFTER PLANTING.

Order	Family	Species	Total no. recovered	Status
Odonata	Coenagrionidae	*Agriocnemis pygmaea*	170	PD
	Libellulidae	*Neurothemis tullia tullia*	41	PD
Orthoptera	Acrididae	*Acrida willemsei*	2	PD
		Conocephalus longipennis	25	PD
		Hieroglyphus banian	41	PD
	Gryllidae	*Anaxipha longipennis*	32	PD
Dermaptera	Chelisochidae	*Euborellia stali*	39	PD
Thysanoptera	Thripidae	*Stenchaetothrip s biformis*	49	PT
Homoptera	Cicadellidae	*Nephotettix virescens*	18	PT
	Delphacidae	*Nilaparvata lugens*	199	PT
		Sogatella furcifera	2	PT
Hemiptera	Alydidae	*Leptocorisa* sp.	48	PT
	Pentatomidea	*Scotinophara coaractata*	2	PT
Coleoptera	Chrysomelidae	*Dicladispa armigera*	11	PT
	Coccinellidae	*Micraspis crocea*	260	PD
	Staphylinidae	*Paederus fuscipes*	2	PD

Lepidoptera	Hesperiidae	*Parnara guttata*	6	PT
	Noctuidae	*Sesamia inferens*	32	PT
	Pyralidae	*Nymphula depunctalis*	19	PT
Diptera	Dolichopodidae	*Medetera* sp.	3	PD
	Ephydridae	*Hydrellia* sp.	583	PT
	Pipunculidae	*Tomosvaryella oryzaetora*	13	PD
Hymenoptera	Bethylidae	*Goniozus nr. triangulifer*	62	PR
	Formicidae	*Solenopsis geminate*	13	PR
	Ichneumonidae	*Amauromorpha accepta metathoracica*	14	PR
		Charops brachypterum	2	PR
		Trichomma cnaphalocrosis	11	PR
		Xanthopimpla flavolineata	5	PR
Araneae	Araneidae	*Argiope catenulata*	45	PD
	Linyphiidae	*Atypena* (*Callitrichia*) *formosana*	16	PD
	Lycosidae	*Lycosa pseudoannulata*	12	PD
	Oxyopidae	*Oxyopes javanus*	7	PD
	Tetragnathidae	*Teteagnatha maxillosa*	128	PD
	Salticidae	*Phidippus* sp.	1	PD

PD = Predator, PR = Parasite, PT = Pest.

TABLE II
ARTHROPOD DIVERSITY IN DIFFERENT STAGES OF RICE GROWTH.

Stage (days)	Number of individuals	Number of species	H_{max}	*H'*	*J'*	D
14	43	7	1.94	1.76	0.90	0.79
28	912	16	2.77	1.51	0.54	0.64
42	159	15	2.70	2.28	0.84	0.87
56	151	20	2.99	2.56	0.85	0.90
70	168	17	2.83	2.23	0.78	0.85
84	203	19	2.94	2.31	0.78	0.86
98	138	12	2.48	1.73	0.67	0.75
112	144	10	2.30	1.63	0.71	0.75

H_{max} = Maximum species diversity (*H'*), *H'* = Shannon Wiener index of diversity; *J'* = Pielou's evenness index (*H'*/H_{max}), D = Simpson's diversity index.

Among the estimated diversity indices, the Shannon-Wiener index (*H'*) for all insects and spiders in all stages of rice development is considered relatively high, ranging from 1.51 to 2.56. Shannon (*H'*) index obtained by computing the pooled data set of this study was 2.54, with high evenness (*J'* = 0.72), and dominance by the Simpson index was high for all rice developing stages (D = 0.86). It was found that 56 days after rice planting showed the highest species diversity index (*H'* = 2.56), whereas 28 days after rice planting had the lowest diversity levels (*H'* = 1.51). All species indices of eight rice growing stages are presented in Table II. Moreover, significant differences in the species diversity indices of eight rice developing stages were detected ($P < 0.05$) in all comparisons. The results showed that such biodiversity parameters as the richness, diversity and composition of these insect communities differ during the various seedling stages.

Based upon the dendrogram obtained by using the clustering method, it is clear that the communities of insect and spider species gathered from all different rice developing stages are significantly different (Fig. 1). The two stages 70 days and 84 days after planting formed a sister group in which the communities of species at these stages were more similar to each other than those found at the various other stages. Additionally, the accumulation curves (observed and expected) in the several stages of rice growth (14, 28, 42, 56, 70, 84, 98, and 112 days after cultivating) (Fig. 2) exhibited a divergence between 95% confidence interval of these curves, with the curve increasing slightly when the survey stopped.

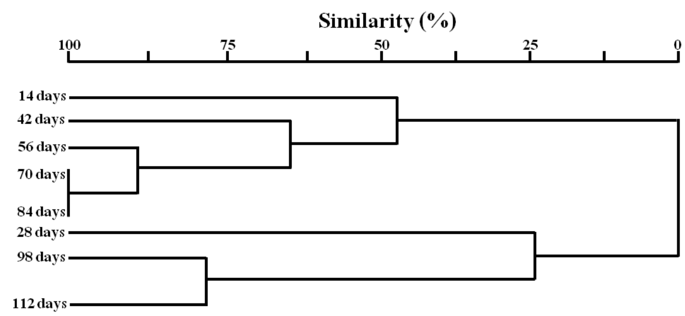

Fig. 1 Dendrogram of the communities of insects and spiders in the various stages of rice growth, obtained by cluster analysis

For the spatial distribution pattern of insects and spiders, the distribution indices --Variance-to-mean ratio ($S^2/\bar{x}$) and Morisita's Index ($I\delta$) -- of each growing stage of rice were presented. It was found that both indices exhibited significantly greater than 1.0 for all stages, indicating clumped distribution (Table III). However, some results in this study clearly showed random (= 1.0) and regular (< 1.0) distribution patterns of insects and spiders in the rice paddy field when analyzed by $S^2/\bar{x}$, for example, long-jawed spiders, *Tetragnatha maxillosa* (1.0), white-backed planthoppers, *Sogatella furcifera* (0.86) and ichneumon, *Charops brachypterum* (0.86). Most rice arthropods exhibited as aggregated pattern of dispersal. It might be affected from several factors such as intrinsic behavior of the individuals, response to the food and habitat resources distribution, level of water and hill density of the rice paddy field [39]. In addition, a proper resource concentration in some areas has been proposed as the general cause of assemblage of most living things [22], [40].

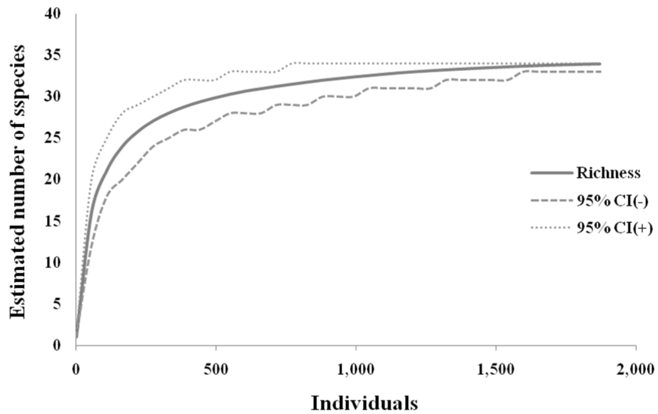

Fig. 2 Species richness in the different stages of rice growth by rarefaction curve with ± 95% confidence intervals shown as dotted lines.

TABLE III
EVALUATION OF SPATIAL DISTRIBUTION PATTERN OF ARTHROPODS FOR RICE AGRO-ECOSYSTEM IN DIFFERENT STAGES OF RICE GROWTH.

Stage (days)	Variance to mean ratio ($S^2/\overline{X}$)	Morisita's Index ($I\delta$)	Distribution pattern
14	7.63	1.21	Clumped
28	306.00	3.88	Clumped
42	17.17	1.59	Clumped
56	10.99	1.52	Clumped
70	19.65	1.70	Clumped
84	22.29	1.87	Clumped
98	30.04	1.97	Clumped
112	31.45	1.53	Clumped

IV. Conclusion

The results revealed that such biodiversity parameters as richness, diversity and composition of these insect and spider communities differ during various seedling stages. All indices also exhibited relatively high values. Based upon the obtained results, it may be concluded that the overall spatial distribution form of insects and spiders observed in this study revealed mostly an aggregated distribution pattern. Moreover, use of sampling strategy that incorporate spatial distribution will be beneficial to provide the information essential for development of appropriate sampling plan and optimum sample size for rice integrated pest management (IPM). It will also reduce the cost of pest management strategy, together with decreasing the toxicity risk from pesticide application.

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References

[1] S. K. DeDatta, *Principles and Practices of Rice Production*. New York: John Wiley, 1981.

[2] M. M. Most, R. Tulley, S. Morales, and M. Lefevre, "Rice bran oil, not fiber, lowers cholesterol in humans." *American Journal of Clinical Nutrition*, 2005, 81: 64–68.

[3] P. Williams, M. J. Brand, and M. Fitzgerald, *Project 4505 GI of Rice*. Leeton, Australia: Cooperative Research Centre for Sustainable Rice Production. 2005, pp. 84–89.

[4] IRRI, *Rice production and processing*. Manila: International Rice Research Institute, 2009, Accessed October 10, 2013. http://www.irri.org/index.php?option=com_k2&view= item &layout =item&id=9151&lang=en.

[5] FAOSTAT, *Countries by Commodity (Rice, Paddy)*. FAO of the United Nations, 2011, Accessed October 10, 2013. http://faostat.fao.org/ site/339/default.aspx.

[6] USDA, *India is world's largest rice exporter: USDA*. The Financial Express, 2012, Accessed October 10, 2013. http://www.financialexpress.com/news/india-is-worlds-largest-rice-exporter-usda/1023491/0.

[7] B. Titapiwatanakun, *The Rice Situation in Thailand*. ADB Technical Assistance Consultant's Report, 2012, 25 pp.

[8] M. D. Pathak, "Application of Insecticide to paddy water for more effective rice pest control." *International Pest Control*, 1968, 10: 12–17.

[9] M. D. Pathak, "Insect pests of rice and their control," in IRRI. (ed.). *Rice Production Manual*. Los Baños: University of the Philippines, College of Agriculture in cooperation with the International Rice Research Institute, 1970, pp. 171–198.

[10] M. D. Pathak, and Z. R. Khan, *Insect Pest of Rice.* Manila: International Rice Research Institute, 1994.

[11] M. J. Way, and K. L. Heong, "The role of biodiversity in the dynamics and management of insect pests of tropical irrigated rice: a review." *Bulletin of Entomological Research*, 1994, 84: 567–587 http://dx.doi.org/10.1017/S000748530003282X

[12] E. D. Magallona, "Effects of insecticides in rice ecosystems in Southeast Asia," in Bourdeau, P., Haines, .J.A., Klein, W. & Krishna Mmti, C.R. (eds.). *Ecotoxicology and Climate*. New York: John Wiley & Sons, 1989, pp. 265–297.

[13] M. G. Wright, M. P. Hoffmann, T. P. Kuhar, J. Gardner,and S. A. Pitcher, "Evaluating risks of biological control introductions: a probabilistic risk-assessment approach." *Biological Control*, 2005, 35. 338–347. http://dx.doi.org/10.1016/j.biocontrol.2005.02.002

[14] M. Jervis, and N. Kidd, *Insect Natural Enemies: Practical Approaches to Their Study and Evaluation*. London: Chapman and Hall, 1996. http://dx.doi.org/10.1007/978-94-011-0013-7

[15] T. Wongsiri, and K. Kovitvadhi, "Insect pests of rice in Thailand," in IRRI, (ed.). *Major Insect Pests of the Rice Plant: Proceedings of a Symposium at the International Rice Research Institute, September, 1964*. Maryland: Johns Hopkins Press, 1967, pp. 571–574.

[16] T. Wongsiri, N. Wongsiri, C. Tirawat, S. Navavichit, A. Lewvanich, and K. Yasumatsu, "Abundance of natural enemies of rice insect pests in Thailand," in N. Nōgyō and K. Sentā, (ed.). *International Symposium on Problems of Insect Pest Management in Developing Countries: Proceedings of a Symposium on Tropical Agriculture Research, Kyoto, August 6-7, 1980*. Japan: Tropical Agriculture Research Center, Ministry of Agriculture, Forestry and Fisheries, 1981. pp. 131–149.

[17] J. Jairin, K. Phengrat, S. Khumma, T. Phomraksa, and S. Teangdeerith, "The survey of natural enemies on rice insect pests in lower part of northeastern Thailand." *Thai Journal of Agricultural Science*, 2001, 19(1): 71–83. (in Thai).

[18] R. M. May, "Patterns of species abundance and diversity," in M. L. Cody, and J. M. Diamond, (eds.). *Ecology and Evolution of Communities*. Cambridge: Harvard University Press, 1975, pp. 81–120.

[19] A. E. Magurran, *Ecological Diversity and Its Measurement.* New Jersey: Princeton University Press, 1988. http://dx.doi.org/10.1007/978-94-015-7358-0

[20] H.F. van Emden, and G. Williams, "Insect stability and diversity in agro-ecosystems." *Annual Review of Entomology*, 1974, 19: 455–475. http://dx.doi.org/10.1146/annurev.en.19.010174.002323

[21] E. Kuno, "Sampling and analysis of insect populations." *Annual Review of Entomology*, 1991, 36: 285–304. http://dx.doi.org/10.1146/annurev.en.36.010191.001441

[22] T. R. E. Southwood, *Ecological Methods, with Particular reference to the study of insect populations*, 2nd ed. London: Chapman and Hall, 1978.

[23] D. Maloney, F. A. Drummond, and R. Alford, *Spider Predation in Agroecosystems: Can Spiders Effectively Control Pest Populations*. Orono: Maine Agricultural and Forest Experiment Station, 2003.

[24] S. Rouyaree, *Learning How to Manage the Integrated Rice Insect Pest*. Bangkok: Thai Agriculture Cooperative Press. (in Thai), 2001.

[25] B. M. Shepard, A. T. Barrion, and J. A. Lisinger, *Helpful Insect, Spiders, and Pathogens: Friends of the Rice Farmer.* Manila: International Rice Research Institution, 1987.

[26] J. A. Ludwig, and J.F. Reynolds, *Statistical Ecology.* New York: John Wiley & Sons, 1988.

[27] C. P. H. Mulder, E. Bazeley-White, P. G. Dimitrakopoulos, A. Hector, M. Scherer-Lorenzen, snd B. Schmid, "Species evenness and productivity in experimental plant communities." *Oikos***,** 2004, 107: 50–63. http://dx.doi.org/10.1111/j.0030-1299.2004.13110.x

[28] E. H. Simpson, "Measurement of diversity." *Nature***,** 1949, 163: 688. http://dx.doi.org/10.1038/163688a0

[29] T. A. Sorensen, "A method of establishing groups of equal amplitude in plant sociology based on similarity of species content, and its application to analyses of the vegetation on Danish commons." *Kongelige Danske Videnskabernes Selskab, Biologiske Skrifter*, 1948, 5: 1–34.

[30] J. R. Bray, and J. T. Curtis, "An ordination of upland forest communities of southern Wisconsin." *Ecological Monographs***,** 1957, 27: 325–349. http://dx.doi.org/10.2307/1942268

[31] M. Morisita, "Measuring of the dispersion of individuals and analysis of the distributional patterns." *Memoirs of the Faculty of Science Kyushu University Series E,* 1959, 2: 215–235.

[32] Morisita, M. 1962. I_δ–index, a measure of dispersion of individuals. *Researches on Population Ecology* 4(1): 1–7. http://dx.doi.org/10.1007/BF02533903

[33] SPSS, *SPSS for Windows: User's guide: Statistics V. 16.0*. North Carolina: Cary, 2007.

[34] B. McCune, and M. J. Mefford, *PC-ORD: Multivariate Analysis of Ecological Data V. 5*. Oregon: MjM Software, Gleneden Beach, 2006.

[35] N. J. Gotelli, and G.L. Entsminger, *EcoSim: Null Models Software for Ecology V. 7*. Acquired Intelligence Inc. & Kesey-Bear. Jericho, VT 05465, 2004. Accessed November 25, 2013. http://garyentsminger.com/ecosim/index.htm.

[36] R. K. Colwell, C. X. Mao, and J. Chang, "Interpolating, extrapolating, and comparing incidence-based species accumulation curves." *Ecology*, 2004, 85(10): 2717–2727. http://dx.doi.org/10.1890/03-0557

[37] W. Sorapongpaisal, S. Tanasinchayakul, W. Promwong, C. Wootisarn, and P. Dokchan, "Species diversity of rice insect pests and natural enemies in organic rice paddy field." *Journal of Agriculture*, 2011, 27(1): 39–48. (in Thai).

[38] P. Jaroenpol, *Integrated Pest Management.* Nakhon Ratchasrima province: Agriculture Department, Huai Tha-land district. (in Thai), 2008.

[39] H. Gogoi, and D. Bora, "Spatial distribution of *Nymphula depunctalis* Guenée larvae (Lepidoptera: Pyralidae), an early vegetative pest of *Oryza sativa* L." *Academic Journal of Entomology*, 2012, 5(1): 41–46.

[40] R. E. Ricklefs and G. L. Miller, *Ecology*, 4th ed. New York: W.H. Freeman and Company, 2000.