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Conservation of Agroecosystem through Utilization of Parasitoid Diversity: Lesson for Promoting Sustainable Agriculture and Ecosystem Health

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For many years, agricultural intensification and exploitation has resulted in biodiversity loss and threaten ecosystem functioning. Developing strategies to bridge human needs and ecosystem health for harmonization of ecosystem is a major concern for ecologist and agriculturist. The lack of information on species diversity of natural enemies and how to utilize them with integration of habitat management that can renovate ecological process was the main obstacle. Parasitoids, a group of natural enemies, play a very important role in regulating insect pest population. During the last ten years, we have been working on exploration of parasitoid species richness, how to use it to restore ecosystem functions, and identifying key factors influencing host-parasitoid interaction. Here, we propose a model of habitat management that is capable of maintaining agricultural biodiversity and ecosystem functions. We present data on parasitoid species richness and distribution in Java and Sumatera, their population structure and its impact toward biological control, relationship between habitat complexes and parasitoid community, spatial and temporal dynamic of parasitoid diversity, and food web in agricultural landscape. Implications of our findings toward conservation of agroecosystem are discussed.

Key words: conservation, agroecosystem, parasitoid, diversity, ecosystem health

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INTRODUCTION

For many years, agriculture has played a role as the world's machine of food production. Various technologies have been developed to increase the quantity and quality of food production. Unfortunately, during the process, many agricultural activities are threatening the ecosystem. Biodiversity loss, desertification and contamination, are among the few impacts that are negatively affecting the ecosystem as a whole (Kruess & Tscharntke 1994; Settle *et al*. 1996; Andren 1997; Steffan-Dewenter & Tscharntke 1999; Kruess & Tscharntke 2000; Rogo & Odulaja 2001; Klein *et al.* 2002).

Due to these impacts, the sustainability of agriculture becomes a question for many to seek answers of. Concepts and insights were brought in to develop agriculture in a sustainable way. Here, we offer an insight regarding the role of agroecosystem as both food production machine and a system that can maintain as much biodiversity as possible. Biodiversity of agroecosystem plays a critical role in providing services for human population such as food and nutrient cycling (Chemini & Rizzoli 2003; Baumgärtner 2007). One important service provided by biodiversity in agroecosystem is natural control by natural enemies i.e parasitoids and predators (Losey & Vaughan 2006). High extent of agrobiodiversity can maintains ecological processes, and allow natural enemies to play their role in regulating herbivorous insect population. Decreasing habitat complexity of agroecosystem due to landuse change and intensified agriculture may have a strong negative impact on natural enemies. Several studies have revealed a strong relationship between parsitoid assemblage and plant diversity (Tooker & Hanks 2000; Sperber *et al.* 2004; Saaksjarvi *et. al*. 2006). Langer and Hance (2004) identified that more intensive agriculture frequently reduces the availability of non-crop habitats where alternative hosts may be present. Marino and Landis (2000) mentioned the scarcity of adult food sources, appropriate microclimates or alternate hosts as important reasons for a reduced abundance, diversity and species richness of natural enemies in agricultural landscapes. Further, Marino *et al.* (2006) emphasized that Hymenopteran generalist parasitoids were associated strongly with lepidopteran alternate hosts that feed on trees and shrubs, whereas hymenopteran oligophagous and specialist parasitoids were associated strongly with lepidopteran alternate hosts that feed on ruderals and shrubs.

Special focus shall be given to parasitoids, whose functional roles as regulators for pests populations are brought forward as one scenario that can bring sustainable agriculture into being. Parasitoids are the most important factor causing mortality of herbivores than do either predators or pathogens (Hawkins *et al.* 1997; Snyder & Ives 2003). Hymenopteran parsitoid, are among the most species-rich and biologically diverse taxa (Naumann 1991; Mason & Huber

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1993; Quicke 1997; Whitfield 1998), and may be one of the most important insect groups playing valuable roles in maintaining the diversity of natural communities (Quicke 1997). Since Hymenopteran parasitoid represent a key factor in regulating natural insect populations, their loss can result in a serious destabilization of natural ecosystems. Therefore, maintaining high extent of parasitoid diversity is very important to preserve the sustaining unpaid natural control services provided by agroecosystem. This paper emphasize the parasitoid diversity and richness by exploring egg parasitoid across Java and Sumatera.

Concepts of conservation are applied to agricultural practices, offering a new paradigm in promoting ecosystem health for sustainable food production. The ultimate aim is the development of a new paradigm and concept on agroecosystem health. The health of the agroecosystem is ensured through the full utilization of agrobiodiversity that ensure ecological processes are taking place in an environmentally friendly way.

MATERIALS AND METHODS

This article is to promote a concept of parasitoid utilization for the conservation of agroecosystem. It contains a synthesis as a result of research series that have been conducted during the last 10 years in Indonesia, and also an overview of various articles (from old to current) supporting the offered concepts.

Parasitoid Community: Species Richnes, Diversity, Distribution, and Landscape Effects. A series research on parasitoid diversity and richness were carried out by exploring egg parasitoid across Java and Sumatera. Parasitoids were sampled by collecting insect eggs in various plant species (paddy, cabbage, corn, shallot, soybean, lettuce, red onion, and cauliflower) and landscapes (lowland paddy field, higland paddy field, highland vegetable plantation, polyculture plantation, and monoculture plantation) from various regions starting from east java (Malang and Situbondo), Central Java (Tawangmangu, Bantul, Kulon Progo, Sleman), West Java (Bogor, Cianjur, Lembang-Bandung, Karawang, Cirebon) to several provinces in Sumatera including West Sumatera, Jambi and Bengkulu. Collected eggs were incubated in laboratory and emerged parasitoids were recorded and identified. This research series were conducted between 1997-2003.

The Importance of Habitat Complexity Toward Parasitoid Community. Effects of habitat complexity toward parasitoid community was evaluated by using two different methods, (i) parasitoid survey in polyculture habitats (traditional paddy fields around Taman Nasional Gunung Halimun (Halimun Mountain National Park) and Purwokerto, at the landscape scale) and monoculture habitats (paddy field in Subang and Bantul, at the landscape scale). Research was conducted from 2000-2002; (ii) Diversity and richness of parasitoid were evaluated by installing habitat types (polyculture and monoculture) at the same agricultural landscape. Research was conducted in 2004-2005. Species number and parasitization level were counted to determine the effect of habitat complexity. Possible interaction pathway between host-parasitoid-hyperparasitoid was developed.

Population Structure and Genetic Variability. Population structure and genetic variability were studied by sampling egg parasitoid acros geographic regions including Bogor (Gunung Bunder, Ciawi), Cianjur (Cugenang, Cibodas, Warung Kondang), Malang, and Asembagus. Genetic distance among parasitoid population was studied by DNA analyses using PCR-RAPD method. This research was conducted between 2004 and 2006.

Temporal and Spatial Dynamic of Parasitoid Community. Spatial and temporal dynamic of parasitoid were studied by surveying parasitoid in various cacao plantations situated in different distances from natural habitat. Insects were sampled three times (July, August 2001, and February 2003) by using spraying method at the same trees. Parasitoids were identified and comparison of species richness between plots (12 cacao plantations situated in different distances from nearest forest, 2 cacao plantations in the forest margin, and 2 sites inside forest; 5 trees per plot) and sampling period was conducted. (Figure 1).

Review of Supporting Articles. Articles that support the idea and concepts were reviewed in order to acquire in- depth understanding toward the issue.

RESULTS

Here we presented the key results of ten years survey on parasitoid in agricultural landscapes. We have succeeded to identify 14 egg parasitoid species to occur in agricultural patches from various hosts across Java and Sumatera (Table 1). Landscape structure was identified to affect the species richness and distribution of egg parasitoid community across the study area. Our survey has also identified that landscape mozaic affected the natural control of herbivorous insects in agroecosystem. This can be seen from higher parasitism recorded in complex habitat than in simple one (Figure 2). This was also verified by our work in evaluating effects of habitat complexes on parasitism that showed higher parasitism in complex habitat (71.6%) than in simple one (67.7%). Based on the result of field survey, we created possible pathway

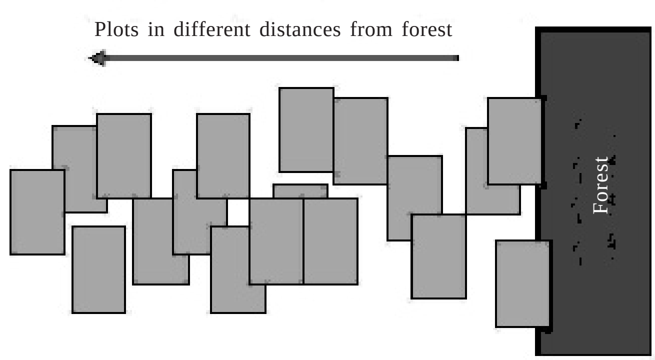

Figure 1. Schematic figure of cacao pantations situated in different distance from nearest forest.

Table 1. Species list of egg parasitoid recorded from various hosts across Java and Sumatera (Complex landscape: crops and non crop habitat; simple landscape: single crop in large area)

Spesies	Host	Habitat	Landscape	Sampling location
Trichogramma flandersi	*Plutella xylostella*	Cabbage habitat	Highland cabbage plantation mixed with other vegetable crops	Tawangmangu (Java)
Trichogramma japonicum	*Scirpophaga incertulas*	Paddy habitat	Paddy field (monoculture) in large area	Karawang, Bantul, Kulonprogo, Sleman, Umbul harjo (Java); Muara Laboh, Saning Bakar, Japonicum (Sumatera)
Trichogramma minutum	Pieridae	“Johar” in vegetable plantation	Highland vegetable plantations	Cianjur (Java)
Trichogrammatoidea cojuangcoi	-*Plutella xylostella* -Diptera Uknown	Cabbage habitat	Higland vegetable plantation both monoculture and polyculture (mixcrop: shallot, cauliflower, carrot, cabbage)	Lembang, Ciloto-Cianjur, Cisarua-Bogor, Tawangmangu, Pujon-Malang, Plumbon-Cirebon (Java); Saning Bakar (Sumatera)
Trichogrammatoidea armigera	-*Plutella xylostella* *Crocidolomia binotalis* -*Helicoverpa armigera* -*Scripophaga incertulas* -*Etiella zinckenella*	Cabbage habitat, paddy habitat, soybean habitat	Highland vegetable plantation with monoculture and polyculture, lowland paddy field, soybean plantation in small area.	Cisarua-Bogor Lembang, Cianjur, Malang, Situbondo (Java); Muara Laboh (Sumatera)
Telenomus remus	*Spodoptera* sp.	Shallot	Lowland	Cianjur, Karawang (Java)
Telenomus dignoides	*Sugarcane stemborer*	Sugar cane	Lowland sugar cane plantation in large area	Majalengka (Java)
Telenomus rowani	*Paddy stemborer*	Paddy habitat	Highland paddy field with complex landscape, lowland paddy with simple landscape in large area.	Halimun, Sukabumi, Bogor, Cianjur, Subang, Karawang (Java); Muara Laboh, Saning Bakar, Bengkulu (Sumatera)
Telenomus dignus	*Paddy stemborer*		Highland paddy field with complex landscape, lowland paddy with simple landscape.	Halimun, Sukabumi, Bogor, Subang, Karawang, (Java); Muara Laboh, Saning Bakar, Bengkulu (Sumatera)
Telenomus Javae	*Hidari Irava*	Coconut tree	Paddy landscape with surrounding coconut trees	Muara Laboh (Sumatera)
Trichogramma chilonis	*Paddy stemborer*	Paddy habitat	Paddy landscape with surrounding coconut	Muara Laboh (Sumatera)
Trichogrammatoidea bactrae-bactrae	*Helicoverpa armigera*	Corn plantation	Small scale corn plantation in complex lanscape with various crops	Bogor (Java)
Trichogrammatoidea bactrae fumata	*Helicoverpa armigera*	Corn plantation	Small scale corn plantation in complex lanscape with various crops	Bogor (Java)
Trichogramma chilotrae	*Helicoverpa armigera*	Corn plantation	Small scale corn plantation in complex landscape with variouss crops	Bogor (Java)

connecting the insect species according ecological function (host, parasitoid, hyperparasitoid) played by each recorded species. This would be powerful method to describe a possible interaction between species and the complexes of interaction in the field. More complicated and overlap interaction was recorded in complex landscape (Figure 3, in contrast simple interaction was found in simple landscape (Figure 4). Isolation between agricultural patches created a metapopulation of parasitoid species. This can be seen from the genetic distance of populations of *Trichogrammatoidea armigera in* the field.

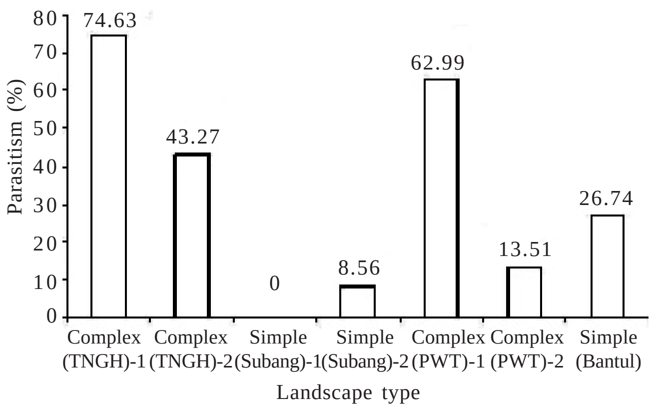

Figure 2. Parasitism level in complex habitat and in simple habitat from various regions in Java [TNGH: Taman Nasional Gunung Halimun (Gunung Halimun National Park); PWT: Purwokerto].

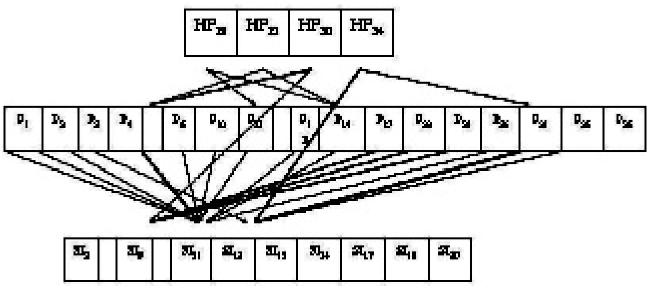

Figure 3. Thropic interaction between herbivorous insect, parasitoid and hyperparasitoid in complex habitat of paddy field (polyculture). (number of letter HP, P and SL, indicated the named species, example: species of hyperparsitoid number 20 attacked parasitoid number 11 that feed on its host number 11) (Source: Hamid 2002, part of the research series). HP: hiperparasitoid species, P: parasitoid species, Sl: host.

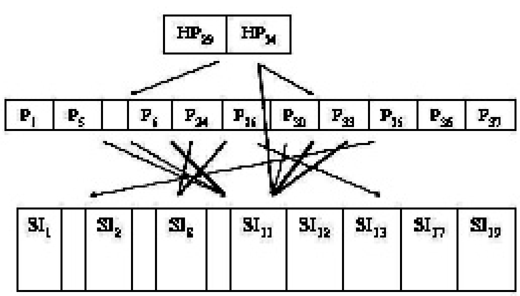

Figure 4. Thropic interaction between herbivorous insect, parasitoid and hyperparasitoid in simple habitat of paddy field (monoculture) (Source: Hamid 2002, part of the research series). HP: hiperparasitoid species, P: parasitoid species, Sl: host.

F_{ST} value was higher than zero, meaning that there is reproductive isolation between populations. This was confirmed by lower migration rate (Nm) that ranged between 0.3-1.3 (Table 2). Habitat isolation also affected the spatial dynamic pattern of parasitoid community. Our survey showed that species richness of parasitoid community decreased with increasing distance to the nearest forest and species composition was significantly different between habitat far away and near to natural habitat. There was also species turnover between sampling periods (Figure 5). Review of supported articles has resulted in a synthesis that is used to create a concept of promoting sustainable agriculture and ecosystem health by using parasitoid.

DISCUSSION

Agroecosystem Health and Sustainable Agriculture: The Role of Natural Enemies. Agriculture that relies heavily on the use of chemical pesticides and fertilizers has been shown to negatively effect the environment. Settle *et al.* (1996) reported that insecticide application had the largest negative effect on the functional group of natural enemies controlling rice brown planthopper such as surface dwelling predators from the family Veliidae, Microveliidae and Hydrometidae. Their research in Indonesia has revealed that insecticide applications in tropical rice are the most likely cause of pest

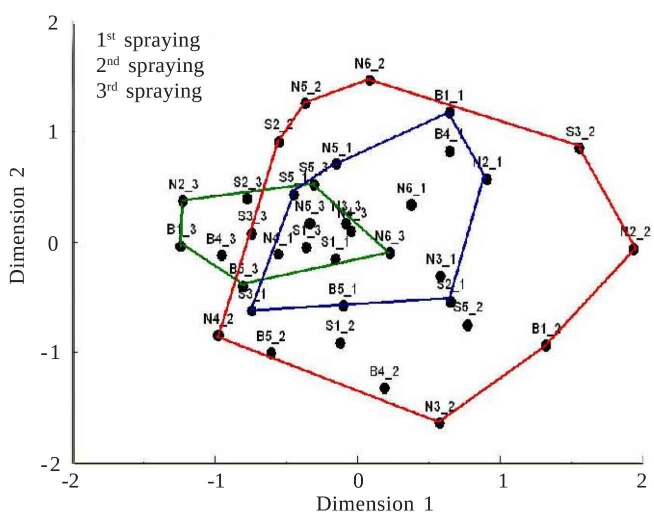

Figure 5. Two dimensional scaling plot based on Sørensen indices for measuring similarity of species composition between single cacao plantations and spraying periods. Samples from different spraying periods are connected by lines (codes, for example B5_2: B5 indicated a plot and 2 indicated a sampling period) (Source: Sahari 2004, part of the research series).

Table 2. Estimated F_{ST} and Nm between population of *Trichogrammatoidea armigera* collected from different location

Metod population	Wright (1951)		Weir and Cockerham (1984)		Lynch and Milligan (1994)	
	F_{ST}	Nm	È	Nm	F_{ST}	Nm
Malang	0.259 (0.231)*	0.7	0.426 (0.292)	0.3	0.380 (0.284)	0.4
Asembagus	0.206 (0.222)	1.0	0.244 (0.288)	0.8	0.304 (0.287)	0.6
Cianjur	0.250 (0.206)	0.7	0.382 (0.262)	0.4	0.419 (0.275)	0.3
Semua	0.162 (0.193)	1.3	0.305 (0.227)	0.6	0.295 (0.210)	0.6

*Standart deviation shown in bracket.

problem due to the resurgence of brown planthopper. Similar results were also reported by Lee *et al.* (2001) who explained that insecticide application caused an intense ecological disturbance on the predatory carabids beetles by disturbing its function as suppressant of pests. It evidently decreased beetle activity and the shift of the community composition in the crop areas. Those facts indicate that any manipulation of field ecosystem that modifies the natural interaction shall change the ecological processes that in the end can cause catastrophe to the system. This knowledge then pushes the development of healthy agroecosystem that promotes sustainability in agriculture. Consequently, conservation becomes an integral part of agriculture management. Thus, conservation of agroecosystem, where practices in agriculture restores, maintains or even increases the roles played by many components of agrobiodiversity, becomes the core of sustainable agriculture. Allowing different groups to function properly ensures the ecological processes to maintain the balance in agroecosystem. A key strategy in sustainable agriculture is to incorporate diversity into the agricultural landscapes that would enhance ecological processes such as parasitism and predation (Nicholls & Altieri 2004).

The important role of agroecosystem for biodiversity conservation has gained more recognition (Wood & Lenne 1999; Altieri & Nicholls 2004). This is in stark contrast to the past, where agroecosystem has been viewed as a modified ecosystem without conservation values and often regarded as a serious threat to biodiversity. Now, many more studies have shown the importance of agricultural system in maintaining biodiversity (Settle *et al.* 1996; Perfecto *et al.* 1997; Rice & Greenberg 2000; Klein *et al.* 2002; Beck *et al.* 2002; Alkorta *et al.* 2003). In the advent of new knowledge on the role of agroecosystem for biodiversity maintenance, more studies related to insect conservation and habitat management have taken place. This development in the science and knowledge of insect biodiversity and land use has added more important information for agriculture sustainability.

The functional roles of insects are well documented (Speight 1999; Price 2001). Of these, the most important functions for agroecosystems are the pests' regulators and pollinators. The central role of beneficial insects play in pollination and reducing pest populations has been shown in many studies (Luck & Dahlsten 1975; Settle 1996; La Salle 1997; La Salle & Gauld 1997; Neff & Simpson 1997; O'Toole 1997; Unruh & Messing 1997). Parasitic wasps are undoubtedly one of the most important components of agrobiodiversity (Clausen 1940; Huber 1993; Quicke 1997). Their ability to parasitize herbivorous insects and use them as hosts for their own reproduction can prevent pests outbreaks, and decrease the need to use chemical means in pest control (Clausen 1940; Noyes & Hayat 1984; Huber 1993; Godfray 1994). Among the parasitic wasps, Ichneumonidae and Braconidae are the most important families frequently encountered to attack a wide variety of Lepidoptera caterpillars, sawfly larvae, as well as larvae and adults of beetles (Clausen 1940). In the last 20 years, many families of parasitic Hymenoptera have been successfully utilized in agriculture to control pest population. One of them is *Encarsia formosa* (Aphelinidae), released to control *Bemisia argentifolii* (Homoptera) (Hoddle *et al.* 1997). In Indonesia, the release of *Diadegma semiclasum* (Ichneumonidae) to control diamondback moth in Sumatera, Sulawesi, and Java was also successfully performed (Sastrosiswojo 1996). Several studies also showed that the release of egg parasitoid Trichogrammatidae significantly decreased pest population in agricultural field Nurindah and Bindra (1989), Nurindah *et al.* (1993), Herlinda (1995), Marwoto and Supriyatin (1999). The release of egg parasitoid *Trichogrammatoidea bactrae-bactrae* has successfully parasitised more than 80% of sampled host eggs from agroecosystem (Marwoto & Supriyatin 1999). These facts showed that agroecosystem management should be geared toward the conservation of these beneficial insects.

Habitat Management and Utilization of Parasitoids for Agroecosystem Restoration. Parasitoid community: species richness and distribution. Utilization of parasitoid for biological control agents has been documented worldwide. In Indonesia, utilization of egg parasitoid of Trichogrammatidae was the most successful example. A series of survey to monitor the species richness and distribution of Trichogrammatid and Scelionid parasitoid in Java and Sumatra has recorded 9 Trichogrammatid species of 13 Trichogrammatids reported to occur in Indonesia (Meilin 1999; Meilin *et al.* 2000; Moy 2005; Bahagiawati *et al*. 2006) and five *Telenomus* species of ten (Hamid 2002; Tabadepu 2003). The result of those surveys implies that agroecosystem contains a high number of parasitoid that is potential to be used for biological control program.

Does Landscape Structure Affect Parasitoid Community? Landscape structure is known to effect parasitoid communities. Several studies have shown that under complex landscape, the community structure of parasitoids are more complex (Kruess & Tscharntke 1994). Implication of these findings is that habitat complexity poses a strong impact on parasitoid community and its functional role. This is true since several investigations revealed that the structural diversity of agricultural landscapes could have a strong impact on the diversity and abundance of natural enemies that occur within crops (Kruess & Tscharntke 1994; Menalled *et al.* 1999; Varchola & Dunn 1999; Marino & Landis 2000). Many studies have in fact proven that the degree of complexity is a critical factor in influencing natural enemy abundance in agricultural landscapes (Menalled *et al.* 1999; Thies & Tscharntke 1999; Banks 2004). Complex landscapes provide pollen, nectar, and alternative prey for predators and parasitoids (Banks 2004). Diverse systems can also support complex food webs and further interactions between species (Nicholls & Altieri 2004). This fact strongly suggested that beneficial insects and habitat management are the key strategy to integrate agriculture and biodiversity conservation.

Impact of Habitat Complexity Towards Parasitism Level. A survey on parasitism level and its relation to habitat type in Java has showed that higher parasitism level was recorded in complex habitat than simple habitat (Figure 1) (Hamid 2002). This was supported by a study to test the impact of habitat type (monoculture and complex or polyculture) towards parasitism of *Telenomus remus*. We found that parasitism level on the complex landscape (71.6%) was found to be higher than in simple one (67.7%) (Anggara 2005). Other studies have also shown similar result, that simplification of landscape can cause the disappearance of many beneficial insects. Thies and Tscharntke (1999) did a study looking at the effect of landscape structure on parasitism of the rape pollen beetle (*Meligethes aeneus*) and bud damage (oilseed rape, *Brassica napus*). Overall, their study showed that in structurally complex landscape, parasitism was higher and crop damage was lower than in simple landscapes. Menalled *et al*. 1999 compared the presence of natural enemies in complex versus simple habitat. However, their study found conflicting results. Only one location has more parasitism rate than simple landscape. A study did by Klein *et al*. 2002 further strengthen the fact that in agroecosystem, structural complexity, species richness, and biological control are often correlated (Klein *et al.* 2002).

Habitat Complexity and Trophic Interaction. Higher structural habitat diversity may provide a higher diversity of basal resources and therefore most likely support a higher diversity of insect communities (Hunter 2002). Increasing number of species diversity in agroecosystem, which is generated from increasing level of habitat complexity is expected to raise the rate of species interaction. It will be able to perform self-control of population. We did a survey to evaluate the relationship between habitat complexity in paddy field ecosystem and possible trophic interaction. The result of our survey identified that interaction among taxonomic group and functional group of insect diversity was more complex in the complex habitat (Figure 3 & 4). These findings suggest that monoculture, which is commonly associated with agriculture intensification will lead to biodiversity loss and the loss of many functions associated with the species. In contrast, habitat diversification may increase natural enemy effectiveness by increasing alternate food, host/prey availability, nectar sources and suitable microhabitats (Sheehan 1986).

Population Structure and Genetic Variability. Natural habitat conversion into agriculture can cause habitat fragmentation and geographical, which consequently create isolated population. Metapopulation as a collection of local populations (subpopulation) (Schoonhoven *et al.* 1998) may have a tremendous implication for biological control success. When genes exchange between populations is scarce, it could create sub populations that may increase genetic variation within a species. In long term, it might possibly trigger reproductive incompatibility due to reproductive isolation (Schoonhoven *et al.* 1998). Our work on population structure identified that there is a distinct genetic distance between subpopulation of *Trichogrammatoidea armigera* attacking *Helicoverpa armigera* eggs on cornfields. Low level of genetic flow among population indicated low migration rate that is capable of creating reproductive isolation (Bahagiawati *et al*. 2006). This was confirmed by cross mating test that there is a reproductive incompatibility among some subpopulations of *Trichogrammatoidea armigera* (Novianti 2006). Implication of these findings is important for mass rearing parasitoids in laboratory. Foundress population and genetic variability of the laboratory populations might effect the success rate of biological control application (Salbiah 2001). What needs to be further considered is how habitat fragmentation in the field causes the existence of metapopulations and what the effect of this condition to the ecology of parasitoids and its success in parasitizing their hosts?

Dynamic of Parasitoid Community: Time, Space or Habitat Specific Pattern? The success of biological control by using parasitoid in the field depends on the dynamic of parasitoid community, which is strongly affected by their habitat stability. Agricultural landscape is a dynamic mosaic of vegetation type. It creates spatial dynamic and it changes by time to time creating temporal variation. Different component of a landscape typically vary in their contribution to the species diversity in the ecosystem (Fleishman *et al*. 2003), including parasitoid community. Determination of what factor affecting the dynamic of parasitoid community is a crucial to develop appropriate strategy for biological control program. Our work in studying parasitoid dynamic in agroecosystem showed that the diversity of parasitoid increasing with time and plant phenology (Sulistyowati 2005). Similar result was documented by Ahmad *et al*. (2003) who found that low establishment of egg parasitoids was recorded in the early crop growing months and gradually increased to peak. Variation in space may also be represented by isolation of agricultural landscape from natural ecosystem that create structural gradient of habitat complexity. Distance from forest may also have an effect toward insect diversity and the services they provide. Klein *et al.* 2003 found that the diversity of social bees decreased with distance to the forest, hence effecting fruit set in areas at different distances of the forest. The response of parasitic wasp community towards isolation of cacao agroforestry system from natural forest was documented by Sahari (2004).

Implications for the Future of Agriculture. Agriculture sustainability through agroecosystem conservation will maintain the ecological function of natural processes in the field. One important factor in conservation of agroecosystem is conservation of natural enemies as a regulatory factor to curb pest explosion. Conservation of natural enemies means that habitat management is an important key (Figure 6). Habitat management means understanding the life history of the parasitoids, the tritrophic interactions between plants, herbivores as hosts and the ecology of the parasitoids/natural enemies. Habitat management has to consider all these factors and integrate it into decision-making process. Habitat management and how it influence population structure, community structure and host parasite interaction are important. Landscape complexity, polyculture, cultural methods to enhance parasitoids presence and non-pesticide technology should be used for sustaining agroecosystem health.

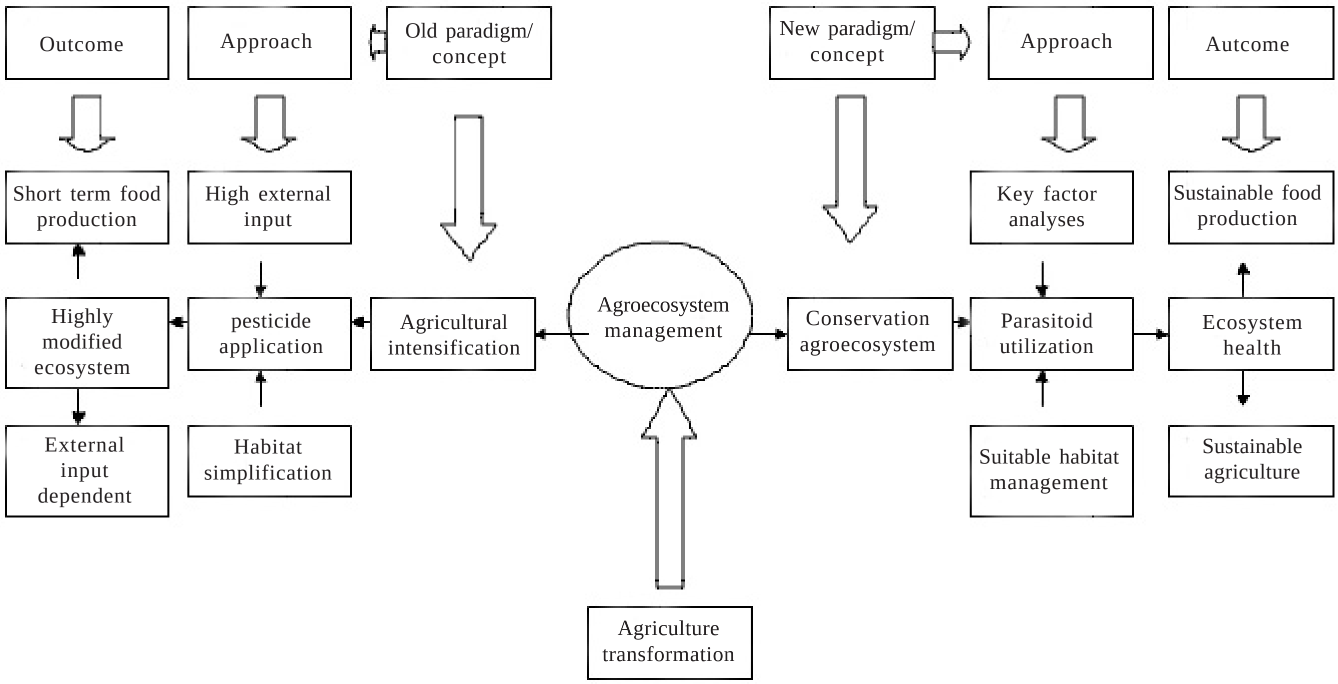

Figure 6. Analyses of agriculture transformation.

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