Studies into the Management and Restoration of Paddy Ecosystems to enhance Biodiversity in South Korea

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Abstract

Paddy fields provide several ecosystem services such as flood control, groundwater recharge, air and water purification, soil erosion and landslide prevention, climate change mitigation, and organic waste processing. In addition, the role of paddy fields in biodiversity conservation and their recreation and amenity value have been recently recognized. The area of paddy fields in South Korea is currently 9660 km^2, comprising 56% of total farmland area. But about 65% of the total paddy field area has been subjected to land consolidation by 2004. This land consolidation has resulted in a loss of natural channels and traditional irrigation ponds used as habitat for organisms living in paddy field ecosystems, and has become one of the factors in the decline of biodiversity. In this chapter, we introduce several case studies that we carried out to investigate ways of enhancing biodiversity in paddy fields and the surrounding environment. A variety of farming practices (winter-flooding, environment-friendly agriculture) and habitat restoration efforts (traditional irrigation pond) were confirmed to improve the biodiversity of aquatic invertebrates, fish and water birds in paddy field ecosystems.

Keywords: biodiversity, environment-friendly agriculture, irrigation pond, South Korea, paddy ecosystem, winter-flooding

1. Introduction

Conservation of agricultural ecosystems is becoming increasingly important from the aspect of enhancing biodiversity and for the construction of healthy ecosystems for sustainable production. Consequently, the development of technologies or practices for the restoration of these agro-ecosystems is needed.

One of the resolutions adopted at the 10th Meeting of the Conference of the Contracting Parties to the Convention on Wetlands [in 2008] was to regard paddy fields as a type of human-made wetland (Resolution X.31). Therefore, to find ways to enhance the biodiversity in paddy fields and the surrounding environment, we carried out several studies to assess paddy field management technologies and practices and their effects on biodiversity. A paddy field ecosystem possesses the unique characteristics of a semi-natural wetland ecosystem with continuous artificial management (Elphick, 2000; Kadoya et al., 2009). The largest human-made wetlands are paddy fields, which account for 18% of the total area of global wetlands (Yoon, 2009). Paddy fields provide several ecosystem services such as flood control, groundwater recharge, air and water purification, soil erosion and landslide prevention, climate change mitigation and organic waste processing (Kim et al., 2006; Natuhara, 2013). In addition, the role of paddy fields in biodiversity conservation and their recreation and amenity value have been recently recognized (Kim et al., 2006; Natuhara, 2013).

We examined three major methods with potential to enhance biodiversity in a paddy field ecosystem: construction of small ponds as a biotope, winter flooding and introduction of environmentally friendly farming practices.

2. Paddy Fields in South Korea

Farmland in South Korea amount to 17300 km^2, or 17% of South Korea's land area, in 2012. The area occupied by paddy fields was 9660 km^2, or 56% of the total area of farmland. The area of upland fields was declining until 1990 but has not changed significantly since then. On the other hand, the area of paddy fields has been declining gradually since 1990 (Fig. 1). These changes are due to the use of agricultural land for housing, buildings, roads, and fallow land.

From the viewpoint of agricultural biodiversity, the biggest change in South Korea's agriculture is the expansion in areas of land consolidation to increase rice production. Land consolidation has been carried out on a nationwide scale since 1960 (Fig. 2). About 65% of paddy fields had been consolidated by 2004. The expansion in the area of consolidated land has resulted in a loss of natural channels and traditional irrigation ponds used as habitat for

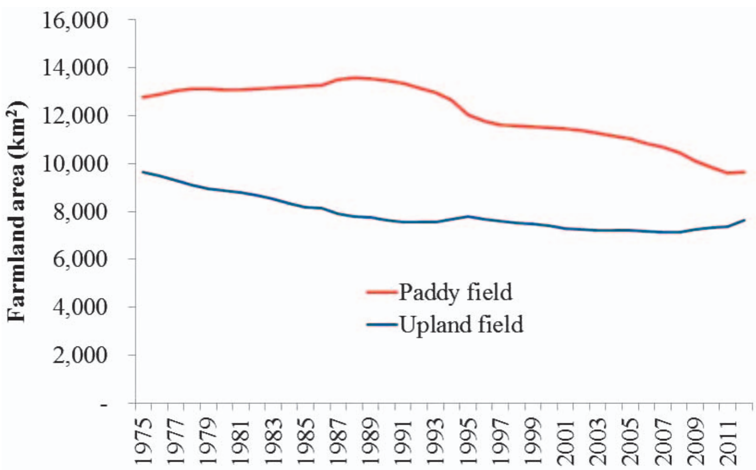

Fig. 1 Change in farmland area in South Korea (Source: KOSIS)

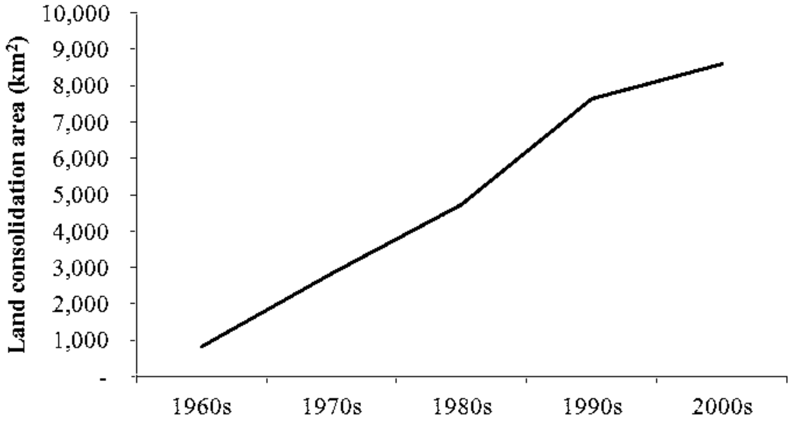

Fig. 2 Change in area of land consolidation in South Korea (Source: KOSIS)

organisms living in paddy field ecosystems, and has become one of the factors in the decline of biodiversity.

On the other hand, in 1998, the South Korean government proclaimed the inception of Environment-Friendly Agriculture (EFA) with various policy incentives, and programs. The government has established a policy to continuously expand EFA farming (Fig. 3). The area occupied by EFA was about 7% of the total farmland area in 2013. There are two types of EFA farming: non-pesticide and organic farming. Non-pesticide farming accounted for most EFA.

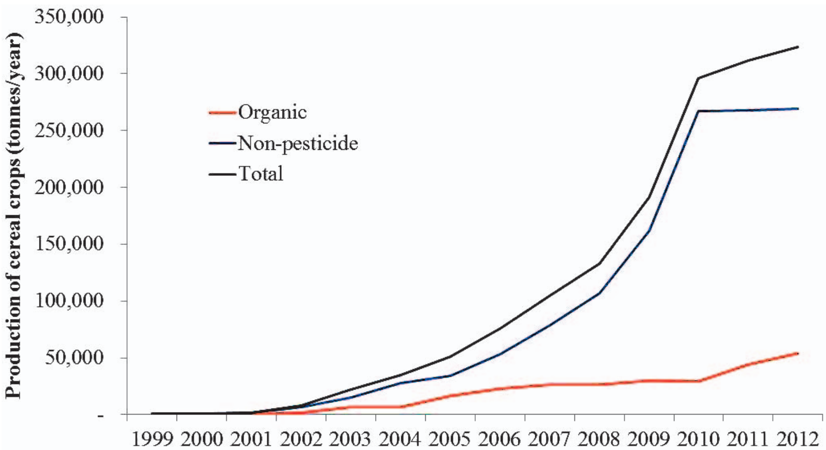

Fig. 3 Change in cereal crop production by Environment-Friendly Agriculture in South Korea (Source: Organic Agriculture Information Center)

3. Effects of Efforts to Enhance Biodiversity

1) Winter Flooding

Winter-flooded fields are important for biodiversity because they provide a habit for migratory birds. Winter flooding is also beneficial for other living things such as invertebrates and fish inhabiting the paddy ecosystems. We investigated the changes in density of invertebrates (individuals m^{-2}) in paddy fields in the rice growing season (June-August) after winter flooding to assess the effect of winter flooding on the paddy ecosystems (Kang et al., 2013). Samples in the paddy fields were randomly collected using quadrat sampling. This was performed using a rectangular plastic quadrat (height 20 cm, base 50x20 cm inside dimensions. We found that the mean density of benthic macroinvertebrates in winter-flooded paddy fields (55755 individuals m^{-2}) was 2.7 times that in non-winter-flooded paddy fields (20352 individuals m^{-2}) (Fig. 4).

Red worms (Tubificidae) are a key component of the soil fauna in wetland paddy field, and play a major role in soil fertility by burying biomass. We investigated the red worm population before (March-April) and after (June-August) the rice planting at winter flooded and non-winter-flooded paddy fields (Han et al., 2013a). Samples were randomly collected using a soil core sampler (height 20 cm, diameter 10 cm). Before the rice planting, the red worms in non-winter-flooded paddy fields were not found, but that in winter-flooded paddy fields were 21046 individuals/m^2. The red worms in non-winter-flooded paddy fields were found after irrigation into the fields. After the rice planting, winter flooding in paddy fields also dramatically increased the red worm population in the rice growing season (Fig. 5): the mean density in winter-flooded paddy fields (171109 individuals m^{-2}) was 190 times that in non-winter-flooded paddy field (1007 individuals m^{-2}).

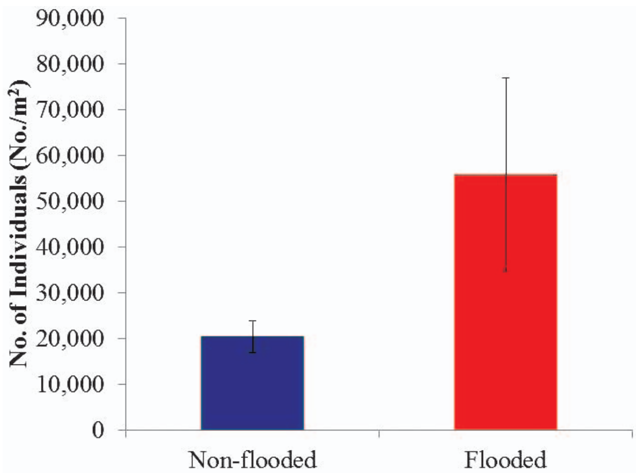

Fig. 4 Comparison of the density of benthic macroinvertebrates in non-winter-flooded and winter-flooded paddy fields (Kang et al., 2013). Sampling period: June-August of 2010 to 2013. The error bars are standard errors (n=3).

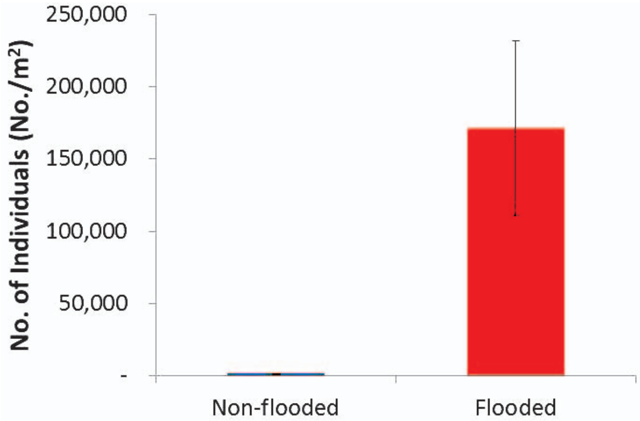

Fig. 5 Comparison of the density of Tubificidae in non-winter-flooded and winter-flooded paddy fields (Han et al., 2013a). Sampling period: June-August of 2010 to 2013. The error bars are standard errors (n=3).

These results indicate that winter flooding affects the biodiversity of organisms living in paddy fields during the rice growing season as well as in the winter.

Flooding paddy fields during winter can help increase the number of red worms, and can enhance biodiversity and control weeds in paddy fields for organic farming. Early shallow flooding of paddy fields could be a good agricultural practice to encourage the growth of red worms.

2) Environment-Friendly Agriculture (EFA)

Today, EFA has become an important feature of agricultural policy in South Korea. The government of South Korea enacted "Environment-Friendly Agriculture Fosterage Act" by 1997. The term "EFA" means agriculture producing safe agricultural, stockbreeding, or forest products by using no chemical materials, or minimizing use of such materials, and maintaining and preserving the agricultural ecosystem and environment. In the act, EFA products were classified into organically grown, pesticide-free, and low-pesticide agricultural products. The low-pesticide agricultural products were omitted in the Act amended on 2009. In 2015, the new "Act on the management and Support for the Promotion of Environment-friendly Agriculture/Fisheries and Organic Foods" consolidates South Korea's organic regulation, and sometimes referred to as the New Organic Regulations. The Minister of Agriculture, Food and Rural Affairs, or the Minister of Oceans and Fisheries shall formulate a plan to promote EFA for the development of EFA every five years, in consultation with the heads of relevant central administrative agencies.

We introduce the study of Han et al. (2013b; c) related to EFA and biodiversity in paddy fields. They investigated benthic macroinvertebrates and dojo loaches (*Misgurnus mizolepis*) in two types of paddy field (an environment-friendly paddy field and a conventionally farmed paddy field) in eleven regions from June to August, 2009, 2010, and 2011 for a community assessment using numbers of individuals and species. According to their result, the EFA paddies had more individuals and species of benthic macroinvertebrates than the conventionally farmed paddy (Fig. 6). EFA farming also affected populations of dojo loach living in paddy fields (Han et al., 2013c). The mean number of individuals of dojo loach caught/trapped per day in EFA paddy fields was 2.2 times that in conventional paddy fields (Fig. 7). The population increased as the number of Chironomidae and Copepoda individuals increased (Fig. 8). One of the reasons that the numbers of dojo loach were higher in EFA fields is the greater abundance of food sources. In addition, the increase in the dojo loach population will lead to an increase in the population of water birds that feed on them.

3) Irrigation Ponds

Irrigation ponds are a type of palustrine wetland created to hold irrigation water, and are commonly utilized in areas of East Asia where paddy field farming depends mainly on rainfall. These ponds support the multiple functions of paddy field systems, including flood control,

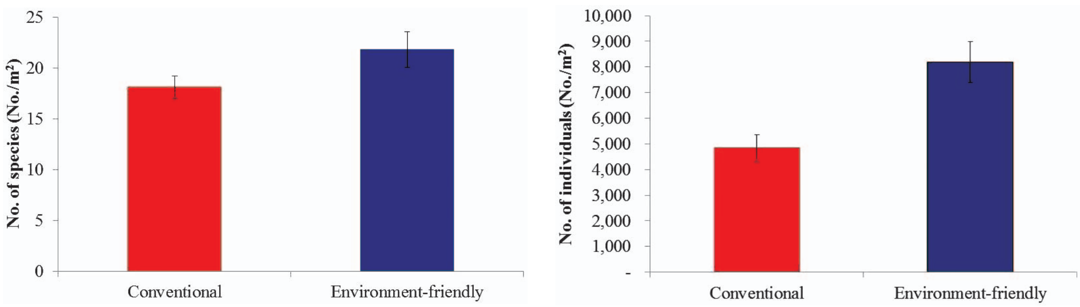

Fig. 6 Comparison of number of species (left) and mean total abundance (right) of benthic macroinvertebrates in environment-friendly paddy fields and conventionally farmed paddy fields during 2009–2011 (Han et al., 2013b). The error bars are standard errors (n=11).

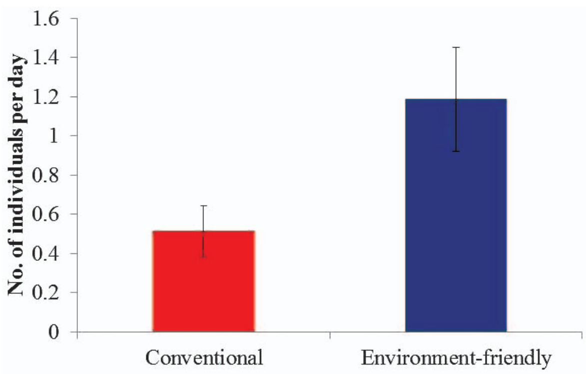

Fig. 7 Comparison of number of individuals of dojo loach in environment-friendly and conventionally farmed paddy fields (Han et al., 2013c). The error bars are standard error (n=8).

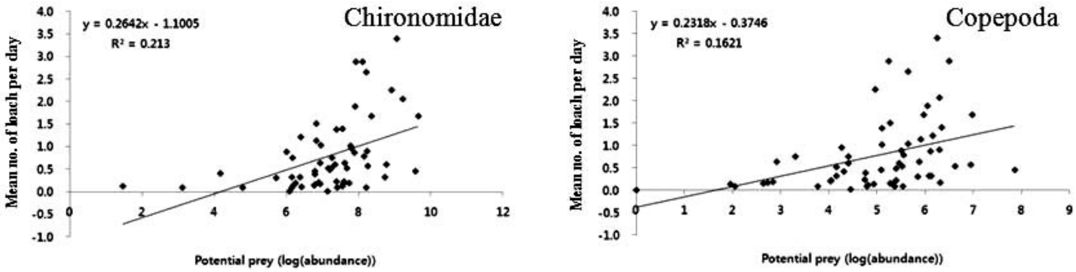

Fig. 8 Correlation between the mean numbers of dojo loach caught per day and its food sources (Chironomidae and Copepoda) (Han et al., 2013c).

groundwater recharge, and water pollution reduction, and also serve as a refuge for aquatic organisms during midsummer and winter. Thus, they play important roles in the conservation of paddy field ecosystems (Saijo, 2001; Harding et al., 2007; Kim et al., 2011). Unfortunately, since the 1950s, most traditional irrigation ponds have disappeared as a result of improved irrigation and drainage systems (Kim et al., 2011).

We assessed the role that irrigation ponds play in biodiversity conservation by investigating benthic macroinvertebrates in paddy fields with and without irrigation ponds in five regions from August to September from 2010 to 2012 (Choe et al., in press). In all regions, species richness and density were significantly higher in paddy fields with ponds (Fig. 9). The species richness of

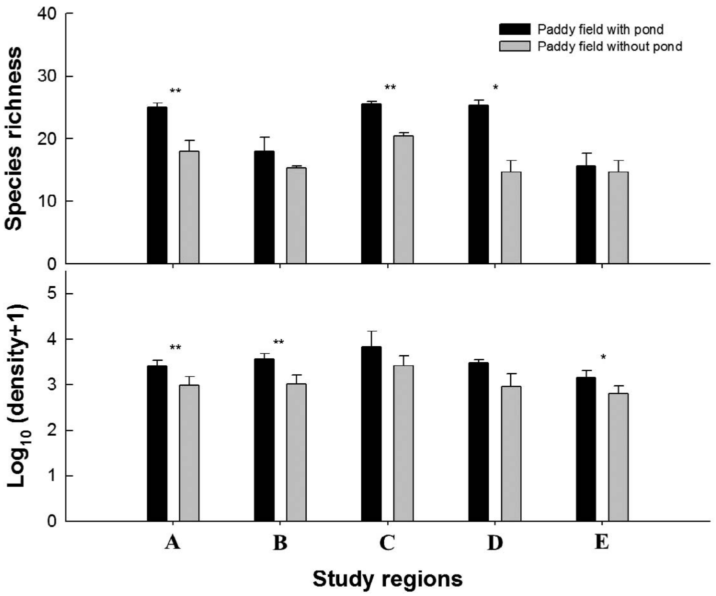

Fig. 9 Comparisons of species richness and density (log10 transformation) in paddy fields with and without irrigation ponds in each survey region (paired t-test, *p<0.05, **p<0.01, ***p<0.001). Error bars are standard errors (Choe et al., in press).

Mollusca, Ephemeroptera, Odonata, and Coleoptera was significantly higher in paddy fields with ponds, but that of the remaining taxonomic groups was not significantly different (Fig. 10). Densities of Mollusca, Annelida, Ephemeroptera, Odonata, Hemiptera, Coleoptera, and Diptera were significantly higher in paddy fields with ponds.

Various aquatic vertebrates and invertebrates use both ponds and paddy fields as habitat (Saijo, 2001; Mukai et al., 2005; Ohba and Goodwyn, 2010). In a study of the migration of aquatic Coleoptera and Hemiptera, Saijo (2001) found that various aquatic insects moved between paddy fields and irrigation ponds for living and reproduction. Irrigation ponds provide a more stable habitat for aquatic organisms than paddy fields, which are temporary wetlands controlled through the management of irrigation and drainage water for the cropping of rice, whereas irrigation ponds are permanent wetlands. The irrigation ponds at the side of paddy fields play an important role as a refuge site for aquatic organisms during periods of winter and midsummer of paddy field drainage, and as a source of aquatic fauna in flooded paddy fields (Saijo, 2001; Harding et al., 2007).

In all regions surveyed, it was shown that irrigation ponds enhance biodiversity. The effect varied according to taxonomic group rather than region. This indicates that the effect of irrigation ponds on biodiversity is related to the dispersal ability of organisms, and this can be expected wherever irrigation ponds are created. Consequently, the study confirmed that the creation of irrigation ponds is an effective method for maintaining and enhancing biodiversity in paddy field ecosystems.

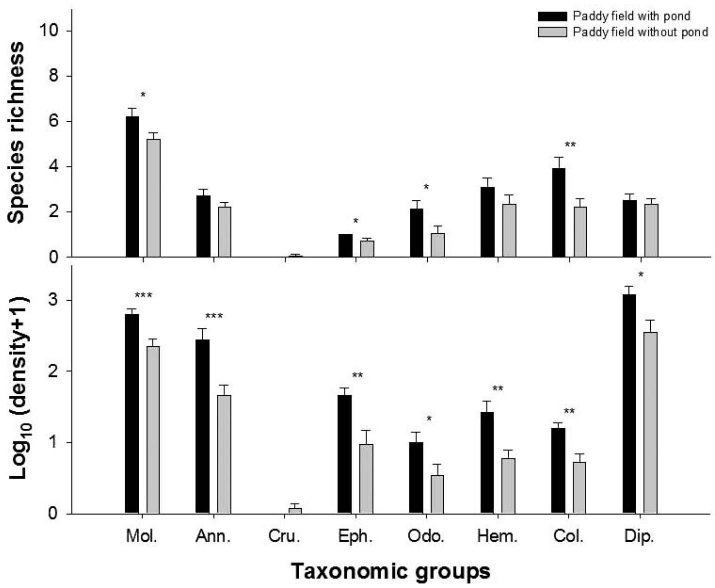

Fig. 10 Comparisons of species richness and density (log10 transformation) for each taxonomic group in paddy fields with and without irrigation ponds (independent t-test, *p<0.05, **p<0.01, ***p<0.001; Mol.: Mollusca; Ann.: Annelida; Cru.: Crustacea; Eph.: Ephemeroptera; Odo.: Odonata; Hem.: Hemiptera; Col: Coleoptera; Dip.: Diptera). Error bars are standard errors (n=14). (Choe et al., in press)

4. Conclusions

Winter flooding, environment-friendly agriculture, and habitat restoration primarily increase the biodiversity of aquatic invertebrates. This increase may lead to an increase in the biodiversity of fish and water birds. We will continue our efforts to enhance the biodiversity of agricultural ecosystems in South Korea, and will conduct long-term monitoring of agricultural ecosystems in the future. Until now, we have focused on identifying the interaction between biodiversity and agricultural ecosystems. From now on, we will make every effort to identify interactions between climate change and agricultural ecosystems. To achieve this goal, we will first select target taxonomic groups or species by referring to existing databases, experimental data, specialist opinion, etc. Second, we will monitor the target species and meteorological condition. Third, we will select environmental factors affecting the phenology and distribution of the target species by analyzing of correlations between phenology and meteorological condition. And fourth, we will project phenological and distributional changes of the target species under various climate change scenarios.

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