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Conservation of Biodiversity and Its Ecological Importance of Korean Paddy Field

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ABSTRACT : Biodiversity is closely related to the conservation of ecosystems. Ecosystems provide more subtle, but equally essential, services. Microorganisms decompose human's waste and renew the soils that produce our food crops. Biodiversity in Korean paddies encompass 54 families and 107 species of freshwater invertebrates. In terms of the number of aquatic insects affected by different sources, the order starting with the highest population was swine slurry > chemical fertilizer > fresh straw with reduced fertilizers > control. The number of freshwater invertebrate and aquatic macro- invertebrate in surface water of the plots without insecticidal application were 2 and 2.1 times greater than in fields receiving insecticide applications, respectively. The soil microfungal flora of the 85 isolates paddy fields in Korea was 30 species in 13 genera and 11 isolates were unidentified yet. Agricultural policy should be changed to assist the conservation of biodiversity because until now the agricultural ecosystems have been negatively affected from the development of high-yield varieties to enhance food production, and the expansion of fertilizer and chemical use. For the conservation of agricultural ecosystems, agricultural practices with less investment and more resource saving, as well as enhancing the safety of agricultural and livestock products are essential. Finally, this paper was written for the contribution for the development of environmentally friendly farming systems with neighboring or whole ecosystems.

Keywords: agricultural ecosystem, aquatic invertebrate, biodiversity, paddy field

Ecological systems are consist with many other systems including: forest, cropland and grassland, urban, air, and water. These systems are the main supporter of biological life and agricultural ecosystem is the central position of forest and water system. However, this agricultural ecosystem has several beneficial effects that help maintain biodiversity in water (Park, 2000; Chung *et al.*, 2002; Cho *et al.*, 2006).

The value and importance of biodiversity. The importance of biodiversity is a complex issue that is difficult to quantify, especially since there is no evaluated data from paddy fields. The limits of quantifying the value of biodiversity are classified by three issues: "Commodity, Amenity, and Morality" (Norton, 1988). Commodity value refers to the economic income or benefit drawn from the sale of the species or their products; amenity value is the level of improvement enjoyed from use of the species; and moral value deals with the subjective importance attached to the existence of individual species. Biodiversity is closely related to the conservation of ecosystems. Ecosystems provide more subtle, but equally essential, services. For the biodiversity, soil microorganisms will be not considered importantly mostly but they biodegrade human's waste while regenerating the soils with nutrients. The microorganisms and the soil microflora populations and the mean numbers of microorganisms in paddy were 121.8 x 10^5 for bacteria, 22.5 x 10^5 for *actinomycetes* and 32.4 x 10^3 for fungi per gram soil(Yoo *et al.*, 1983). However, the mean numbers of microflora in upland soils were 89.2 x 10^6 for bacteria, 30.1 x 10^5 for *actinomycetes*, and 73.4 x 10^3 for fungi per gram dry soil(Yoo *et al.*, 1983; Yoo *et al.*, 1984). Also, a significant positive correlation was obtained between the number of microorganisms and soil chemical properties, which included available phosphorus, K^+, Mg^{++}, T-C and soil pH. Microorganism populations were also very different among cropping systems, soil depth and water regimes. The no-till, no-fertilized wheat-rice cropping system increased soil microbial population by 2 to 4 times compared to conventional transplanted paddy soil(Yoo *et al.*, 1984) (Fig. 1). Before and after water submerging, the total microbial population was 5 to 10 times greater than the submerged condition. One month after wintering, the total microbial population was greater in the subsoil (10-20 cm) than the top soil (0-5 cm) but two months after wintering, the microbial population was greatest a higher soil depth (5-10 cm). Therefore, rice cropping system should be reconsidered as an environmentally friendly alter-

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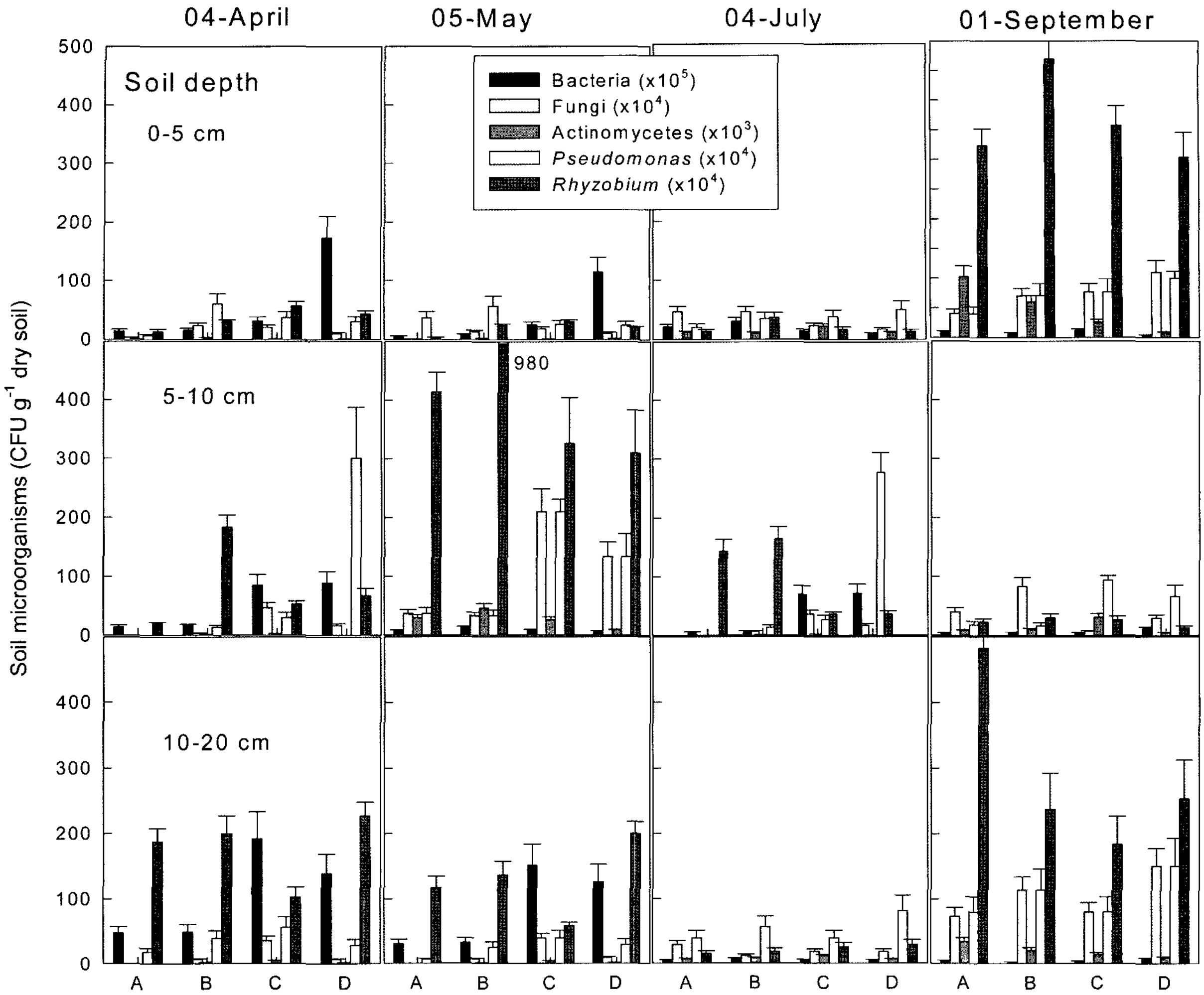

Fig. 1. Soil microorganisms as affected by no-tillage years, soil depth, and sampling date (date-month) under rice-wheat relaying cropping system. A: Conventional rice cultivation system, B: No-tillage, 1year, C: No-tillage, 4 years, D: No-tillage, 7 years. Vertical bars represent double standard errors of mean.

native without significant yield loss. That cropping systems were developed or evaluated in Korea and Japan(Cho *et al.*, 2001a; Cho *et al.*, 2001b; Cho *et al.*, 2003; Hidaka *et al.*, 1996).

Thirty species in 13 genera were identified and 11 isolates were unidentified(Min *et al.*, 1982a). Among these, 6 species of *Deuteromycetous fungi*, *Penicillium spp.*, were found to be dominant in paddy field soils. *Penicillium funiculosum*, *P. piceum*, *P. roqueforti* and *P. verruculosum* were described as new to Korea(Min *et al.*, 1982a). Additionally soil microfungi isolated for 14 species among the 30 species identified were undescribed fungi in Korea. Species of the genus Tararomyces were found to be dominant in paddy field soils(Min *et al.*, 1982a).

Invertebrates in paddy field

The secondary higher ecological level in paddy field is invertebrates. Biodiversity in Korean paddies consisted of 54 families and 107 species of freshwater invertebrate. The number of aquatic insects was affected by the fertilizer or organic sources high in the order of swine slurry > chemical fertilizer > fresh straw with reduced fertilizers > control(Han *et al.*, 2001). The numbers of freshwater invertebrate and aquatic macro-invertebrates in the surface water of the plots without insecticidal application were higher, 2 and 2.1 times, than those in fields where insecticides were not applied, respectively (Table 1).

The aquatic insect populations with similar inclination to the fresh water invertebrates and it was the greatest in the rice straw return with N, P, and K plot but the lowest in the no-fertilized plots(Han *et al.*, 2001) (Table 2). However, plots with insecticide applications reduced 1.2 to 2 times compared to plots with no insecticide application plots. Fertilization methods had an effect on numbers freshwater invertebrates in surface water of paddy fields.

These days, natural enemy is main research topics for the control of insect-pest in paddy fields. Cho *et al.*[6] introduced that Agamermis unka, a mermithid parasite of the brown planthopper (BPH), Nilaparvata lugens, is the most important natural enemy of BPH and white-backed planthopper (WBPH), *Sogatella furcifera* in Korea. Density of A. unka was higher in the pesticide-untreated plots than fungicide-treated or insecticide-treated plots of forecasting paddies (Cho, 2002). Lee *et al.*(1997) analyzed arthropod community patterns in rice fields associated with different planting methods (water seeding, drill seeding, and transplanting) in Korea in 1994. They collected 15 orders and 45 families of arthropod. No differences were observed in pest abundance and species richness and diversity of the spider community in rice fields associated with different planting methods. However, the non-pest abundance was higher in direct seeding sites than in transplanting sites, and especially abundant in a seeding site.

Sometimes, major biodiversity conservatives attacked and damaged to grain. For water birds, including migratory birds, paddy fields serve as both feeding and dwelling places. The loss of feeding ground due to decreasing paddy field areas, along with indiscriminate hunting has been pointed out as factors leading to the extinction of rare birds. These days, so many birds and animals are endangered and recorded on the red list of extinction. Cranes are one of the most endangered birds, under the risk of extinction worldwide. In Korea, their major habitats are found in mid and southern Korean peninsular. Preservation of cranes not only requires safe habitat but also abundant food source. Urbanization of great magnitude has been occurring in East Asian countries, which constitute the largest habitat of cranes globally, making it extremely difficult for birds to find food during the winter season in these areas. Lee and Rhim(1999) found that the remaining grains in paddy fields after harvest are wonderful sources of food for cranes. They also revealed a close correlation between the number of the two different types of cranes in three regions of Cholwon, North-eastern

Table 1. Change in number of the freshwater invertebrates in the paddy field (Han *et al.*, 2001).

Year	Insecticide					None				
	STF	Non	CFS	NS100	Avg.	STF	Non	CFS	NS100	Avg.
	PYTS					PYTS				
1998	48	55	81	82	66	243	240	314	578	343
1999	788	386	621	647	610	1629	775	1053	1063	1130
2000	2348	1169	1857	2625	2006	4378	3164	3347	4539	2060
Av.	1070	537	853	1118	894 (100)	2083	1393	1571	3857	1777 (199)

STF: Soil testing fertilizer application, Non fertilizer application, PYTS: last year produced total straw, In.: Index, CFS: N.P.K contents of total straw produced last year + (Soil testing fertilizer application-N,P,K contents of total straw)=chemical fertilizer application supplement, NS100: N,P,K contents of total straw produced last year + (Soil testing fertilizer application – N contents of total straw)= 100% supplement of contents swine slurry nitrogen, Av.: average, ( ): index, unit: number per 6 liter water sampling.

Table 2. Change in number of aquatic insects in the paddy field (Han *et al.*, 2001).

Year	Insecticide					None				
	STF	Non	CFS	NS100	Avg.	STF	Non	CFS	NS100	Avg.
	PYTS					PYTS				
1998	41	47	66	65	55	85	72	103	141	100
1999	117	90	109	92	102	129	179	148	156	153
2000	364	228	344	393	332	399	325	368	370	366
Av.	174	122	173	183	163(100)	204	192	206	222	207 (127)

unit : number per 6 liter water sampling, ( ): index

Table 3. Correlation between cranes and rice grains remaining after harvest in paddy fields.

	Region1	Region2	Region3
Number of grains (mean ± s.e)	28±4.98	5±3.78	37±7.25
No. of red -crowned crane	84	21	173
No. of white-nape crane	197	57	239

part of Republic of Korea and the average number of grains per 30 cm^2 of paddy fields (Table 3). Protection of valuable cranes is only one example of the contributions of paddy rice production to biological diversity.

Importance of weeds

Harada(2001) introduced that weeds are the enemies of farmers by covering agricultural fields and damaging crop production. This means weeds are always the targeted to be controlled. However, humans have used weeds in various ways. Weed species, including wild plants, have been utilized by humans and animals as food, medicinal purposes, housing materials, materials for handicrafts and ornaments, agricultural use and so on(Harada, 1987; Harada and Nagatalevu, 1989; Harada and Nagatalevu, 1990).

Dominant weeds in Korean and Japanese paddy fields

The life cycles of weeds and weed occurrence (dominance, %) in rice fields in Korea are shown in Table 5. The current major weed species in paddy fields for Korea and Japan.

Dominant annual species are barnyard grass (*Echinochloa crusgalli*), small flower umbrella sedge (*Cyperus difformis* L.), monochoria (*Monochoria vaginalis*), toothcup (*Rotala indica*), false pimpernel (*Lindernia spp.*), ammannia (*Ammannia multiflora*) and others, while common perennials are knotgrass (*Paspalum distichum*), "mizugayatsuri" (*Cyperus serotinus*), spikerush (*Eleocharis acicularis*), bulrush (*Scirpus juncoides*), sagittaria (*Sagittaria pygmaea*) and others(Shibayama, 2001). Bog pondweed (*Potamogeton distinctus*), is more common in Korea than in Japan(Huh, 1985).

Table 4. The life cycles of total weeds occurring in agricultural land in Korea (Kang 1999).

Life cycle	Total weeds	Paddy field weeds and hydrophyte	Halophyte	Upland field weeds and xerophyte
Total weeds	1,448 (100) (100)	223(100) (15.4)	74(100) (5.1)	1,151(100) (79.5)
Annual weeds	366(25.3) (100)	81(36.3) (22.1)	20(27.0) (5.5)	265(23.0) (72.4)
Winter annual or Biannial weeds	210(14.5) (100)	10(4.5) (4.8)	13(17.6) (6.2)	187(16.2) (89.0)
Perennial weeds	814(56.2) (100)	132(59.2) (16.2)	37(50.0) (4.5)	645(56.0) (79.2)
Woody Weeds	58(4.0) (100)	0(0.0) (0)	4(5.4) (6.9)	54(4.7) (93.1)

Table 5. Weed occurrence (dominance, %) in rice fields (Kim *et al.*, 1992; Kim, 1983).

1971		1981		1991	
Rotala indica	34.5	Monochoria vaginalis	22.2	Eleocharis kuroguwai*	19.6
Eleocharis acicularis	11.9	Sagittaria pygmaea*	17.5	Sagittaria pygmaea	15.6
Monochoria vaginalis	11.1	Sagittaria trifolia*	9.0	Sagittaria trifolia	13.2
Cyperus difformis	8.7	Potamogeton distinctus*	9.0	Echinochloa crus-galli	12.2
Echinochloa crus-galli	6.9	Cyperus serotinus*	8.5	Monochoria vaginalis	11.2
Lindernia procumbens	3.3	Rotala indica	6.0	Cyperus serotinus*	4.6
Potamogeton distinctus*	3.1	Aneilema japonica	4.4	Potamogeton distinctus*	3.3
Aneilema japonia	2.4	Lindernia procumbens	3.9	Ludwigia prostrata	2.6
Eleocharis kuroguwai*	1.8	Eleocharis kuroguwai*	3.4	Aneilema japonia	2.5
Polygonum hydropiper	1.8	Ludwigia prostrata	3.0	Cyperus difformis	2.3
		Polygonum hydropiper	2.7	Rotala indica	2.2
		Echinochloa crus-galli	2.3	Leersia japonica	1.3
		Leersia japonica*	2.1	Polygonum hydropiper	1.1
		Eleocharis acicularis*	1.6	Lindernia procumbens	0.7
		Scirpus hotarui	1.3	Fimbristylis miliacea	0.6

* Indicated weeds are perennials.

Weed occurrence under different cultural practices in Korea and Japan is summarized(Kim *et al.*, 1992; Kim *et al.*, 1997; Ku *et al.*, 1993) in Tables (4, 5, 6).

Cultivation methods can be adjusting the weed population

Weed populations were lowest in transplanted paddy, doubled in flooded, direct-seeded paddy and tripled in dry, direct-seeded paddy. The dominant weed species in machine transplanted paddy occurred in the following order: *Monochoria vaginalis, Cyperus difformis, Persicaria hydropiper, Echinochloa crus-galli and Aneilema japonica*. The dominant weed species in flooded direct-seeded paddy were *Monochoria vaginalis, Persicaria hydropiper, Cyperus difformis, Echinochloa hydropiper, Echinochloa crus-galli, Scirpus hotarui, Ludwigia prostrata* and *Aneilema japonica*(Ku *et al.*, 1993; Choi *et al.*, 1997; Huh *et al.*, 1995a; Huh *et al.*, 1995b). In dry direct-seeded paddy, *Echinochloa crus-galli, Cyperus difformis*, and the upland weed species *Digitaria sanguinalis, Capsella bursa-pastoris, Fimbristylis miliacea*, and *Setaria viridis* were dominant during the early period of cultivation. Over time, *Echinochloa crus-galli* became more prominant in dry direct seeded paddy. The number of weed species since the 1990's, taking regional differences into consideration were reported to be 7 to 8 in the transplanted paddy and 15 to 16 in dry, direct-seeded paddy(Cho *et al.*, 2003; Ku *et al.*, 1993; Kim *et al.*, 1998) (Tables 6, 7). The highest number of weed species has been consistently reported to occur in dry, direct-seeded paddy.

Weed occurrence and rice yield

Gressel(1999) reported that grain yield decreased by up to 60 % in the presence of *Echinochloa oryzicola* mostly due to a reduction in panicle number per plant. Yield loss (%) caused by competition from weeds relative to cultural practices in Korea is presented in Table 6 (Kim *et al.*, 1998). Percent yield loss without weed control was 10-20% in hand transplanted paddy, 25-30% in machine transplanting, 40-60% in flooded, direct-seeding and 70-100% in dry, direct-seeded paddy. Therefore, the competition between rice and weeds is stronger in direct-seeded rice cultivation, especially in dry paddy because of the concurrent germination of rice and weeds.

Trends of weed science in the 21st century

Asia is undergoing a process of change in its cropping systems due to a shortage of labor. Increased labor costs have caused a shift from transplanting to direct seeding in a few South-East Asian countries where population densities are low and the labor costs are escalating. This shift in crop establishment exacerbates the problems of grass weeds and weedy rice (Gressel, 1999).

Barnyard grass, weedy rice and sedges are listed as 'millennial weeds' in rice that are not being adequately controlled worldwide (Gressel, 1999). *Echinochloa* species have always been problem weeds in paddy, but they are now developing resistance to the herbicides used for their control. Weedy rice will cause more problems in direct-seeded rice due to its genetic and morphological similarities to domestic rice and also due to the easy shattering nature and prolonged dormancy of its seed. There is a great potential for direct seeding in paddy, but for the time being, it will be limited to South-East Asian countries where population densities are low and farm wages are rapidly increasing (Kim, 2000).

Table 6. Weed occurance and percent yield loss of rice as influenced by cultural practices (Kim *et al.*, 1992).

Cultural practice	Weed occurrence		Yield loss
	g/m^2	Index	(%)
Hand transplanting	741	100	10-20
Machine transplanting			
20-d-old seedlings	843	114	25-30
8-d-old seedlings	1,020	138	30-35
Direct-seeding			
On flooded paddy	1,643	222	40-60
On dry paddy	2,300	310	70-100

Threatened paddy weeds in Korea and Japan

In Korea and Japan, most of the old paddy weeds are endangered and on the list are 30 families and 35 species (Table 7). As time passes, these endangered weeds will disappear due to the heavy applications of herbicides and highly précised mechanical farming systems.

Strategy for the conservation of biodiversity

Agricultural policy should be altered to assist the conservation of biodiversity because until now the agricultural ecosystem has been negatively affected from the development and supply of high-yield varieties that enhance food production, and through the use of fertilizers and chemicals. The policy should also deal with problems of environmental pollution prohibition in preparation for natural environmental conservation and safe agricultural and livestock products which have recently become hot issues worldwide.

Table 7. List of plant species in Korea categorized as threatened paddy weeds in Japan.

Species	Family	Category†	Weed‡
Isoetes japonica A.Br.	Isoetaceae	VU	
Marsilea quadrifolia L.	Marsileaceae	VU	○
Salvinia natans All.	Solviniaceae	VU	○
Azolla imbricata Nakai	Azollaceae	VU	○
Azolla japonica Fr. et Sav.	Azollaceae	VU	○
Persicaria taquetii Koidz.	Polygonaceae	VU	
Ranunculus extorris Hance	Ranunculaceae	VU	
Hypericum oliganthum Fr. et Sav.	Guttiferae	EN	
Rorippa cantoniensis Ohwi	Crucuferae	NT	○
Penthorum chinense Pursh	Saxifragaceae	VU	○
Trapa incisa Sieb. et Zucc.	Trapaceae	VU	
Rotala leptopetala Koehne var. littorea Koehne	Lythraceae	EN	○
Rotala pusilla Tulasne	Lythraceae	VU	○
Myriophyllum ussuriense Maxim.	Haloragaceae	NT	○
Nymphoides coreana Hara	Menyanthaceae	VU	
Eusteralis stellata Murata	Labiatae	VU	○
Salvia plebeia R.Br.	Labiatae	NT	
*Deinostema adenocaulum*Yamazaki	Scrophulariaceae	EN	○
Microcarpaea minima Merr.	Scrophulariaceae	EN	
Gratiola japonica Miq.	Scrophulariaceae	VU	○
Limnophila indica Druce	Scrophulariaceae	VU	
Veronica undulata Wall.	Scrophulariaceae	NT	○
Utricularia australis R.Br.	Lentibulariaceae	VU	○
Utricularia minor L.	Lentibulariaceae	VU	
Eupatorium fortunei Turcz.	Compositae	VU	
Sagittaria aginashi Makino	Alismataceae	NT	○
Blyxa ceratosperma Maxim.	Hydrocharitaceae	VU	○
Potamogeton cristatus Regel etMaack	Potamogetonaceae	EN	○
Monochoria korsakowii Regel etMaack	Pontederiaceae	VU	○
Eriocaulon parvum Koern.	Eriocaulaceae	EN	○
Habenaria radiata Spreng.	Orchidaceae	VU	

†Endangered category in Jaoan; Threatened levels is EN > VU > NT.
‡Weed flora in Korea by Ahn *et al.* (1982).

Agricultural system of present and future

Today, precision agriculture (PA) is booming in most of the countries depending on mechanical farming. Most of the PA occurs in upland condition or very big block size at least 100 x 100 m (Umeda, 2002). However, Korean and Japanese rice farming is endangered by the high price compare to imported rice prices which are 4-7 times cheaper than Korean (Choi, 2000) or Japanese rice prices. The main reason is high input rice farming systems which include tillage, fertilization and chemical depending fertilizer, raising seedling, transplanting, and harvesting (Cho, 1999). These kinds of high input rice farming systems should be replaced by no-till or shallow tilled direct-seeding or transplanting systems. Even though precision agriculture improves the working efficiency though maintaining biodiversity in the paddy fields, it is very difficult. Farming large blocks will hamper the maintenance of levee diversity, especially those made of cement concrete but levees made of compact soil will improve biodiversity. A mudfish, carp, cyprinodont and et cetera are valuable source of eating and improving soil physicochemical factors (Cho and Rutto, 2002). However, biodiversity is not whole beneficial.

CONCLUSION

In the time of decreasing of paddy fields but increasing upland, conservation of the naturally well organized biodiversity is urgently needed. Microbial population and other insects or birds populations are lower in paddy field than upland. Aquatic organisms are can live on the paddy field or some clean stream except the water polluted areas, so paddy field is the most convenient and masterful place for maintaining total biodiversity. Making habitats are essential during the winter season and rice cropping season also for the more advanced biological or biodiversity rice farming in paddy field.

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