Chapter 11

Paddy Fields as Green Infrastructure: Their Ecosystem Services and Threatening Drivers

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Abstract The paddy field is a typical ecosystem in monsoon Asia. The main purpose of a paddy field is food production (i.e., a provisioning ecosystem service), but it also has several other ecosystem services. Therefore, we can consider paddy fields as components of green infrastructure (GI) that are already widely distributed. To maintain and improve the value of paddy fields as GI, we should strive to maintain and improve other ecosystem services besides provisioning services. However, issues that reduce the value of paddy fields as GI remain, and these are related to the consolidation and abandonment of paddy fields in recent years. In this paper, we focus on two ecosystem services of paddy fields, other than the provisioning service: (1) the habitat service and (2) the regulating service. Both these services are relatively well-evaluated ecosystem services of paddy fields in Japan. We discuss the effects of both consolidation and abandonment on these ecosystem services as well as their corresponding countermeasures. Based on this, we also discuss the challenges in applying and expanding the idea of paddy fields as GI.

Keywords Agricultural abandonment · Consolidation · Ecosystem-based disaster risk reduction · Ecosystem service · Habitat service · Wetlands

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11.1 Introduction

Paddy fields are a typical agricultural land type in monsoon Asia, mainly for rice crops. In Japan, paddy fields occupy much of the country's coastal plain (Natuhara 2013), with an area of approximately 24,000 km², which represents 6% of the total land area (Ministry of Agriculture, Forestry and Fishery [MAFF], Japan; <https://www.maff.go.jp/j/tokei/sihyo/data/10.html>; accessed on March 10, 2021). Paddy fields are the second largest land cover type in Japan after forests and are distributed throughout the country (Osawa et al. 2013, 2016a, b). Thus, paddy fields represent one of the most common seminatural ecosystems in Japan.

The essential purpose of maintaining paddy fields is for agricultural food production, i.e., for a provisioning ecosystem service. It is well known that paddy fields can provide several ecosystem services other than their provisioning service. For instance, paddy fields provide a supporting (habitat) service for several wetland species (Yoon 2009; Natuhara 2013; Katayama et al. 2015) in addition to providing a regulating service, such as flood control (Matsuno et al. 2006; Natuhara 2013; Osawa et al. 2020a), greenhouse gas emission control (Ahmad et al. 2009; Yang et al. 2012), landslide prevention (Natuhara 2013), and decreasing pests (insects) (Jincai et al. 1994). Japan's MAFF has claimed that paddy fields provide not only food production, i.e., a provisioning service, but also diverse multiple services, referred to as "multiple functions of agricultural lands." Thus, the MAFF has supported some of these functions through a grant system (https://www.maff.go.jp/j/nousin/kanri/tamen_siharai.html; accessed on March 10, 2021).

Green infrastructure (GI) has been defined as natural, seminatural, and artificial networks of multiple functional ecological systems within, around, and between human residential communities at all spatial scales (Tzoulas et al. 2007). At the same time, GI should have multiple ecosystem services based on its ecosystem functions (Sandstrom 2002; Tzoulas et al. 2007). Thus, based on these definitions, we can also consider paddy fields as GI (Fig. 11.1). However, in recent years, the situations of many agricultural lands, including paddy fields, have changed. Changes in agricultural land mainly consist of either modernization or abandonment (Osawa et al. 2013; Katayama et al. 2015). Both these changes in land use can exert negative effects on the ecosystem functions of the land (Benayas et al. 2007; Yoshida et al. 2012; Osawa et al. 2013). Consequently, such changes in paddy fields might cause their inherent ecosystem functions and services to collapse (Osawa et al. 2020a, b).

The concept of GI, particularly in monsoon Asia (including Japan), should be expanded. Paddy fields represent one of the most important ecosystems with potential as GI because they are very widespread and could thus offer multiple ecosystem services. Therefore, it is important to understand the threats and current status of multiple ecosystem services of paddy fields for sustainable use. In this paper, we focus on two ecosystem services—habitat and regulating services—of paddy fields that have been relatively well-evaluated in Japan recently and discuss their current status and threats as well as the countermeasures against these threats.

Green Infrastructure

Green Infrastructure should have multiple ecosystem services

Paddy field

Paddy fields have several ecosystem services other than food production

Fig. 11.1 The relationship between the definition of green infrastructure (GI) and paddy fields

Then, we discuss the challenges in applying and expanding the idea of paddy fields as GI.

11.2 Habitat Service: Biodiversity Conservation in Paddy Fields

The idea that paddy fields can provide habitats for several wetland species is already well-established (Toral et al. 2012; Katayama et al. 2015; Osawa 2017; Osawa et al. 2020b). The review of the biota of Japanese paddy fields by Katayama et al. (2015) revealed that paddy fields can harbor several small aquatic organisms (Yamazaki et al. 2001), at least 184 weed (i.e., non-crop) species, 27 aquatic invertebrate species (not including rice pests), 15 species and 2 subspecies of amphibians, 11

fish species, and 49 bird species, even considering underestimation due to data availability (Katayama et al. 2015). The value of paddy fields as habitats for several wetland species and in contributing to regional biodiversity is clear. However, in recent years, a drastic decline in species has been observed in Japanese paddy fields (Katayama et al. 2015; Osawa 2017). This trend indicates that paddy fields have been recently losing their ecosystem services, namely, their habitat service. Losing an ecosystem service is linked to losing GI value. Thus, maintaining the habitat service is an important issue when considering paddy fields as GI.

Agricultural modernization is one of the most severe drivers of habitat degradation in paddy fields (Katayama et al. 2015; Osawa 2017). After World War II, Japanese agriculture increased both chemical usage and land consolidation, both related to mechanization (Katayama et al. 2015; Osawa 2017). These practices have been clearly successful in increasing the effectiveness of agricultural activities such as time efficiency and yield per area (Katayama et al. 2015). In other words, this strategy specifically improved the provisioning service of paddy fields. However, there is often a trade-off between such agricultural modernization and biodiversity in paddy fields (Katayama et al. 2015; Osawa et al. 2016b; Osawa 2017; Osawa and Mitsuhashi 2017). In particular, the effect of land consolidation, which changes the ecosystem structure from a wetland habitat to a dryland habitat, is severe because paddy fields act as alternative wetland habitats (Osawa et al. 2016b, 2020b). Wetlands are one of the habitats that are on the decline worldwide (Denny 1994; Loughheed et al. 2008). This is one of the reasons that could affect the value of paddy fields as GI. However, paddy fields that have experienced land consolidation provide little or no habitat service for wetland species (Osawa et al. 2016b, 2020b). Thus, because such paddy fields lack multiple ecosystem services, their GI value might be relatively low.

Agricultural modernization can be accompanied by agricultural abandonment, mainly in areas that are unsuitable for modernization, such as hilly and mountainous areas (Katayama et al. 2015). Agricultural abandonment signifies losing the provisioning service in that area, thus reducing the value of paddy fields as GI. Moreover, previous studies have suggested that agricultural abandonment could degrade the habitat service of paddy fields (Osawa et al. 2013; Uchida and Ushimaru 2014). Abandoned paddy fields have relatively little value as GI because they do not have any ecosystem services, i.e., at least provisioning and/or habitat services. Therefore, changes in agricultural land use, either through consolidation or abandonment, might reduce the land's value as GI. In particular, these could reduce the variety of the ecosystem service, because abandonment is a severe negative driver that causes the loss of not only habitat services but also provisioning services, which are essential ecosystem services in paddy fields.

11.3 Regulating Service: Disaster Risk Reduction (DRR) by Paddy Fields

In recent years, interest from both researchers and practitioners has grown in ecosystem services that reduce the frequency and severity of natural disasters (Dudley et al. 2015; Renaud et al. 2016; Ministry of Environment, Japan; <https://www.env.go.jp/nature/biodic/eco-drr.html>; accessed on April 28, 2021). These types of ecosystem services are often known as Ecosystem-based DRR (Eco-DRR) (Martin and Watson 2016; Furuta and Shimatani 2017; Scarano 2017; Nakamura et al. 2019; Osawa et al. 2020a). The use of GI for Eco-DRR has gained much research interest because of the low costs of introduction and maintenance and its provision of other ecosystem services (Sudmeier-Rieux et al. 2013; Furuta and Shimatani 2017; Onuma and Tsuge 2018; Osawa et al. 2020a). Paddy fields have been expected to function mainly for flood control, i.e., by increasing the water storage capacity of river basins, reducing the peak flow of rivers, and increasing groundwater recharge (Matsumo et al. 2006), all of which can help mitigate the risk of flood disaster. As an ecosystem service, Eco-DRR is a regulating service (Bennett et al. 2009), and thus we should also consider Eco-DRR to be relevant when considering paddy fields as GI.

Recently, studies on Eco-DRR for flooding in paddy fields have progressed. For instance, we have shown that paddy fields located in water storage zones, i.e., paddy fields that are located in previous wetland habitats, are very effective in preventing flooding (Osawa et al. 2020a). A simulation study revealed that paddy fields with runoff control devices installed in their drainage boxes effectively draw down flood by the storing rainwater (Yoshikawa et al. 2009, 2010). Thus, there is some evidence that paddy fields could have Eco-DRR potential against floods.

However, a previous study indicated that abandoned paddy fields could reduce the Eco-DRR function against flooding, both due to decreased penetration capability and water runoff from degraded ridges (Yoshida et al. 2012). Thus, abandonment could result in the loss of not only the provisioning service but also the regulating service of a paddy field. Moreover, as we have already shown in the previous section, abandonment could also result in loss of the habitat service (Osawa et al. 2013; Uchida and Ushimaru 2014). Conversely, to the best of our knowledge, there are no studies that indicate a negative effect of agricultural modernization, i.e., consolidation, on Eco-DRR. Consolidation might actually have a positive effect on Eco-DRR because concrete ridges could prevent water runoff from paddy fields, which could increase the capacity of water storage during heavy rain (Yoshikawa et al. 2010). Although both abandonment and consolidation are major changes in agricultural land use, their effects on paddy fields (in relation to GI) differ.

11.4 A Strategy to Use and Maintain Paddy Fields as GI

GI is expected to provide multiple ecosystem services (Sandstrom 2002; Tzoulas et al. 2007). Therefore, to use an ecosystem as GI, land managers and decision makers should focus on certain expected ecosystem services and then make the appropriate efforts to maintain and enhance these services. However, managing the target ecosystem services can be difficult, as ecosystem services can be related to each other (Bennett et al. 2009). Moreover, Bennett et al. (2009) reported that some ecosystem services could be positively or negatively influenced by one driver: human activity (Fig. 11.2). Thus, if land managers and decision makers put some effort into maintaining and enhancing only one ecosystem service, it might result in a reduction in other ecosystem services. Agricultural modernization of paddy fields is a typical example of this because it improves the provisioning service but reduces the habitat service (Osawa et al. 2016b, 2020b). Thus, if land managers and decision makers expect the habitat service from paddy fields when they use them as GI, it will be difficult to achieve the high yield and work efficiency provided by modernization. Conversely, previous studies indicate that organic farming, which is an environmentally friendly farming system, could contribute to the biodiversity of several taxa (Fuller et al. 2005; Hole et al. 2005; Katayama et al. 2019). Thus, organic farming could even be compatible with both provisioning and habitat services that have relatively low yields or low work efficiencies compared to fully modernized agricultural areas. This suggests that certain related ecosystem services that have a trade-off relationship could be compatible at moderate levels.

Fig. 11.2 Positive and negative drivers for ecosystem services in paddy fields

To achieve multiple ecosystem services from a target ecosystem to be considered as GI, land managers and decision makers should carefully manage these ecosystem services by considering the relationship between focused ecosystem services and the management method, i.e., the driver for ecosystem services.

However, abandoned paddy fields have already lost their essential role, namely, their provisioning service. Thus, abandoned paddy fields cannot act as agricultural GI land that should provide multiple ecosystem services including the provisioning service. In addition, we believe that abandonment not only results in the loss of the provisioning service but also reduces the regulating and habitat services (Yoshida et al. 2012; Osawa et al. 2013). Nevertheless, recent studies suggested that some abandoned farmlands, including paddy fields, can harbor the biodiversity of several taxa, i.e., provide habitat services (Morimoto et al. 2017; Yamanaka et al. 2017; Hanioka et al. 2018a, b), depending on the location, condition, and historical land use of that area (Osawa and Mitsuhashi 2017). As habitat services (i.e., supporting services) are prerequisites for all ecosystem services (Sarukhán et al. 2005), we could expect that areas with high habitat services could provide several ecosystem services. Therefore, for the use of abandoned paddy fields as GI, land managers and decision makers should change their strategy to focus on ecosystem services other than provisioning services, such as using areas like non-farmland. If an abandoned paddy has a high level of biodiversity, converting it into a conservation area could represent a practical option.

11.5 Conclusion and Perspective

In this paper, we have focused on two ecosystem services and have discussed the potential of paddy fields as GI as well as changing land uses as a driver threatening this potential. The most important point in this paper is that the significance of a paddy field as GI might be different from that of a paddy field as a specific agricultural area, i.e., an intense food production zone. As paddy fields that represent GI should have multiple ecosystem services, concentrating on the provisioning service alone through modernization is not an effective way to promote GI. If land managers and decision makers want to apply the idea of GI to paddy fields, they should adopt a different strategy that focuses on combining paddy fields with provisioning services and other ecosystem services. Traditional agricultural promotion basically concentrates on food production; however, this does not suit a strategy that considers a paddy field as GI. Moreover, many countries, including Japan, are currently experiencing a phase of population decline (Osawa 2017; <https://population.un.org/wpp/>; accessed on April 29, 2021). Given this situation, a strategy that concentrates on food production might not be an effective strategy for maintaining paddy fields because of decreasing food demands. Other than the provisioning service (i.e., food production), we assessed two ecosystem services, providing wetland habitat and Eco-DRR, that are appropriate for paddy fields as GI; however, it remains unclear which service could coexist with the provisioning

service. If a trade-off exists between food production and other services, not focusing on food production might be one option for land managers and decision makers to promote paddy fields as GI, considering the situation of population decline. Fortunately, previous studies have suggested that flood control (i.e., Eco-DRR) and food production could coexist (Kramer et al. 1997; Bennett et al. 2009), whereas there might be a trade-off between the habitat service and agricultural modernization, which contributes to food production (Katayama et al. 2015; Osawa et al. 2016b; Osawa and Mitsuhashi 2017) (Fig. 11.2). To balance food production and the habitat service, these ecosystem services should be maintained at a moderate level.

Nevertheless, one driver could enhance multiple ecosystem services (Bennett et al. 2009). Thus, focusing on compatible ecosystem services could be another effective option to promote GI. Flood control and food production is one potential combination. However, in our opinion, enhancing human activities such as consolidation is not a smart way to expand on the concept of GI because ecosystem services should depend on inherent ecosystem functions. Ideas of ecological intensification already exist and are defined as realizing the intensive and smart use of ecosystem functions for multiple ecological services (Bommarco et al. 2013; Tittone 2014). This should represent a nature-based solution, which is defined as a transition toward ecosystem services with decreased input of nonrenewable natural capital and increased investment in renewable natural processes (Maes and Jacobs 2017). Ecosystem- or nature-based approaches should be one of the most important ideas to be applied to the idea of GI.

In addition, we should emphasize that abandonment is a driver of the loss of essential ecosystem services, namely, the provisioning service in paddy fields (Fig. 11.2). Therefore, land managers and decision makers should strive to prevent agricultural abandonment when they want to promote paddy fields as GI. However, when abandonment does occur, land managers and decision makers have different options, including recovering the paddy field (i.e., provisioning service) or recovering its natural ecosystem. Regardless of the option selected for restoration, efforts should be made to support the recovery of any ecosystem service (Osawa et al. 2016b). In abandoned paddy fields, food production is probably not the most important ecosystem service. Thus, returning the paddy fields to an intact ecosystem is one of the options. Given the importance of GI, human society should invest in maintaining such infrastructure. Moreover, promoting GI is a cost-effective strategy because of its multiple benefits to people. Overall, paddy fields have good potential as GI because of their multiple ecosystem services and widespread distribution.

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