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# Comparative analysis of terrestrial arthropod community and biomass in differently managed rice fields in Korea

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**Abstract:** The present study was conducted to investigate the differences in managed farming practices, including low-intensive farming, duck farming, and golden apple snail farming, in a rice ecosystem by comparing terrestrial arthropod communities. A total of 75 species from 70 genera belonging to 43 families in 11 orders were identified from 9,622 collected arthropods. Araneae, Hemiptera, and Coleoptera were the richest taxa. Collembola was the most abundant, followed by Diptera, Hemiptera, and Araneae. Bray-Curtis similarity among the farming practices was very high (76.7%). The biodiversity of each farming practice showed a similar seasonality pattern. The richest species group was the predators, followed by the herbivores. The species richness and diversity of ecologically functional groups among the farming practices were not statistically significant, except for the abundance of predators in golden apple snail farming. The biodiversity seasonality of ecological functional groups in each farming practice showed similar patterns. The biomass of Araneae, Hemiptera, Coleoptera, and Diptera was greater than the other taxa, in general. The biomass of each ecological functional group showed little difference and the biomass fluctuation patterns in each farming practice were almost the same. Collectively, the community structures and biodiversity of terrestrial arthropods among the farming practices in the present study were not different. The present study may contribute to sustain rich biodiversity in irrigated rice fields and to advanced studies of food webs or energy flow structures in rice fields for ecological and sustainable agriculture.

**Keywords:** arthropod community, rice field, farming practice, ecological functional group, biodiversity, biomass, seasonality

## INTRODUCTION

Rice (*Oryza sativa* L.) is the most important staple crops in East and South Asia, the Middle East, Latin America, and the West Indies. Rice is normally grown as an annual plant with irrigated water. Over the last ten years, there has been an increased awareness of environment, human health and amenity features of agriculture. Recently, agriculture including rice culture is at a turning point from conventional farming which uses various agricultural pesticides to environmentally friendly farming or organic farming which uses environment friendly substances for plant pest and disease control worldwide including Korea for food security and sustainable agriculture. Agri-environment schemes including organic farming and other environmentally friendly practices are today considered the most important instruments to counteract the negative effects of modern agriculture (EEA 2004).

Community of rice ecosystem may vary with farming practices as well as with contiguous environment, varieties and cropping patterns. Arthropods are the main terrestrial invertebrates in rice fields. Arthropod community in rice fields consists mainly of insect and spiders. At rice establishment, arthropod species colonize and increase in diversity and abundance with successional age and their composition is known to change with the rice growth. Fernando (1993) stated that the ecology of the rice fields is dominated by rapid physical, chemical and biological changes. They also influent on the biomass change in rice ecosystem. Loevinsohn (1994) has discussed various forces that determine the presence and abundance of insect pests in rice agroecosystems, including their adaptations to the rice environment, the influence of the cropping system, and the dynamics of the pest populations in relation to the cultural environment. Seasonal fluctuation of arthropod abundance, diversity, species richness and biomass through community structure are thus important considerations in designing rice pest management strategies. Although the species composition of terrestrial arthropod pests and natural enemies in rice ecosystem throughout the world is frequently documented, only a few studies have examined the overall biodiversity in rice fields. And investigation on the biomass in rice ecosystem was very rare until now. Previous studies on the rice field biota in Korea mainly deal with inventory and seasonal fluctuation of certain rice insect pests, their natural enemies and the effect of insecticidal application on the both have been partially surveyed. Despite the recent growth of organic agriculture, there has been a lack of research-based information on which to base a greater understanding of the mechanisms operating in organic farming systems (Geoff *et al.* 2007).

The primary objective of present study was to investigate the differences among different farming practices in rice ecosystem through comparing community structure and biomass based on an intensive field survey. The specific objectives of the study were: First, to compare the community structures depend on the farming practices including ecological functional groups, Second, to determine the biomass of rice plant and arthropods, Third, to investigate the seasonal fluctuation of abundance and biomass throughout the rice growing season.

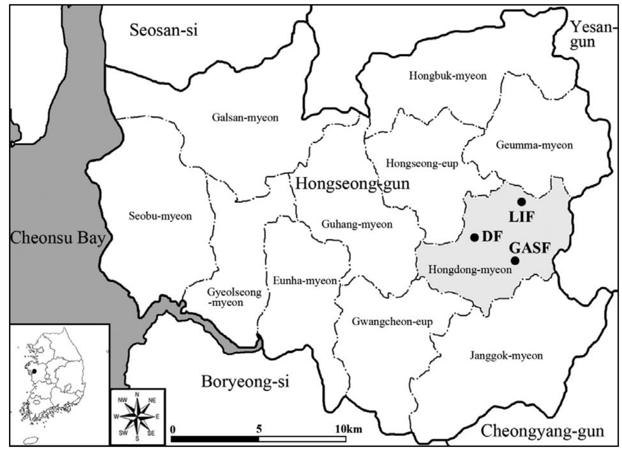


**Fig. 1.** Map of investigation area (LIF, low intensive farming; DF, duck farming; GASF, golden apple snail farming).

## MATERIALS AND METHODS

### 1. Study sites

The study was conducted on two environmentally friendly (duck farming and golden apple snail farming (*Pomacea canaliculata*)) and low intensively managed irrigated rice fields of Hongseong area in Chungcheongnam-do, Korea in 2010 (Fig. 1). Environmentally friendly and low intensively managed fields with the same variety were selected close together (within 3 km each other) to minimize the differences of community structure from regional micro-environmental variables and host plant preference. Investigated fields were about 0.2 ha (2,000 $m^2$) each. The fields were tilled and irrigated for about 10 days before transplanting. Rice seedlings were transplanted on around 5 June. Agricultural practices according to farming practices were summarized in Table 1.

### 2. Sampling and identification

Rice plants, soil and terrestrial arthropods were sampled total of 16 occasions by weekly during the rice growing season from transplanting to harvest. A battery-powered suction device (DC 12V, Bioquip Co., Rancho Dominguez, CA) was used to collect insects and spiders inhabiting the lower and middle parts of the rice plant above the water surface. Also, sweep net (38 cm in diameter) was used to collect insects and spiders inhabiting the upper and top section of the rice plant. Suction and sweeping were randomly selected in each occasion and made in 0.5 $m^2$, respectively. Sampling fields were replicated 3 times in each

 

**Table 1.** Control characteristics in rice fields according to farming practices

| Farming practices | Rice variety | Rice transplanting | Control characteristics | Control target |
|---|---|---|---|---|
| Low intensive farming | Glutinous rice (*Oryza sativa* var. *glutinosa*) | 5, June | Pesticides treated once at early after transplanting | *Lissorhoptrus oryzophilus* |
| Duck farming | | | Ducks released during 45–50 DAT | Pests / Weeds |
| Golden apple snail farming | | | Golden apple snails released throughout the rice growing season | Weeds |

**Table 2.** Comparisons of species richness, abundance and species diversity of arthropods in the farming practices

| Indices | Farming practices | | | ANOVA | |
|---|---|---|---|---|---|
| | Low intensive farming | Duck farming | Golden apple snail farming | *F* | *p* |
| Species richness (mean ± SE) | $38.67 \pm 2.73^{ab}$ | $41.00 \pm 1.00^{a}$ | $33.00 \pm 0.58^{b}$ | $5.78_{(2, 6)}$ | 0.040 |
| Abundance (mean ± SE) | $1219.33 \pm 89.76^{a}$ | $1080.33 \pm 43.35^{ab}$ | $908.67 \pm 40.67^{b}$ | $6.27_{(2, 6)}$ | 0.034 |
| Species diversity (mean ± SE) | $2.17 \pm 0.03$ | $2.28 \pm 0.04$ | $2.20 \pm 0.02$ | $3.99_{(2, 6)}$ | 0.079 |

farming practice. Each sampling was taken place at least 10 m apart from the plot edges. Sampled insects and spiders were brought to the laboratory and freeze to kill in −25°C and identified to species level under a dissecting microscope. Sampled arthropods were divided into five functional groups, general arthropods, herbivores, predators, parasitoids and filter feeder/detritivores as shown in Table 3.

### 3. Rice growth stages

Rice growth stages were determined as 5 stages; seedling stage (7–21 DAT), tillering stage (28–49 DAT), booting stage (56–63 DAT), heading stage (70–77 DAT) and ripening stage (84–112 DAT), based on the observation of rice growth in the fields. DAT in the manuscript and tables means days after transplanting.

### 4. Measurement of biomass

Samples (rice plant, insects and spiders) of each sampling date were dried in glass vials at 72°C for 72 hours for measurement of biomass and weighted to 2nd decimal point. Growth stage of insects and spiders include adults and juveniles from field samples were used to measure dry weight. In this way, measured biomass may reflect the real age structure of arthropods in the field. Abbreviations N and B in Appendix 1–3 means number of individuals and biomass, respectively.

### 5. Data analysis

Data from suction and sweeping are combined before analyzing. Because arthropods have different phenology and habitual space depends on the individual species, combined data may be more reliable for a comprehensive understanding of whole community structure. Community structure and biomass for each farming practice were compared. The total abundance of arthropods and species richness was determined seasonally for each farming practice. Biodiversity was calculated by means of the Shannon's diversity index (Shannon and Weaver 1949).

To summarize and compare terrestrial arthropods compositions among three different farming practices, a similarity matrix of Bray-Curtis similarity values (Clarke and Warwick 2001) obtained from the terrestrial arthropod community data was analyzed.

Multivariate analyses and calculation of the biodiversity index were performed using PRIMER v5.0 software (Clarke and Warwick 2001). One-way ANOVA (Proc GLM) in SAS (SAS Institute 2004) was used to compare differences among farming on the number of individuals, number of species and Shannon's diversity index. Mean separation was conducted with the Tukey HSD test.

## RESULTS

### 1. Terrestrial arthropod community structure, biodiversity and seasonality

A total of 75 species of 70 genera belonging to 43 families in 11 orders were identified from sampled arthropods, including a total of 9,622 individual arthropods (3,657

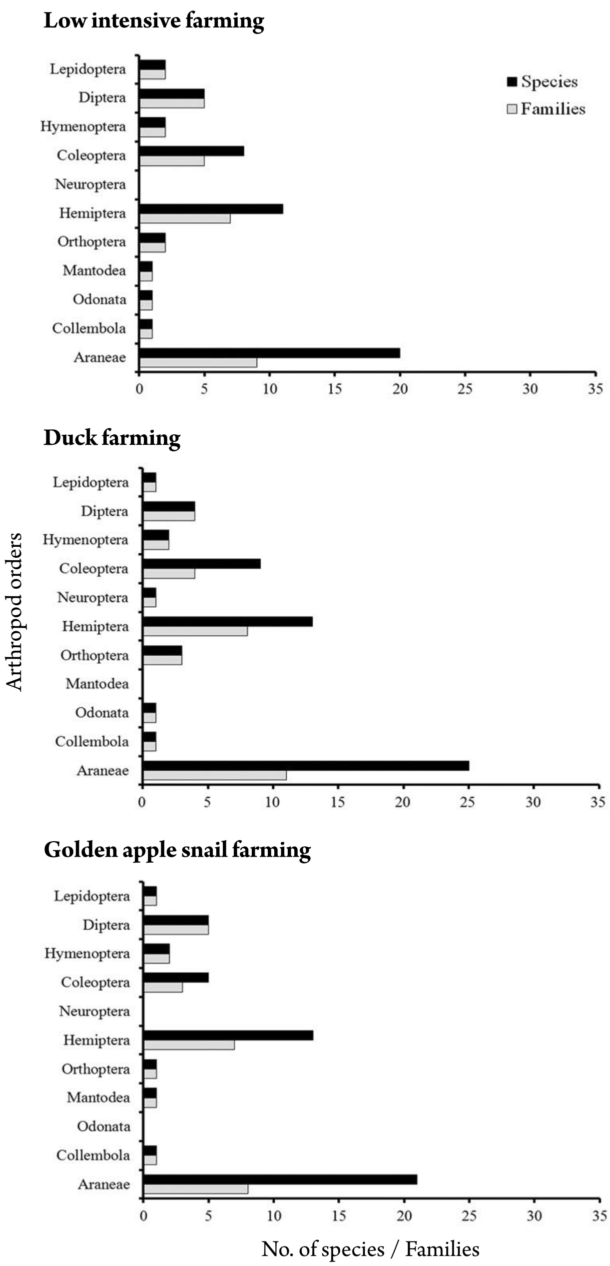


**Fig. 2.** Taxonomic richness of arthropods in each farming practice.

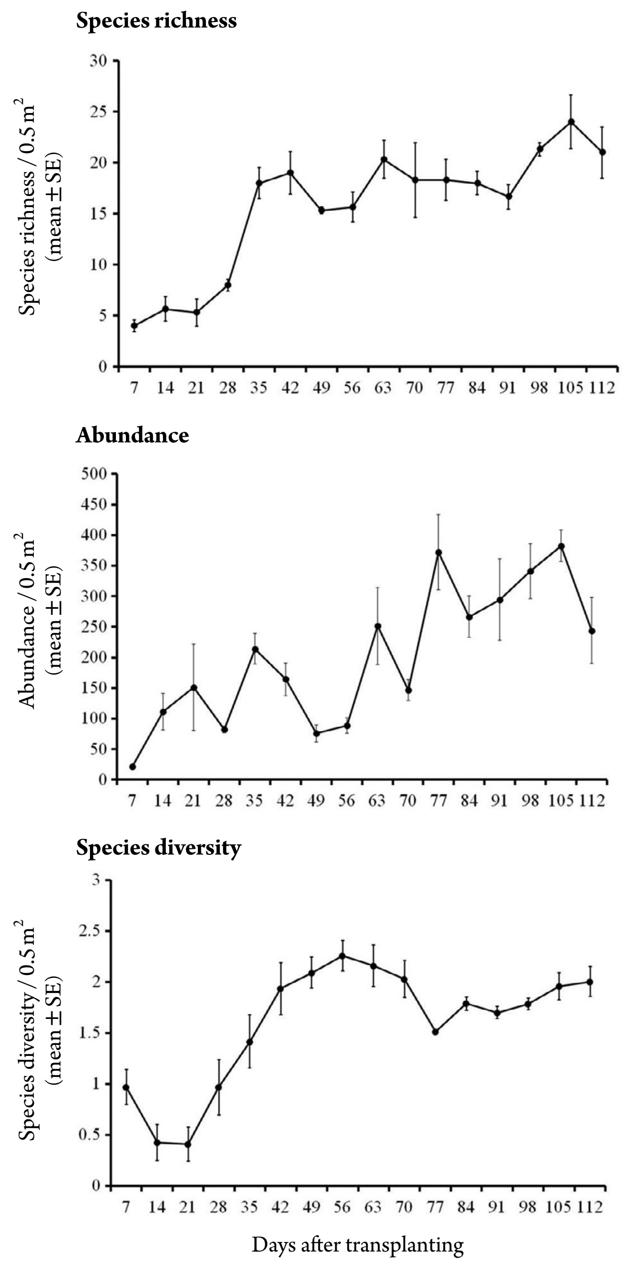


**Fig. 3.** Seasonality of arthropod biodiversity in rice fields.

from low intensive farming, 3,241 from duck farming and 2,724 from golden apple snail farming); 53 species of 50 genera belonging to 34 families in 10 orders from low intensive farming, 60 species of 58 genera belonging to 36 families in 10 orders from duck farming and 51 species of 47 genera belonging to 30 families in 9 orders from golden apple snail farming. A list of collected insects and spiders and their total abundance in the different farming practices throughout the rice growing season is presented in Appendix 1-3.

Of the 75 species collected, 42 were represented by $<10$ individuals, and 15 of these species were represented by only a single individual. Araneae (41.33%), Hemiptera (22.67%), Coleoptera (14.67%) and Diptera (6.67%) were by far the richest taxa collected in species richness (Fig. 2), collectively accounting for 85.33% of the total species richness. However, Collembola (33.29%) by only a single species was the most abundant followed by Diptera (24.15%),

 

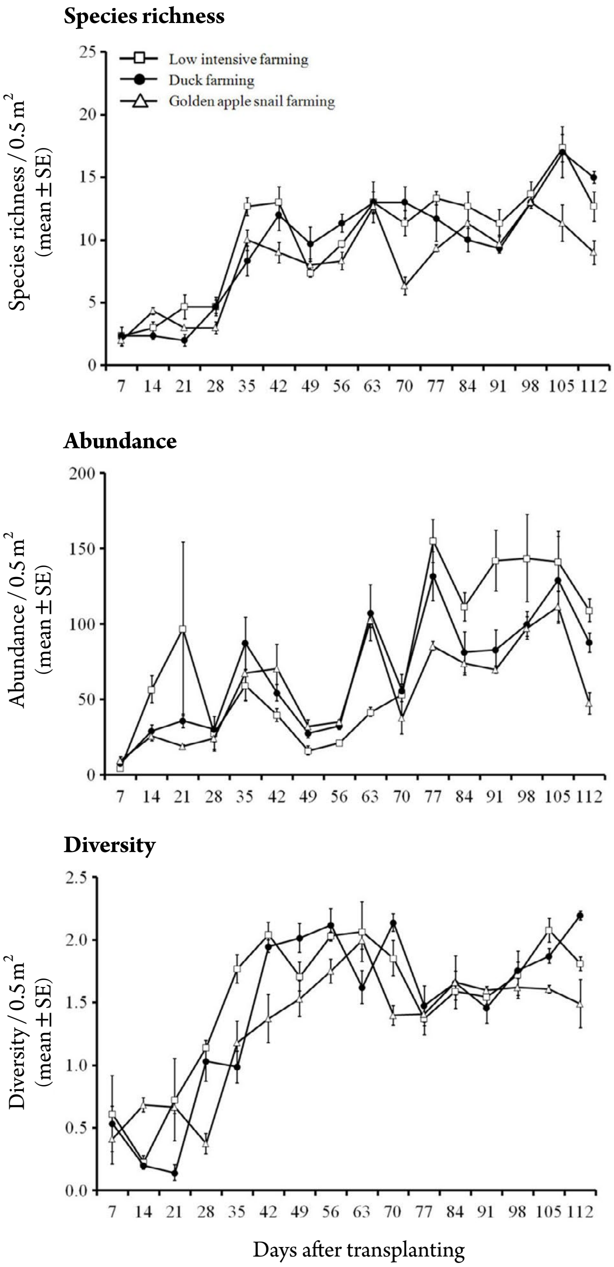


**Fig. 4.** Seasonality of species richness, abundance, and species diversity of arthropods in each farming practice.

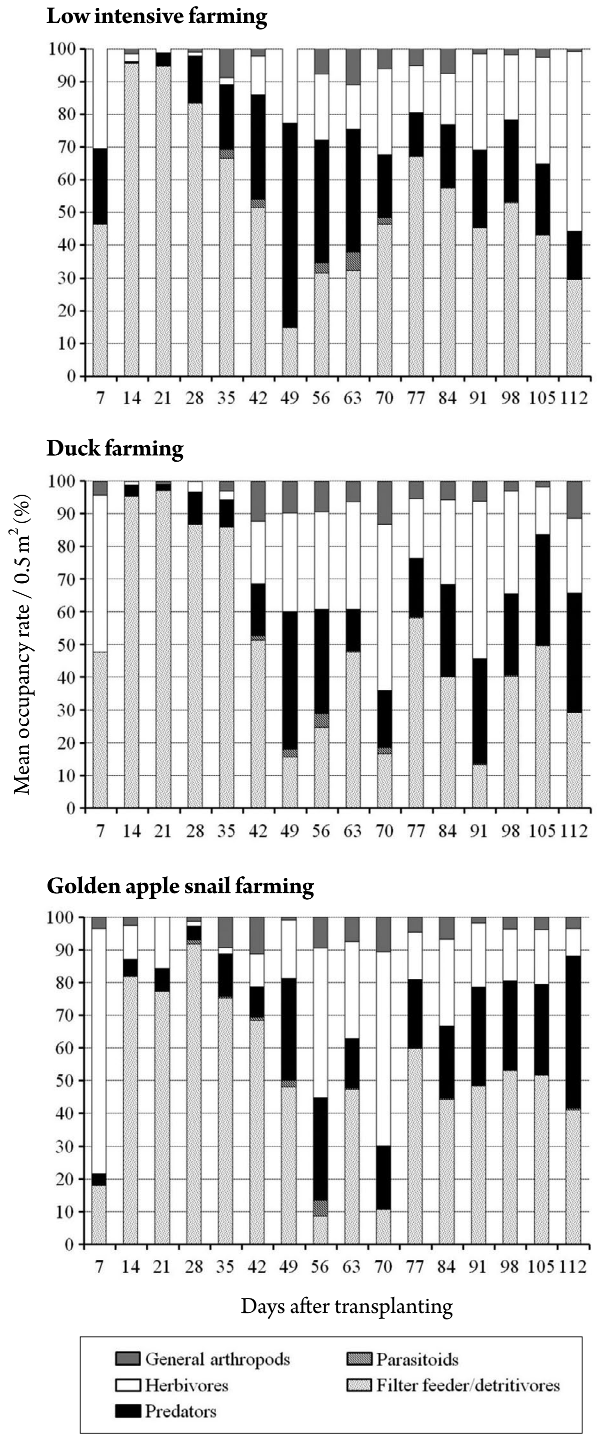


**Fig. 5.** Seasonality of percent occupation of ecological functional groups in each farming practice.

Hemiptera (18.46%), Araneae (19.90%) and Coleoptera (3.20%) in order (Fig. 5), collectively accounting for 99.00% of the total number of individuals collected. This composition structure was the almost same in different farming practices (Fig. 2).

Species richness among farming practices ranged 51 to 60 species. Species richness ($F_{2, 6} = 5.78$, $p = 0.040$) and abundance ($F_{2, 6} = 3.99$, $p = 0.034$) of golden apple snail farming was statistically significant with duck farming and

**Table 3.** Taxa allocated to ecological functional groups

| Ecological functional group | Order | Family | Scientific name |
|---|---|---|---|
| General arthropods | Diptera | Diptera | Diptera spp. |
| | | Tabanidae | Tabanidae sp. |
| Herbivores | Orthoptera | Acrididae | *Oxya chinensis sinuosa* |
| | | Gryllidae | Gryllidae sp. |
| | | Tettigoniidae | Tettigoniidae sp. |
| | Hemiptera | Aphididae | *Sitobion avenae* |
| | | Cicadellidae | *Nephotettix cincticeps*, *Recilia dorsalis* |
| | | Coreidae | *Cletus schmidti* |
| | | Delphacidae | *Laodelphax striatellus*, *Nilaparvata lugens*, *Sogatella furcifera* |
| | | Derbidae | *Diostrombus politus* |
| | | Hebridae | *Hebrus nipponicus* |
| | | Lygaeidae | Lygaeidae sp. |
| | | Miridae | *Trigonotylus coelestialium*, Miridae sp. |
| | | Pentatomidae | *Antheminia varicornis*, *Eysarcoris aeneus*, *Scotinophara lurida*, *Pentatomidae* sp. |
| | Coleoptera | Curculionidae | *Lissorhoptrus oryzophilus*, Curculionidae sp. |
| | | Elateridae | *Aeoloderma agnata* |
| | Lepidoptera | Noctuidae | *Naranga aenescens* |
| | | Pyralidae | *Cnaphalocrocis medinalis* |
| Predators | Odonata | Coenagrionidae | *Ischnura asiatica* |
| | Mantodea | Mantidae | *Tenodera aridifolia* |
| | Hemiptera | Ochteridae | *Ochterus marginatus* |
| | Neuroptera | Chrysopidae | Chrysopidae sp. |
| | Coleoptera | Carabidae | *Agonum daimio*, *Anoplogenius cyanescens*, *Lachnocrepis prolixa*, *Odacantha aegrota* |
| | | Coccinellidae | *Propylea japonica*, Scymnini sp. |
| | | Staphylinidae | *Paederus fuscipes*, *Stenus distans* |
| | Diptera | Sciomyzidae | *Sepedon aenescens* |
| | Araneae | Araneidae | *Larinioides cornutus*, *Neoscona adianta*, *Neoscona scylloides* |
| | | Clubionidae | *Clubiona kurilensis* |
| | | Ctenidae | *Anahita fauna* |
| | | Gnaphosidae | *Zelotes* sp. |
| | | Linyphiidae | *Bathyphantes gracilis*, *Erigone koshiensis*, *Gnathonarium dentatum*, *Ummeliata insecticeps* |
| | | Lycosidae | *Arctosa ebicha*, *Pirata subpiraticus*, *Trochosa ruricola* |
| | | Nesticidae | *Nesticella mogera* |
| | | Pisauridae | *Dolomedes sulfureus* |
| | | Salticidae | *Mendoza canestrinii*, *Mendoza elongate*, *Myrmarachne formicaria*, *Sibianor pullus* |
| | | Tetragnathidae | *Pachygnatha clercki*, *Pachygnatha quadrimaculata*, *Pachygnatha tenera*, *Tetragnatha maxillosa*, *Tetragnatha vermiformis* |
| | | Theridiidae | *Chrysso octomaculata*, *Enoplognatha abrupta*, *Paidiscura subpallens*, *Parasteatoda oculiprominens* |
| | | Thomisidae | *Ebrechtella tricuspidata*, *Ozyptila nongae*, *Xysticus* sp. |
| Parasitoids | Hymenoptera | Braconidae | Braconidae sp. |
| | | Ichneumonidae | Ichneumonidae sp. |
| | Diptera | Tachinidae | Tachinidae sp. |
| Filter feeder/ detritivores | Collembola | Tomoceridae | Tomoceridae sp. |
| | Diptera | Chironomidae | Chironomidae sp. |

low intensive farming, respectively (Table 2). According to Bray-Curtis similarity, community structure of arthropods was divided into two groups; low intensive farming and golden apple snail farming vs. duck farming. Similarity among farming practices, however, was very high in 76.7%.

Seasonality of species richness, abundance and species diversity of the total throughout the rice growing season are shown in Fig. 3. Species richness increased from 21 DAT and showed serrated pattern with 3 peaks. Abundance increased just after transplanting and showed serrated pattern

 

**Table 4.** Comparisons of species richness in the functional groups in the farming practices

| Biodiversity index | Ecological functional group | | Farming practices: Low intensive farming (mean ± SE) | Duck farming (mean ± SE) | Golden apple snail farming (mean ± SE) | ANOVA: $F$ | $p$ |
|---|---|---|---|---|---|---|---|
| Species richness | General arthropods | | 1.33 ± 0.33 | 1.00 ± 0.00 | 1.67 ± 0.33 | $1.50_{(2, 6)}$ | 0.296 |
| | Herbivores | | 12.67 ± 0.33 | 14.00 ± 1.53 | 11.33 ± 0.67 | $1.85_{(2, 6)}$ | 0.237 |
| | Natural enemy | Predators | 20.67 ± 2.33 | 22.67 ± 0.88 | 16.33 ± 0.33 | $4.96_{(2, 6)}$ | 0.053 |
| | | Parasitoids | 1.67 ± 0.33 | 1.33 ± 0.33 | 1.33 ± 0.33 | $0.33_{(2, 6)}$ | 0.729 |
| | Filter feeder/detritivores | | 2.00 ± 0.00 | 2.00 ± 0.00 | 2.00 ± 0.00 | – | – |
| Abundance | General arthropods | | 44.67 ± 7.36 | 61.67 ± 4.33 | 51.00 ± 5.03 | $2.25_{(2, 6)}$ | 0.186 |
| | Herbivores | | 254.00 ± 13.05 | 254.33 ± 33.72 | 179.33 ± 11.78 | $3.87_{(2, 6)}$ | 0.083 |
| | Natural enemy | Predators | 235.67 ± 4.10$^a$ | 240.33 ± 8.33$^a$ | 198.33 ± 6.06$^b$ | $12.93_{(2, 6)}$ | 0.007 |
| | | Parasitoids | 8.00 ± 2.08 | 5.00 ± 1.00 | 4.67 ± 0.67 | $1.75_{(2, 6)}$ | 0.252 |
| | Filter feeder/detritivores | | 676.67 ± 94.77 | 519.00 ± 27.02 | 474.67 ± 23.38 | $3.30_{(2, 6)}$ | 0.108 |
| Species diversity | General arthropods | | 0.03 ± 0.03 | 0.00 ± 0.00 | 0.06 ± 0.03 | $1.43_{(2, 6)}$ | 0.311 |
| | Herbivores | | 1.70 ± 0.04 | 1.61 ± 0.10 | 1.58 ± 0.05 | $0.85_{(2, 6)}$ | 0.474 |
| | Natural enemy | Predators | 1.83 ± 0.15 | 1.75 ± 0.12 | 1.61 ± 0.02 | $1.04_{(2, 6)}$ | 0.410 |
| | | Parasitoids | 0.28 ± 0.15 | 0.23 ± 0.23 | 0.23 ± 0.23 | $0.02_{(2, 6)}$ | 0.983 |
| | Filter feeder/detritivores | | 0.59 ± 0.04 | 0.64 ± 0.03 | 0.66 ± 0.01 | $1.30_{(2, 6)}$ | 0.340 |

with 5 large or small peaks. Species richness increased from 21 DAT with the peak at 56 DAT and stabilized at 84 DAT. Biodiversity of each farming practice showed a similar seasonality pattern.

## 2. Structure and seasonality of ecological functional groups

Taxa allocated to ecological functional groups based on the feeding habit are shown in Table 3. Species richness of predators and herbivores were higher than the others, accounting for 44 species of 20 families and 24 species of 16 families, respectively. The most abundant arthropods of ecological functional groups were almost same in each farming practice. The most abundant general arthropod was Diptera spp. The most abundant herbivores were *Nephotettix cincticeps* of Cicadellidae and *Sogatella furcifera* of Delphacidae in Hemiptera. Tomoceridae sp. of Collembola and Chironomidae sp. of Diptera belonging to filter feeders or detritivores were found in very high number throughout the rice growing season. The most abundant parasitoids were Braconidae sp. of Hymenoptera which was observed throughout the season in all farming practices. Rice field spiders were the most abundant among natural enemy groups. They made up approximately 92.4% (low intensive farming 89.2%, duck farming 93.1% and golden apple snail farming 94.9%) in abundance from the whole natural enemy groups. The most abundant spider species which is the main predator group in rice fields was *Pirata subpiraticus* of Lycosidae.

Species richness and diversity of ecological functional groups among farming practices were not statistically significant. However, abundance of predators in golden apple snail farming was statistically significant with the others ($F_{2, 6} = 12.93$, $p = 0.007$). Filter feeder/detritivores were the most abundant followed by herbivores and predators. Species diversity was the highest in predators followed by herbivores (Table 4).

Seasonality of species richness, abundance and species diversity of ecological functional groups in each farming practice throughout the rice growing season which were shown in Fig. 4 showed a similar pattern. Seasonal fluctuations of biodiversity showed serrated pattern and their values increased with the time to harvest. Species richness increased rapidly at 35 DAT and reached the 2$^{nd}$ peak at 105 DAT. Abundance showed 5 peaks at 21, 35, 63, 77 and 105 DAT, respectively. Species diversity showed rapidly increase after transplanting and decreased at 70 DAT. General patterns of seasonality of abundance and relative portion of ecological functional groups among farming practices showed somewhat different. Despite this, some ecological functional groups showed common fluctuation in seasonality. Herbivores which was a mainly *Lissorhoptrus oryzophilus* in seedling stage (7–20 DAT) and mixed of planthoppers, leafhoppers and moths with *L. oryzophilus* after late tillering stage (49 DAT) were abundant in early transplanting period (7 DAT) and late tillering stage (49 DAT) to ripening stage (84–112 DAT). Predators which were mainly composed of spiders were abundant from early tillering stage (14 DAT) to ripening stage. Herbivores fluctuated with the opposite of predators. In other words, when predators increased, herbivores decreased and vice versa (Fig. 5).

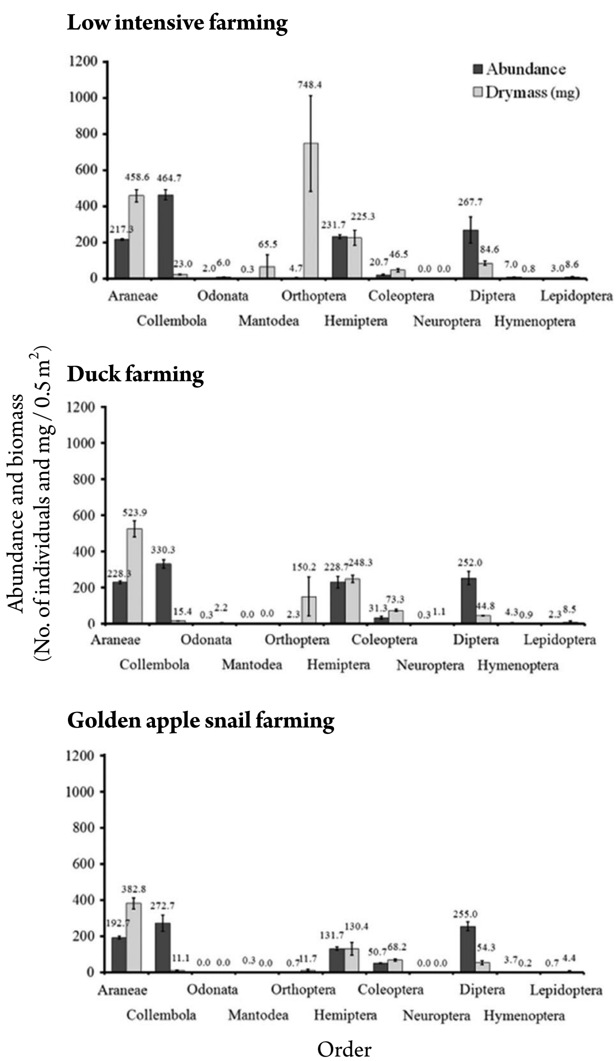


Fig. 6. Abundance and biomass of arthropod orders in each farming practice.

## 3. Biomass fluctuation of rice plant and arthropods

Density and biomass of each arthropod are shown in

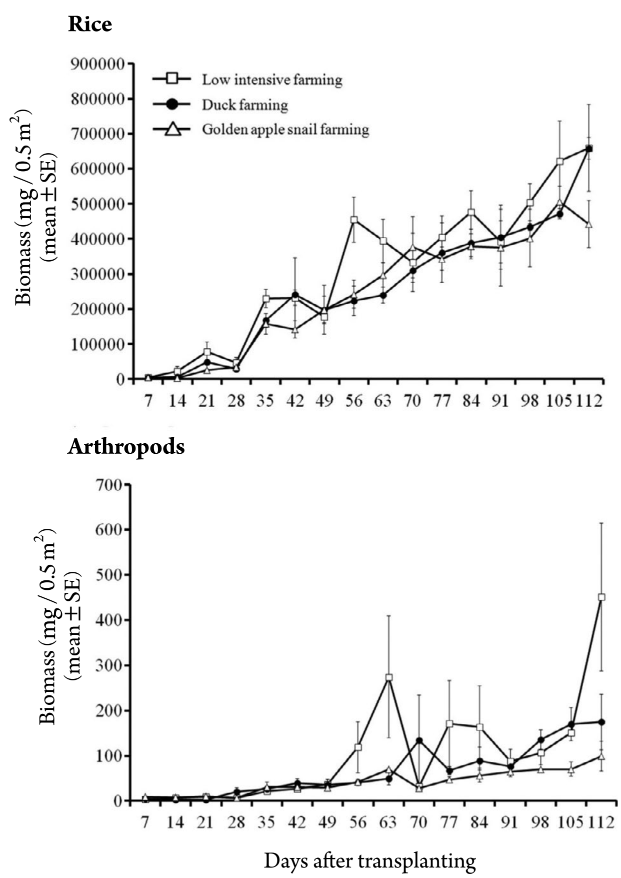


Fig. 7. Seasonality of biomass of rice and arthropods in each farming practice.

Table 5. Comparisons of rice biomass and ecological functional groups in the farming practices

| Ecological functional group | | | Farming practices: Low intensive farming (mg, mean ± SE) | Farming practices: Duck farming (mg, mean ± SE) | Farming practices: Golden apple snail farming (mg, mean ± SE) | ANOVA: *F* | ANOVA: *p* |
|---|---|---|---|---|---|---|---|
| Rice | | | 314516.38 ± 127168.03 | 261498.17 ± 11180.17 | 245432.10 ± 102878.26 | $1.60_{(2, 6)}$ | 0.278 |
| Arthropods | General arthropods | | 52.14 ± 12.63 | 41.01 ± 2.13 | 50.49 ± 8.29 | $1.67_{(2, 6)}$ | 0.265 |
| | Herbivores | | 999.48 ± 228.53[a] | 434.53 ± 96.28[ab] | 201.9 ± 29.70[b] | $8.09_{(2, 6)}$ | 0.020 |
| | Natural enemy | Predators | 591.81 ± 68.81 | 576.23 ± 39.16 | 399.33 ± 24.78 | $4.98_{(2, 6)}$ | 0.053 |
| | | Parasitoids | 0.85 ± 0.20 | 1.43 ± 0.59 | 0.33 ± 0.07 | $2.25_{(2, 6)}$ | 0.186 |
| | Filter feeder/detritivores | | 44.62 ± 5.17 | 38.52 ± 4.19 | 48.57 ± 3.85 | $1.30_{(2, 6)}$ | 0.339 |

 

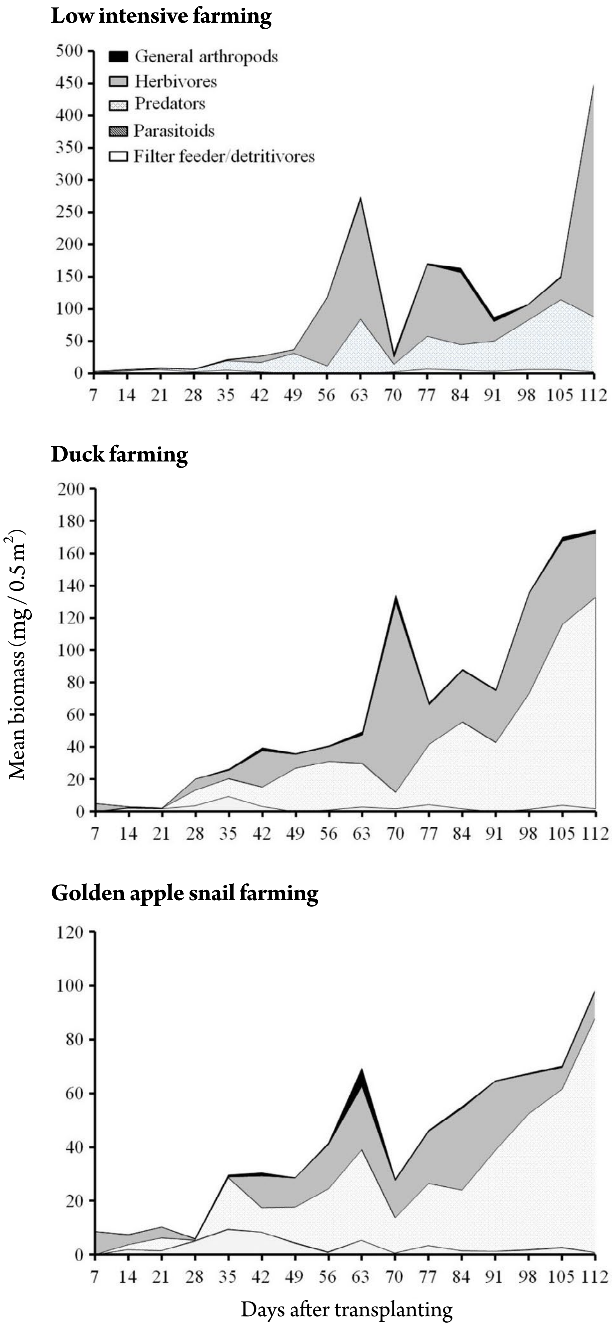


**Fig. 8.** Seasonality of arthropod biomass in each farming practice.

Appendix 1–3. In the biomass of arthropod families, Araneae was the highest in duck farming and golden apple snail farming, whereas Orthoptera was the highest in low intensive farming (Fig. 6). Hemiptera, Coleoptera and Diptera were greater than the other taxa in general. Despite high abundance of Colembolla and Diptera, their biomasses were relatively too low. Biomass of rice plant among farming practices was not significantly different as well as in general arthropods, predators, parasitoids and filter feeder/detritivores. Biomass of herbivores of low intensive farming ($F_{2, 6} = 8.09$, $p = 0.020$) was significantly different with the others (Table 5).

Biomass of rice plant and arthropods increased with rice growth from transplanting to harvest in all farming practices (Fig. 7). Biomass fluctuation of ecological functional groups among farming practices is shown in Fig. 8. Though biomass of each ecological functional group showed little difference, fluctuation pattern of biomass in each farming practice was almost same. Total arthropod biomass increased gradually at late seedling stage (28 DAT) and was higher at late booting stage (63 DAT) and late ripening stage (112 DAT). Seasonal fluctuation of each ecological functional group among farming practices is shown in Fig. 9. All ecological functional groups showed similar fluctuating pattern except parasitoids. Seasonality of biomass of each ecological functional group was; (1) general arthropods increased from 56 DAT with 2 peaks, (2) herbivores were increased from 49 DAT and decreased from 91 DAT, (3) predators increased gradually from transplanting to harvest and parasitoids were the most unstable and fluctuating in each farming practice, and (4) filter feeder/detritivores were higher at the first half than the second half around 63 DAT.

## DISCUSSION

Most of the rice fields in Korea is now cultivated once a year with an intensive irrigated system. Irrigated rice fields are characterized as temporary aquatic agricultural ecosystems with a dry period, managed with a variable degree of intensity and various farming practices (Halwart 1994). Although being a monoculture agricultural ecosystem, a rice field undergoes three major ecological phases; aquatic, semi-aquatic and a terrestrial dry phase, during a single paddy cultivation cycle (Fernanado 1995).

Community and biodiversity in rice fields have been relatively well documented from tropical Asia; Heckman (1974, 1979) in Laos and Thailand, Heong *et al.* (1991) and Schoenly *et al.* (1996) in Philippines, and Bambaradeniya *et al.* (2004) in Sri Lanka. However, previous studies related to rice field fauna in Korea mainly deal with agronomic aspects, where the individual rice pests, their natural enemies

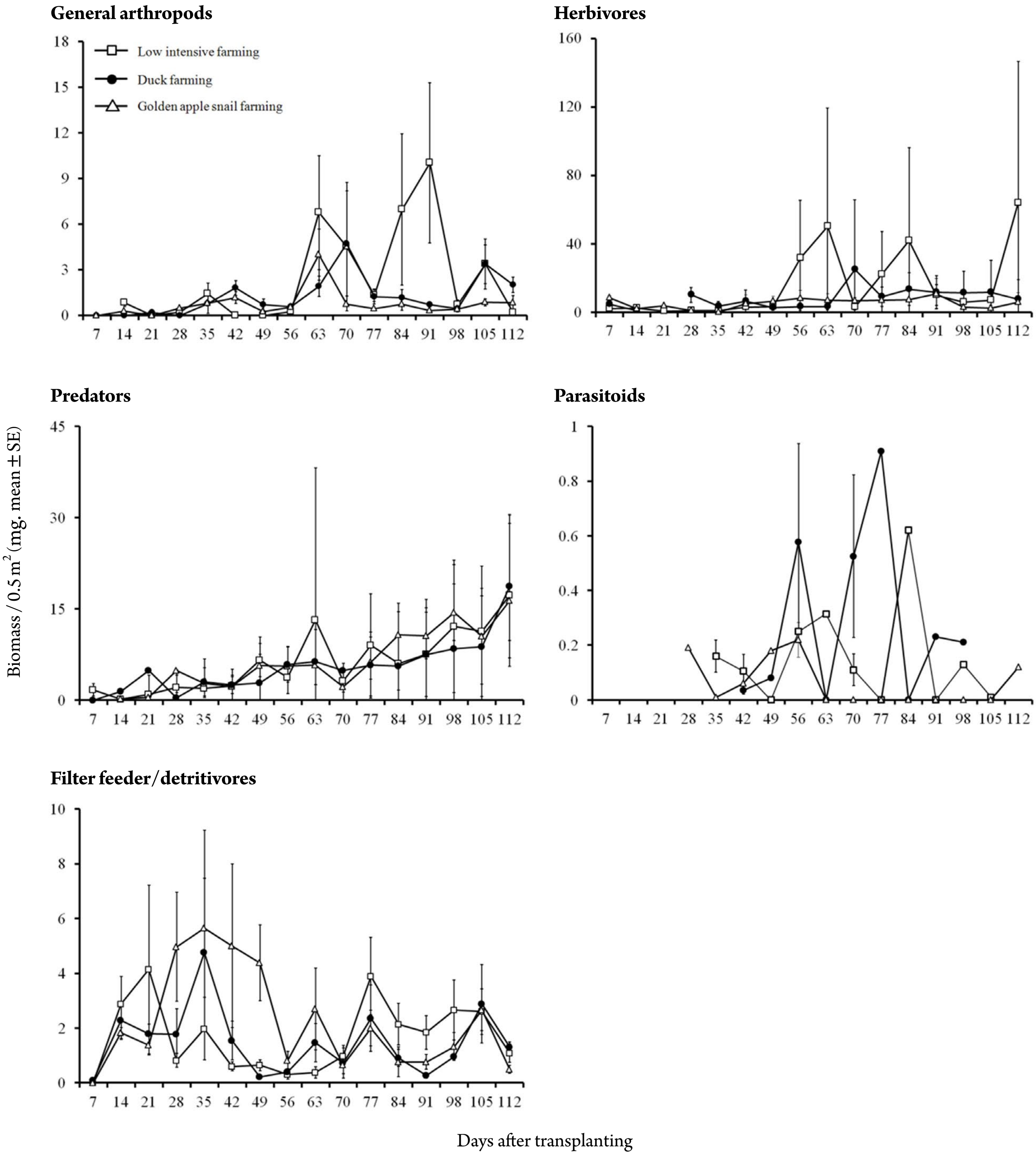


**Fig. 9.** Seasonality on biomass of ecological functional groups in each farming practice.

and resistant rice varieties, insecticidal effects to insect pests and natural enemies have been surveyed restrictively. As a result, there is not fully understandable documentation on the overall community and biodiversity from Korean rice fields. Moreover, despite increase of various environmentally friendly farming during last two decades, there was not comparative study between conventional farming and environmentally friendly farming. Therefore, present study will be a key study to understand the terrestrial arthropod fauna in Korean rice fields.

Present study identified a total of 75 species of 70 genera belonging to 43 families in 11 orders from 9,622 collected arthropods. Paik (1967) implicated 98 rice insect pests based on the former reports from Korean rice fields with 16 economically important species and Korean Society of Plant Protection (1986) listed 143 rice insect pests. Among them, some of the important species, rice stem borer (*Chilo suppressalis*), rice leaf beetle (*Oulema oryzae*), rice stem maggot (*Chlorops oryzae*) and rice leafminer (*Hydrellia griseola*) were not collected in study area. The colonization and occurrence of arthropods in rice fields depend not only on its irrigated conditions, but also on the presence of the rice plants and agricultural practices. Compositional structure among farming practices in present study, however, were the almost same. Araneae, Hemiptera, Coleoptera and Diptera were by far the richest taxa accounting for 85.33% of the total and Collembola by only a single species was the most abundant followed by Diptera, Hemiptera, Araneae and Coleoptera accounting for 99.00% of the total number of individuals collected. Our results indicate that terrestrial arthropod community in irrigated rice fields is structured by a few dominant taxa and surrogate that only a small number of hydrophilic taxa could adapt to the irrigated conditions in rice fields. Though golden apple snail farming was statistically significant with low intensive farming and duck farming in species richness and abundance, Bray-Curtis similarity showed very high similarity by 76.7% among farming practices. Biodiversity of each farming practice also showed a similar seasonality pattern.

In the ecological functional groups based on the feeding habit, most abundant arthropods of ecological functional groups were almost same in each farming practice. The most abundant herbivores were green rice leafhopper (*Nephotettix cincticeps*) and white backed planthopper (*Sogatella furcifera*) in Hemiptera. Rice field spiders (Araneae) were the most abundant among natural enemy groups occupying approximately 92.4%. Spiders have been known to play an important role in regulating insect pests in agricultural ecosystem (Specht and Dondale 1960; Nyffeler and Benz 1987; Sunderland 1999). Kiritani (1979) stated that lower pest densities have been attributed to spider activity in Asian rice fields. And the role of spiders as predators in reducing insect pests in rice fields were clearly described by many publications (Hamamura 1969; Sasaba *et al.* 1973; Gavarra and Raros 1973; Kobayashi 1977; Chiu 1979; Holt *et al.* 1987; Tanaka 1989; Barrion and Litsinger 1995; Settle *et al.* 1996). Contribution of spiders on the naturally occurred biological control seems to be universal in irrigated rice fields worldwide. Among the rice field spiders, the most abundant spider species was *Pirata subpiraticus* (Lycosidae). Rice field spiders are generalist predators and comprise 145 species of 84 genera in 22 families in Korea (Kim 1998). Among them, *P. subpiraticus* is the most abundant spider species throughout Korea (Park *et al.* 1972; Choi and Namkung 1976; Okuma *et al.* 1978; Paik *et al.* 1979; Paik and Namkung 1979; Yoon and Namkung 1979; Paik and Kim 1979; Im and Kim 1996; Yun 1997; Lee *et al.* 1998; Kim 1998; Kim *et al.* 2011). Predatory capacity of *P. subpiraticus* is the highest among rice field spiders (Paik *et al.* 1979; Lee and Kim 2001) and prey mostly on planthoppers and leafhoppers (Kim 1998; Yu *et al.* 2002). Hence, *P. subpiraticus* may play a greater role in suppressing planthoppers and lesfhoppers in Korean rice fields.

Species richness and diversity among farming practices was not statistically significant. Species richness and diversity were high in predators and herbivores were the next. Filter feeder/detritivores were the most abundant followed by herbivores and predators. In most instances, the species richness and abundance of the predator populations may be greater than those of pest populations, when little or no insecticides are used (Way and Heong 1994). However, abundance of predators in golden apple snail farming was statistically significant with the others. This result was caused by the decrease of the spiders. Rice fields of golden apple snail farming were damaged by wind and most of rice plants were collapsed covered with muddy soils. This condition, insufficient prey and unfavorable microhabitat, might accelerate the dispersal of spider assemblage to adjacent habitat. From the collective results, biodiversity among farming practices is also similar as well as in community composition. Additionally, draining of water resulted in a short semi-aquatic or dry phage after heading stage. During this phase, 14 arthropod species were newly introduced into the main fields from the levee. The dry rice plants also provided an ideal habitat for insects, while certain species of spiders also remained in the field. This confirmed the fact that newly introduced species enter the main fields when the fields begin to dry contribute to the biodiversity of rice fields.

Present study did not find remarkably different seasonality pattern in arthropod community as well as in ecological functional groups among farming practices. However, parasitoids showed very low abundance with fluctuating seasonality pattern. Generally, parasitoids are specialist predator which has narrow prey range and more sensitive to insecticides than generalist predators like spiders. Their small number and fluctuating pattern may be caused by long-term use of insecticides and prey selectivity. Present study found that when predators increased, herbivores decreased and vice versa. This surrogate that predators regulate insect pest population practically in terms of naturally occurred biological control. Seasonality has an important meaning more than simple numerical fluctuation of certain community. Wealthy information on the seasonality of ecological functional groups is essential for control decision making through scouting system. Integrated Pest Management (IPM) is a technology that resonates with the concepts of sustainable agricultural development. It is undeniable fact that IPM has been developed with plenty of ecological information such as agricultural environments, ecological characteristics of pests and natural enemies including community structure, biodiversity and seasonality, and development of low toxic and selective pesticides.

Present study determined the biomass of rice plants and terrestrial arthropods inhabiting in rice fields. In the biomass of arthropod families, Araneae was the highest and Hemiptera, Coleoptera and Diptera were greater than the other taxa in general. Menhinick (1967) reported that spiders constitute over 50% of both numbers and biomass of carnivorous arthropods. Though biomass of herbivores of low intensive farming was significantly different with the others, those of rice plant and ecological functional groups among farming practices seems to have similar biomass structure. The difference was caused by a single species with small number captured, adults of rice grasshopper (*Oxya chinensis sinuosa*), of which dry weight was 207.7 mg. Dry weight of rice grasshopper was heavier 32 folds than total mean of other arthropods. Biomass is one of another way to understand community structure and is generally a better indicator of the functionality of a species within a community through food web or energy flow, as it is strongly correlated with metabolism. Provencher and Riechert (1994) used computer simulations and field tests to show that an increase in spider species richness leads to a decrease in prey biomass. As Persson (1991) and Brown *et al.* (2004) stated, biomass is a key variable in ecology, particularly in terms of energy flow, productivity and food-web dynamics, and is a strong indicator of community structure.

Collectively, we conclude that community structure and biodiversity of terrestrial arthropods among farming practices in present study are not different. In other words, current farming practices in rice field ecosystem in Korea, operating on a temporal scale, may not be a major contributing factor to its rich and varied biodiversity. Certainly, cropping system or farming practices may influence the terrestrial arthropod community. However, our conclusion is reasonable with some points of view. Low intensive farming which use less insecticides for control of *Lissorhoptrus oryzophilus* did not disturb the overall community structure and biodiversity because of the limited efficacy and short duration of insecticides at early rice growing stage. Though, ducks may feed arthropods besides weeds, they did not influence the overall community structure and biodiversity. Because they were exposed to rice fields during 45−50 DAT and biodiversity began to colonize at 45−50 DAT with accumulation of arthropods. Golden apple snails for weed control which are present throughout the rice growing season through self-reproduction and omnivorous also did not change the overall community structure and biodiversity because they mainly inhabit under the irrigated water unlike terrestrial arthropods inhabiting above water surface and don't feed arthropods.

Until the late 1980s, biological conservation limited to undisturbed natural habitats. However, the focus on the biological conservation expanded to agricultural ecosystem for conservation of agricultural biodiversity and sustainable agriculture and since then. The study of biodiversity associated with agricultural ecosystems such as rice fields is of significance for agroecologists and conservation biologists, since maintenance of biological diversity is essential for productive agriculture, and ecologically sustainable agriculture is in turn essential for maintaining biological diversity (Pimental *et al.* 1992). As Bambaradeniya and Amarasinghe (2004) stated, there also do not seem to be ecological studies contrasting the biodiversity of traditional rain-fed ricelands with more intensive irrigated systems. Comparative biodiversity studies that would yield such temporal (i.e. before and after the replacement) or spatial (rice ecosystem vs. adjoining natural ecosystem, or traditional vs. intensive cultivation) contrasts could make a valuable contribution to knowledge that may result in the development of more ecologically friendly rice ecosystem. Maintaining or enhancing agricultural practices while using less pesticides through effective using of natural enemies will be promoted. Biodiversity implications of IPM are newly interesting research field. The results of the present study may clearly contribute to the irrigated rice fields towards sustaining a rich biodiversity and to advanced study such as food web or energy flow structure in rice fields in terms of ecological and sustainable agriculture.

 

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**Appendix 1.** List of arthropods with density and biomass in low-intensive farming

| Order | Scientific name | DAT | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7 | | 14 | | 21 | | 28 | | 35 | | 42 | | 49 | | 56 | | 63 | | 70 | | 77 | | 84 | | 91 | | 98 | | 105 | | 112 | |
| | | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B |
| Collembola | Tomoceridae sp. | | | 1 | 0.1 | 3 | 0.1 | 36 | 1.4 | 57 | 2.5 | 46 | 2.0 | | | 10 | 0.4 | 31 | 1.0 | 66 | 3.1 | 301 | 17.5 | 181 | 9.0 | 190 | 7.2 | 213 | 10.9 | 164 | 9.7 | 95 | 4.1 |
| Odonata | *Ischnura asiatica* | | | | | | | | | | | | | 1 | 3.9 | | | 1 | 3.1 | 1 | 2.4 | | | 1 | 3.4 | 1 | 2.1 | 1 | 2.9 | | | | |
| Mantodea | *Tenodera aridifolia* | | | | | | | | | | | | | | | | | 1 | 196.5 | | | | | | | | | | | | | | |
| Orthoptera | *Oxya chinensis sinuosa* | | | | | | | | | | | | | | | 2 | 290.4 | 4 | 537.7 | | | 1 | 169.2 | 1 | 290.4 | | | | | | | 3 | 863.4 |
| | Tettigoniidae sp. | | | | | | | | | | | | | | | 1 | 20.8 | | | | | 1 | 11.7 | | | | | | | | | 1 | 61.8 |
| Hemiptera | *Eysarcoris aeneus* | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 8.0 | | | | | | |
| | *Hebrus nipponicus* | | | | | | | | | | | | | | | | | | | 1 | 0.2 | | | | | | | 1 | 0.2 | 4 | 0.5 | | |
| | *Laodelphax striatellus* | | | | | | | | | | | 1 | 0.0 | | | 1 | 0.2 | 2 | 0.5 | | | 3 | 0.9 | | | | | 2 | 0.7 | | | 11 | 3.0 |
| | Lygaeidae sp. | | | | | | | | | | | | | | | | | 1 | 2.5 | | | | | | | | | | | | | | |
| | Miridae sp. | | | | | | | | | 1 | 0.2 | | | | | | | | | 1 | 0.1 | 2 | 0.3 | | | 1 | 0.0 | | | | | | |
| | *Nephotettix cincticeps* | | | | | | | | | | | | | | | 1 | 0.9 | | | 12 | 13.4 | 34 | 37.3 | 35 | 39.0 | 44 | 44.2 | 55 | 61.7 | 32 | 23.3 | 62 | 23.4 |
| | *Nilaparvata lugens* | | | | | | | | | | | | | | | | | 1 | 0.4 | 1 | 1.0 | | | | | 66 | 31.7 | 5 | 3.1 | 16 | 14.2 | 5 | 4.8 |
| | *Recilia dorsalis* | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 0.9 | | | | |
| | *Scotinophara lurida* | | | | | | | | | | | 1 | 18.1 | | | | | | | 1 | 8.4 | 8 | 104.8 | | | | | | | 2 | 45.6 | 4 | 116.0 |
| | *Sitobion avenae* | | | | | 3 | 0.2 | | | | | | | | | | | | | | | | | | | | | 4 | 1.0 | 71 | 13.1 | 92 | 16.8 |
| | *Sogatella furcifera* | | | | | | | | | | | 4 | 0.6 | 1 | 0.3 | 2 | 0.4 | 3 | 0.6 | 23 | 7.6 | 14 | 6.5 | 15 | 3.2 | 13 | 6.0 | 16 | 4.5 | 13 | 5.7 | 1 | 0.3 |
| Coleoptera | *Aeoloderma agnata* | | | | | | | | | | | | | | | 1 | 0.9 | | | | | | | | | | | | | | | | |
| | *Lachnocrepis prolixa* | | | | | | | | | | | | | 1 | 21.7 | | | | | | | | | 1 | 17.2 | 1 | 8.7 | | | | | 1 | 24.5 |
| | *Lissorhoptrus oryzophilus* | 4 | 4.6 | 4 | 5.3 | 1 | 1.3 | 1 | 1.1 | 2 | 2.6 | 6 | 7.4 | 8 | 9.5 | 5 | 5.9 | 4 | 4.8 | 3 | 3.0 | 4 | 4.2 | | | | | | | | | 1 | 1.1 |
| | *Odacantha aegrota* | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 6.2 | | | | |
| | *Paederus fuscipes* | | | | | | | | | 1 | 1.5 | | | | | | | 1 | 1.4 | | | | | | | | | | | | | 1 | 2.1 |
| | *Propylea japonica* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 0.4 | | |
| | Scymnini sp. | | | | | | | | | | | | | | | | | | | 1 | 0.3 | | | | | | | | | | | | |
| | *Stenus distans* | | | | | | | 1 | 0.8 | 1 | 0.4 | 1 | 0.7 | 1 | 0.9 | | | | | | | | | | | | | 2 | 0.7 | 1 | 0.5 | | |
| Hymenoptera | Braconidae sp. | | | | | | | | | 2 | 0.3 | 3 | 0.2 | | | 2 | 0.3 | 7 | 0.6 | 3 | 0.2 | | | 1 | 0.6 | | | 2 | 0.1 | 1 | 0.0 | | |
| | Ichneumonidae sp. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Diptera | Chironomidae sp. | 6 | 0.0 | 161 | 11.5 | 271 | 16.4 | 33 | 2.7 | 61 | 9.4 | 15 | 1.6 | 7 | 1.9 | 10 | 1.4 | 9 | 0.9 | 8 | 1.8 | 10 | 2.0 | 10 | 3.8 | 2 | 0.2 | 14 | 5.1 | 18 | 6.0 | 1 | 0.3 |
| | Diptera spp. | | | 3 | 1.7 | | | 1 | 0.2 | 16 | 2.9 | 3 | 0.0 | | | 5 | 0.8 | 14 | 13.5 | 9 | 1.0 | 25 | 4.0 | 26 | 20.9 | 7 | 20.1 | 9 | 2.1 | 12 | 6.8 | 3 | 0.4 |
| | *Sepedon aenescens* | | | | | | | | | 5 | 13.5 | 1 | 2.1 | 7 | 23.0 | | | 4 | 14.4 | 3 | 9.3 | 2 | 6.2 | 3 | 9.6 | 2 | 5.8 | 1 | 4.8 | | | 2 | 8.7 |
| | Tabanidae sp. | | | | | | | | | | | | | | | | | | | 1 | 17.2 | | | | | | | | | | | | |
| | Tachinidae sp. | | | | | | | | | 3 | 0.2 | | | | | | | | | | | | | | | | | | | | | | |
| Lepidoptera | *Cnaphalocrocis medinalis* | | | | | | | | | | | 1 | 0.7 | | | | | | | | | | | 1 | 3.2 | 1 | 1.6 | | | | | | |
| | *Naranga aenescens* | | | | | | | | | 1 | 0.5 | 1 | 2.6 | 2 | 7.6 | | | 2 | 9.5 | | | | | | | | | | | | | | |
| Araneae | *Arctosa ebicha* | | | | | | | | | | | | | 1 | 19.1 | | | | | | | 2 | 62.7 | | | | | | | 2 | 128.5 | 1 | 60.7 |
| | *Bathyphantes gracilis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 0.5 | 1 | 0.0 |
| | *Chrysso octomaculata* | | | | | | | | | 1 | 0.1 | | | | | | | 1 | 0.1 | 1 | 0.0 | 1 | 0.2 | 1 | 1.0 | 2 | 0.3 | | | 3 | 0.2 | | |
| | *Clubiona kurilensis* | 1 | 1.0 | | | | | | | 2 | 0.2 | 2 | 3.2 | 1 | 0.2 | | | 4 | 9.2 | 1 | 5.0 | | | 2 | 10.8 | 8 | 5.2 | 8 | 11.1 | 12 | 21.6 | 8 | 13.1 |
| | *Enoplognatha abrupta* | | | | | | | | | 3 | 3.9 | 5 | 3.3 | 1 | 0.8 | | | 1 | 7.0 | | | 2 | 9.8 | | | | | | | 2 | 1.8 | | |
| | *Erigone koshiensis* | | | | | | | | | | | | | | | | | 1 | 0.2 | | | | | 1 | 0.1 | | | | | | | | |
| | *Gnathonarium dentatum* | | | | | | | | | | | 1 | 0.0 | | | | | 1 | 0.1 | 1 | 0.4 | 2 | 0.4 | 1 | 0.5 | | | | | | | | |
| | *Mendoza canestrinii* | | | | | | | | | | | | | | | | | | | | | 2 | 1.6 | 1 | 3.9 | | | | | | | | |
| | *Mendoza elongata* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 6.0 | | |
| | *Neoscona adianta* | | | | | | | | | 2 | 0.1 | 1 | 0.1 | | | | | | | | | | | | | 1 | 15.7 | | | | | | |
| | *Nesticella mogera* | | | | | | | | | | | 1 | 0.4 | | | | | | | | | | | | | | | | | | | | |
| | *Pachygnatha clercki* | 1 | 0.0 | | | 3 | 1.0 | 5 | 12.4 | 2 | 3.5 | 6 | 22.6 | 1 | 2.7 | 1 | 1.5 | 5 | 9.3 | 1 | 0.3 | 4 | 11.8 | 5 | 10.1 | 5 | 7.6 | 8 | 31.0 | 10 | 16.1 | 3 | 11.0 |
| | *Pachygnatha quadrimaculata* | | | | | | | | | | | | | | | 1 | 0.7 | | | | | | | | | | | 1 | 0.6 | 1 | 0.4 | | |
| | *Paidiscura subpallens* | | | | | | | | | 1 | 0.0 | 1 | 0.0 | | | | | 1 | 0.6 | | | | | | | | | | | 1 | 0.0 | | |
| | *Pirata subpiraticus* | 1 | 4.2 | | | 2 | 2.6 | 1 | 0.3 | 10 | 13.9 | 14 | 13.6 | 14 | 18.4 | 14 | 24.5 | 21 | 8.4 | 20 | 19.2 | 33 | 49.3 | 38 | 58.9 | 63 | 89.7 | 78 | 156.1 | 29 | 108.0 | 26 | 132.7 |

**Appendix 1.** Continued

| Order | Scientific name | DAT 7 | | 14 | | 21 | | 28 | | 35 | | 42 | | 49 | | 56 | | 63 | | 70 | | 77 | | 84 | | 91 | | 98 | | 105 | | 112 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B |
| | *Sibianor pullus* | | | | | 1 | 2.7 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Tetragnatha maxillosa* | | | | | | | 1 | 1.0 | 4 | 9.3 | | | 1 | 1.4 | | | | | 1 | 0.7 | 1 | 1.6 | 4 | 1.9 | 3 | 1.8 | 5 | 15.8 | 1 | 0.7 | 2 | 0.7 |
| | *Tetragnatha vermiformis* | | | | | | | | | 1 | 0.8 | | | | | 1 | 1.5 | | | | | | | | | | | | | | | | |
| | *Ummeliata insecticeps* | | | 1 | 0.2 | 6 | 1.4 | 4 | 0.6 | 2 | 0.5 | 4 | 1.8 | 1 | 0.2 | 7 | 5.3 | 5 | 1.0 | 1 | 0.5 | 12 | 7.3 | 6 | 3.9 | 15 | 6.7 | 1 | 0.6 | 20 | 7.6 | 2 | 1.3 |
| | *Xysticus* sp. | | | | | | | | | | | 1 | 0.0 | | | | | | | | | 1 | 3.3 | | | | | 1 | 0.4 | 5 | 36.2 | 1 | 4.9 |

**Appendix 2.** List of arthropods with density and biomass in duck farming

| Order | Scientific name | DAT 7 | | 14 | | 21 | | 28 | | 35 | | 42 | | 49 | | 56 | | 63 | | 70 | | 77 | | 84 | | 91 | | 98 | | 105 | | 112 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B |
| Collembola | Tomoceridae sp. | | | | | | | 26 | 1.4 | 37 | 1.5 | 29 | 1.3 | | | 19 | 1.2 | 134 | 6.1 | 17 | 0.3 | 226 | 11.1 | 86 | 3.4 | 31 | 0.8 | 119 | 3.2 | 192 | 11.5 | 75 | 4.4 |
| Odonata | *Ischnura asiatica* | | | | | | | | | | | | | | | | | | | | | 1 | 6.7 | | | | | | | | | | |
| Orthoptera | Gryllidae sp. | | | | | | | | | | | | | 1 | 2.6 | | | | | | | | | | | | | | | | | | |
| | *Oxya chinensis sinuosa* | | | | | | | 1 | 17.9 | | | 1 | 39.7 | 1 | 4.7 | | | | | 1 | 279.0 | | | | | | | | | | | | |
| | Tettigoniidae sp. | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 27.0 | | | 1 | 79.7 |
| Hemiptera | *Antheminia varicornis* | | | | | | | | | | | | | | | | | | | | | 1 | 31.2 | 1 | 49.0 | | | | | | | | |
| | *Cletus schmidti* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 19.4 |
| | *Diostrombus politus* | | | | | | | | | | | | | | | | | | | 2 | 3.7 | | | | | | | | | | | | |
| | *Hebrus nipponicus* | | | | | | | | | | | | | 1 | 0.1 | | | | | | | | | | | | | 1 | 0.2 | 1 | 0.0 | 2 | 0.3 |
| | *Laodelphax striatellus* | | | | | | | | | | | | | | | 1 | 0.4 | 6 | 1.4 | | | | | 1 | 0.2 | | | 6 | 2.2 | 4 | 1.5 | | |
| | Miridae sp. | | | | | | | | | | | | | | | | | 4 | 0.3 | 2 | 0.0 | 4 | 0.6 | | | | | 1 | 0.1 | | | 1 | 0.2 |
| | *Nephotettix cincticeps* | | | | | | | | | 2 | 1.4 | 1 | 2.1 | | | 2 | 2.4 | 8 | 14.4 | 27 | 38.3 | 51 | 34.3 | 55 | 43.9 | 109 | 76.1 | 69 | 66.6 | 21 | 17.6 | 14 | 5.8 |
| | *Nilaparvata lugens* | | | | | | | | | | | | | | | | | | | | | | | | | 5 | 1.0 | 4 | 2.6 | 11 | 8.1 | 11 | 6.0 |
| | *Recilia dorsalis* | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 1.8 | 2 | 1.1 | 1 | 0.8 |
| | *Scotinophara lurida* | | | | | | | | | | | | | | | | | 1 | 0.6 | 1 | 1.0 | | | | | 1 | 17.5 | 3 | 84.6 | 4 | 123.6 | | |
| | *Sitobion avenae* | | | | | | | | | | | 1 | 0.1 | | | | | | | | | | | | | | | 2 | 0.3 | 10 | 1.0 | 29 | 6.5 |
| | *Sogatella furcifera* | | | | | | | | | | | 17 | 10.9 | 10 | 3.6 | 11 | 2.9 | 77 | 19.1 | 46 | 21.9 | 16 | 7.6 | 6 | 2.4 | 4 | 1.0 | 3 | 1.1 | 3 | 2.0 | | |
| | *Trigonotylus coelestialium* | | | | | | | | | | | | | | | | | | | 3 | 1.7 | | | | | 1 | 0.5 | | | | | | |
| Neuroptera | Chrysopidae sp. | | | | | | | | | | | | | | | | | | | 1 | 3.2 | | | | | | | | | | | | |
| Coleoptera | *Agonum daimio* | | | | | | | | | | | | | | | 1 | 5.1 | | | | | | | | | | | | | | | | |
| | *Anoplogenius cyanescens* | | | | | | | | | 1 | 4.1 | | | | | | | | | | | | | | | | | | | | | | |
| | *Lachnocrepis prolixa* | | | | | | | | | | | | | | | | | 1 | 12.1 | | | | | 1 | 10.0 | 1 | 19.4 | 1 | 5.3 | 2 | 39.2 | | |
| | *Lissorhoptrus oryzophilus* | 11 | 14.8 | 1 | 1.2 | | | 2 | 2.7 | 2 | 2.4 | 10 | 13.4 | 12 | 14.8 | 14 | 18.6 | 9 | 12.5 | 2 | 2.2 | | | | | | | | | | | | |
| | *Odacantha aegrota* | | | | | | | | | | | | | | | 1 | 2.9 | | | | | 1 | 1.4 | | | | | | | 6 | 23.2 | | |
| | *Paederus fuscipes* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 4.5 |
| | *Propylea japonica* | | | | | | | | | | | | | | | | | | | 1 | 2.8 | | | | | | | | | | | 1 | 0.1 |
| | Scymnini sp. | | | 1 | 0.5 | | | | | | | | | | | 1 | 0.7 | | | | | | | | | | | | | | | | |
| | *Stenus distans* | | | | | 1 | 0.9 | | | | | 1 | 0.3 | | | | | 3 | 1.2 | | | | | | | 1 | 0.6 | | | 2 | 2.4 | 1 | 1.1 |
| Hymenoptera | Braconidae sp. | | | | | | | | | | | 2 | 0.1 | 2 | 0.1 | 2 | 0.3 | 1 | 0.0 | 3 | 1.1 | 1 | 0.9 | | | 1 | 0.2 | 1 | 0.2 | | | | |
| | Ichneumonidae sp. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Diptera | Chironomidae sp. | 11 | 0.3 | 83 | 6.9 | 104 | 5.4 | 53 | 9.3 | 188 | 27.1 | 55 | 8.0 | 13 | 0.6 | 5 | 0.8 | 20 | 2.7 | 11 | 4.0 | 4 | 0.7 | 12 | 2.1 | 2 | 0.2 | 2 | 0.7 | 1 | 0.0 | 2 | 0.8 |
| | Diptera spp. | 1 | 0.0 | | | 1 | 0.2 | | | 8 | 2.3 | 20 | 5.5 | 8 | 1.4 | 9 | 1.7 | 20 | 5.8 | 22 | 14.2 | 21 | 3.7 | 14 | 2.4 | 15 | 2.2 | 9 | 1.4 | 7 | 6.8 | 30 | 6.1 |
| | *Sepedon aenescens* | | | | | | | | | | | | | 2 | 5.8 | | | | | 1 | 4.1 | | | | | | | | | | | | |
| | Tachinidae sp. | | | | | | | | | | | | | | | 2 | 1.5 | | | | | | | | | | | | | | | | |

 

**Appendix 2.** Continued

| Order | Scientific name | DAT 7 | | 14 | | 21 | | 28 | | 35 | | 42 | | 49 | | 56 | | 63 | | 70 | | 77 | | 84 | | 91 | | 98 | | 105 | | 112 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B | N | B |
| Lepidoptera | *Naranga aenescens* | | | | | | | | | 3 | 11.7 | 1 | 1.3 | | | 1 | 3.5 | 1 | 4.4 | 1 | 4.5 | | | | | | | | | | | | |
| Araneae | *Anahita fauna* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 8.8 | | |
| | *Arctosa ebicha* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 59.1 |
| | *Bathyphantes gracilis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 1.1 | | |
| | *Chrysso octomaculata* | | | | | | | | | | | | | | | | | | | 2 | 0.6 | 4 | 1.5 | 1 | 0.9 | | | | | | | | |
| | *Clubiona kurilensis* | | | | | | | | | 1 | 0.0 | 3 | 4.5 | 2 | 0.2 | | | | | 2 | 6.9 | 2 | 7.4 | 2 | 6.3 | 4 | 2.1 | 7 | 8.7 | 8 | 11.6 | 9 | 13.6 |
| | *Dolomedes sulfureus* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 12.5 | 3 | 27.1 |
| | *Ebrechtella tricuspidata* | | | | | | | | | | | | | | | | | | | | | | | 2 | 4.8 | | | | | | | | |
| | *Enoplognatha abrupta* | | | | | | | 1 | 0.7 | 2 | 5.3 | 2 | 6.8 | 1 | 1.0 | | | | | | | | | | | | | | | 2 | 0.8 | 1 | 0.9 |
| | *Erigone koshiensis* | | | | | | | | | | | 1 | 0.1 | | | | | | | | | | | | | | | | | | | | |
| | *Gnathonarium dentatum* | | | | | | | | | 2 | 0.2 | 3 | 0.2 | | | | | 2 | 0.5 | | | 1 | 0.6 | 4 | 0.7 | | | 2 | 0.7 | | | | |
| | *Larinioides cornutus* | | | | | | | | | | | 1 | 0.9 | | | | | | | | | | | | | | | | | | | | |
| | *Mendoza canestrinii* | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 17.7 | | | | |
| | *Neoscona adianta* | | | | | | | | | 1 | 0.0 | | | | | | | | | | | | | | | | | | | | | | |
| | *Ozyptila nongae* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1.4 | | |
| | *Pachygnatha clercki* | | | 2 | 0.2 | 1 | 0.1 | 3 | 15.0 | 5 | 14.4 | 4 | 0.4 | 7 | 7.9 | 9 | 17.3 | 5 | 7.0 | 1 | 0.0 | 10 | 13.3 | 2 | 5.4 | | | 11 | 51.9 | 26 | 137.6 | 23 | 141.0 |
| | *Pachygnatha quadrimaculata* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 1.6 | 5 | 4.1 |
| | *Pachygnatha tenera* | | | | | | | | | | | 1 | 1.7 | | | | | | | | | | | | | | | | | | | | |
| | *Paidiscura subpallens* | | | | | | | | | 1 | 0.0 | | | | | | | | | | | 1 | 0.4 | | | | | | | | | | |
| | *Parasteatoda oculiprominens* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 0.2 | | |
| | *Pirata subpiraticus* | | | | | | | 3 | 12.7 | 6 | 0.9 | 5 | 7.2 | 16 | 60.3 | 8 | 42.3 | 25 | 57.3 | 12 | 3.8 | 43 | 68.7 | 52 | 127.9 | 70 | 101.8 | 47 | 127.6 | 60 | 85.5 | 43 | 116.2 |
| | *Tetragnatha maxillosa* | | | | | | | 2 | 0.8 | 2 | 7.9 | 5 | 14.0 | 2 | 1.3 | 5 | 16.6 | 2 | 1.4 | 4 | 6.1 | 5 | 9.7 | 1 | 1.9 | 2 | 3.1 | | | 3 | 1.5 | | |
| | *Trochosa ruricola* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 22.6 |
| | *Ummeliata insecticeps* | | | | | | | | | 1 | 0.0 | | | 5 | 3.4 | 5 | 3.5 | 3 | 1.5 | 5 | 3.3 | 3 | 2.6 | 4 | 3.4 | 2 | 0.6 | 2 | 0.5 | 5 | 2.1 | 5 | 2.4 |
| | *Xysticus* sp. | | | | | | | | | | | | | | | 1 | 1.1 | | | | | | | | | | | 4 | 3.8 | 4 | 0.9 | | |
| | *Zelotes* sp. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 6.6 | 1 | 1.3 |

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**Appendix 3.** List of arthropods with density and biomass in golden apple snail farming

| Order | Scientific name | DAT 7 N | 7 B | 14 N | 14 B | 21 N | 21 B | 28 N | 28 B | 35 N | 35 B | 42 N | 42 B | 49 N | 49 B | 56 N | 56 B | 63 N | 63 B | 70 N | 70 B | 77 N | 77 B | 84 N | 84 B | 91 N | 91 B | 98 N | 98 B | 105 N | 105 B | 112 N | 112 B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Collembola | Tomoceridae sp. | | | | | | | | | 4 | 0.3 | 9 | 0.3 | | | | | 87 | 1.8 | 5 | 0.1 | 146 | 8.3 | 91 | 4.2 | 98 | 3.2 | 151 | 5.3 | 173 | 8.0 | 54 | 1.8 |
| Mantodea | *Tenodera aridifolia* | 1 | 0.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Orthoptera | Tettigoniidae sp. | | | | | | | | | | | | | | | | | | | | | 1 | 16.8 | 1 | 18.3 | | | | | | | | |
| Hemiptera | *Cletus schmidti* | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 17.4 | | | | |
| | *Eysarcoris aeneus* | | | | | | | | | | | | | 1 | 3.7 | | | | | | | | | | | | | | | | | | |
| | *Laodelphax striatellus* | | | | | | | | | | | | | | | 2 | 0.4 | | | | | | | 3 | 0.5 | | | 2 | 0.1 | 3 | 0.9 | | |
| | Miridae sp. | | | | | | | | | 1 | 0.3 | | | | | | | 1 | 0.0 | | | | | 1 | 0.6 | | | | | | | | |
| | *Nephotettix cincticeps* | | | | | | | | | | | 1 | 1.1 | | | | | 16 | 11.8 | 8 | 13.7 | 30 | 35.5 | 45 | 26.7 | 34 | 26.7 | 28 | 18.4 | 22 | 16.1 | 7 | 3.4 |
| | *Nilaparvata lugens* | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 | 4.4 | 2 | 1.1 | | |
| | *Ochterus marginatus* | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 10.5 | | | | | | |
| | Pentatomidae sp. | | | 1 | 1.9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Recilia dorsalis* | | | | | | | | | | | | | | | | | | | | | | | 2 | 0.7 | | | | | | | | |
| | *Scotinophara lurida* | | | | | | | | | | | 6 | 27.2 | | | | | | | | | | | 2 | 42.6 | 2 | 48.0 | | | | | 1 | 25.3 |
| | *Sitobion avenae* | | | | | | | | | 2 | 0.0 | | | | | | | | | | | | | | | | | 3 | 0.4 | 28 | 5.6 | 3 | 0.6 |
| | *Sogatella furcifera* | | | | | | | | | | | 11 | 3.3 | 1 | 0.3 | 5 | 1.3 | 35 | 8.9 | 55 | 22.3 | 4 | 1.9 | 5 | 1.9 | 4 | 1.6 | 2 | 0.0 | 1 | 0.7 | 1 | 0.5 |
| | *Trigonotylus coelestialium* | | | | | | | | | 1 | 0.4 | | | | | | | | | 1 | 2.5 | | | | | | | | | | | | |
| Coleoptera | Curculionidae sp. | | | 1 | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Lachnocrepis prolixa* | | | | | | | | | | | | | | | | | | | 1 | 16.4 | | | | | | | | | | | | |
| | *Lissorhoptrus oryzophilus* | 21 | 25.9 | 6 | 8.6 | 9 | 12.1 | 1 | 1.3 | | | 3 | 3.8 | 14 | 17.8 | 41 | 47.9 | 39 | 50.2 | 3 | 3.2 | 1 | 1.4 | | | 1 | 0.9 | 3 | 3.2 | | | | |
| | *Odacantha aegrota* | | | | | | | | | | | | | | | | | | | | | | | 3 | 8.4 | | | | | | | | |
| | *Stenus distans* | | | | | | | | | | | 1 | 0.8 | 1 | 0.8 | | | 1 | 0.9 | | | | | | | | | 1 | 0.4 | 1 | 0.2 | | |
| Hymenoptera | Braconidae sp. | | | | | | | 1 | 0.2 | 1 | 0.0 | 2 | 0.1 | 2 | 0.2 | 2 | 0.1 | 1 | 0.0 | | | | | 1 | 0.0 | | | | | | | 1 | 0.1 |
| | Ichneumonidae sp. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Diptera | Chironomidae sp. | 5 | 0.0 | 63 | 5.5 | 44 | 4.1 | 66 | 14.9 | 148 | 28.0 | 135 | 24.7 | 46 | 13.2 | 9 | 2.4 | 58 | 14.4 | 7 | 1.9 | 7 | 1.7 | 7 | 0.4 | 3 | 0.6 | 4 | 0.0 | | | 4 | 0.7 |
| | Diptera spp. | 1 | 0.0 | 2 | 0.3 | | | 1 | 0.5 | 19 | 2.4 | 24 | 3.5 | 1 | 0.3 | 10 | 1.7 | 21 | 6.0 | 12 | 1.5 | 12 | 1.4 | 15 | 2.2 | 4 | 0.6 | 11 | 1.2 | 13 | 1.7 | 5 | 1.7 |
| | *Sepedon aenescens* | | | | | | | | | | | | | 2 | 7.8 | 1 | 3.3 | | | | | | | | | | | | | | | | |
| | Tabanidae sp. | | | | | | | | | | | | | | | | | 2 | 14.0 | | | | | | | | | | | | | | |
| | Tachinidae sp. | | | | | | | | | | | | | | | 3 | 0.3 | | | | | | | | | | | | | | | | |
| Lepidoptera | *Naranga aenescens* | | | | | | | | | | | | | 1 | 10.8 | | | | | | | 1 | 2.4 | | | | | | | | | | |
| Araneae | *Chrysso octomaculata* | | | | | | | 1 | 0.3 | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Clubiona kurilensis* | | | | | | | | | 2 | 0.2 | 1 | 1.4 | | | 2 | 5.7 | | | | | | | 4 | 5.3 | 7 | 6.6 | 6 | 8.2 | 13 | 16.9 | 4 | 3.7 |
| | *Ebrechtella tricuspidata* | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 0.4 | 1 | 0.4 | | |
| | *Enoplognatha abrupta* | | | | | | | | | 1 | 0.3 | | | 2 | 1.9 | | | 1 | 8.0 | | | | | 1 | 0.1 | 1 | 4.2 | 2 | 0.2 | | | 1 | 0.7 |
| | *Erigone koshiensis* | | | | | | | | | 1 | 0.2 | | | | | | | | | | | | | | | | | | | | | | |
| | *Gnathonarium dentatum* | | | | | | | | | | | | | | | | | 3 | 0.9 | | | | | | | | | | | | | | |
| | *Mendoza canestrinii* | | | | | | | | | 1 | 0.2 | | | | | | | 1 | 1.8 | | | | | | | | | | | 1 | 0.6 | | |
| | *Mendoza elongata* | | | 1 | 1.8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Myrmarachne formicaria* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 0.5 | | |
| | *Neoscona adianta* | | | | | | | | | 3 | 0.1 | 1 | 0.1 | | | | | | | | | | | | | | | | | 1 | 31.1 | 1 | 16.6 |
| | *Neoscona scylloides* | | | | | | | | | 1 | 29.0 | | | | | | | | | | | | | | | | | | | | | | |
| | *Pachygnatha clercki* | | | 1 | 0.4 | | | | | 4 | 0.2 | 1 | 0.0 | 2 | 1.0 | 1 | 5.4 | 2 | 0.5 | | | 7 | 4.0 | 4 | 2.2 | 5 | 5.6 | 9 | 10.3 | 11 | 27.3 | 2 | 14.0 |
| | *Pachygnatha quadrimaculata* | | | | | | | | | | | | | | | | | 1 | 0.6 | | | 1 | 1.4 | 1 | 0.4 | 1 | 0.5 | 1 | 0.0 | 2 | 1.0 | 1 | 1.0 |
| | *Paidiscura subpallens* | | | | | | | | | | | | | | | | | | | | | 1 | 0.2 | | | | | | | | | | |
| | *Parasteatoda oculiprominens* | | | | | | | | | | | | | 1 | 0.0 | | | | | | | | | | | | | | | | | | |
| | *Pirata subpiraticus* | | | 2 | 3.7 | 2 | 13.8 | | | 5 | 12.8 | 6 | 16.7 | 14 | 22.2 | 18 | 44.7 | 31 | 74.4 | 16 | 15.5 | 36 | 54.0 | 31 | 48.2 | 36 | 59.0 | 53 | 113.0 | 52 | 89.2 | 44 | 94.5 |
| | *Tetragnatha maxillosa* | | | | | | | 1 | 0.8 | 5 | 13.9 | 7 | 7.9 | 5 | 5.5 | 4 | 8.8 | 2 | 10.3 | 3 | 5.1 | 2 | 1.5 | | | | | 1 | 3.5 | 1 | 2.3 | | |
| | *Tetragnatha vermiformis* | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 3.7 | | | | | | |
| | *Trochosa ruricola* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 35.5 |
| | *Ummeliata insecticeps* | | | | | 2 | 0.9 | 1 | 0.2 | 3 | 0.9 | 3 | 0.6 | 2 | 0.5 | 7 | 2.8 | 4 | 3.5 | 2 | 2.3 | 6 | 5.5 | 5 | 2.8 | 3 | 0.6 | 2 | 0.3 | 5 | 1.3 | | |
| | *Xysticus* sp. | | | | | | | | | | | | | 1 | 0.0 | | | 1 | 0.3 | | | 1 | 3.0 | | | 5 | 22.0 | 4 | 15.8 | 4 | 5.8 | 12 | 96.1 |