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Effects of land use on trophic states and multi-taxonomic diversity in Japanese farm ponds

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A B S T R A C T

Farm ponds are among the most biodiverse anthropogenic freshwater habitats because of their small size, shallow water depth, and aquatic vegetation. Land-use changes, such as converting riparian vegetation to human use or changing the management practices of farm ponds, are assumed to be major factors that change such ecosystems from a clear-water state to a turbid state, leading to deterioration of water quality and biodiversity in such ponds. Using the database of a large-scale pond survey, we evaluated the effects of surrounding land use (landscape factors and modern pond management practices), fish abundance, and other environmental variables on total phosphorus concentration and taxonomic richness patterns of six biological indicators associated with changes in the trophic state. Local- and landscape-level vegetation structure associated with land use and total fish abundance were among the factors influencing the total phosphorus concentration of farm ponds, a main driver of trophic state changes. In addition, a transition from a clear-water state to a turbid state was associated with lower taxonomic richness of aquatic plants, macroinvertebrates, and adult Odonata, and a higher taxonomic richness of phytoplankton and fish. Based on these results, we discuss potential land-use and pond management strategies for conserving and/or restoring the water quality and biodiversity of farm ponds through maintenance of a clear-water state.

1. Introduction

Land-use changes, such as conversion of natural vegetation to farmland or residential areas and changing traditional management practices of secondary nature, have bi-directional consequences for the environment and human society. On the one hand, some land-use practices, such as creation of farmland or urbanisation, are essential to meet the increasing demand for food and/or space for human society. On the other hand, such practices have detrimental impacts on biodiversity and ecosystem functions and thereby affect the ecosystem services upon which human society depends. It is widely acknowledged that solely conserving or restoring biodiversity and ecosystem services in protected areas is insufficient for sustainable conservation and use of natural resources (Lundholm and Richardson, 2010; Chester and Robson, 2013). For the purpose of reconciling biodiversity conservation and human use of natural resources, management of human-altered landscapes is important (Rosenzweig, 2003; Dudgeon et al., 2006).

Despite the common view that anthropogenic ecosystems have low levels of biodiversity, recent studies have shown that water bodies in agricultural and urban landscapes, such as farm ponds, highway ponds, paddy fields, and irrigation ditches, play important roles in biodiversity conservation (Elphick, 2000; Céréghino et al., 2008; Le Viol et al., 2009; Negishi et al., 2014; Wezel et al., 2014). Farm ponds in particular have been shown to be among the most biodiverse water bodies because of their small size, shallow water depth, and aquatic vegetation (Williams et al., 2004; Davies et al., 2008). Developing strategies to manage the multiple functions of anthropogenic freshwater ecosystems beyond their roles of irrigating, cropping, or controlling storm water is a key challenge in conservation science.

In Japan, most natural floodplain wetlands in lowland areas have been converted into agricultural or urban areas. Although farm ponds are created primarily for irrigation purposes to meet the increasing

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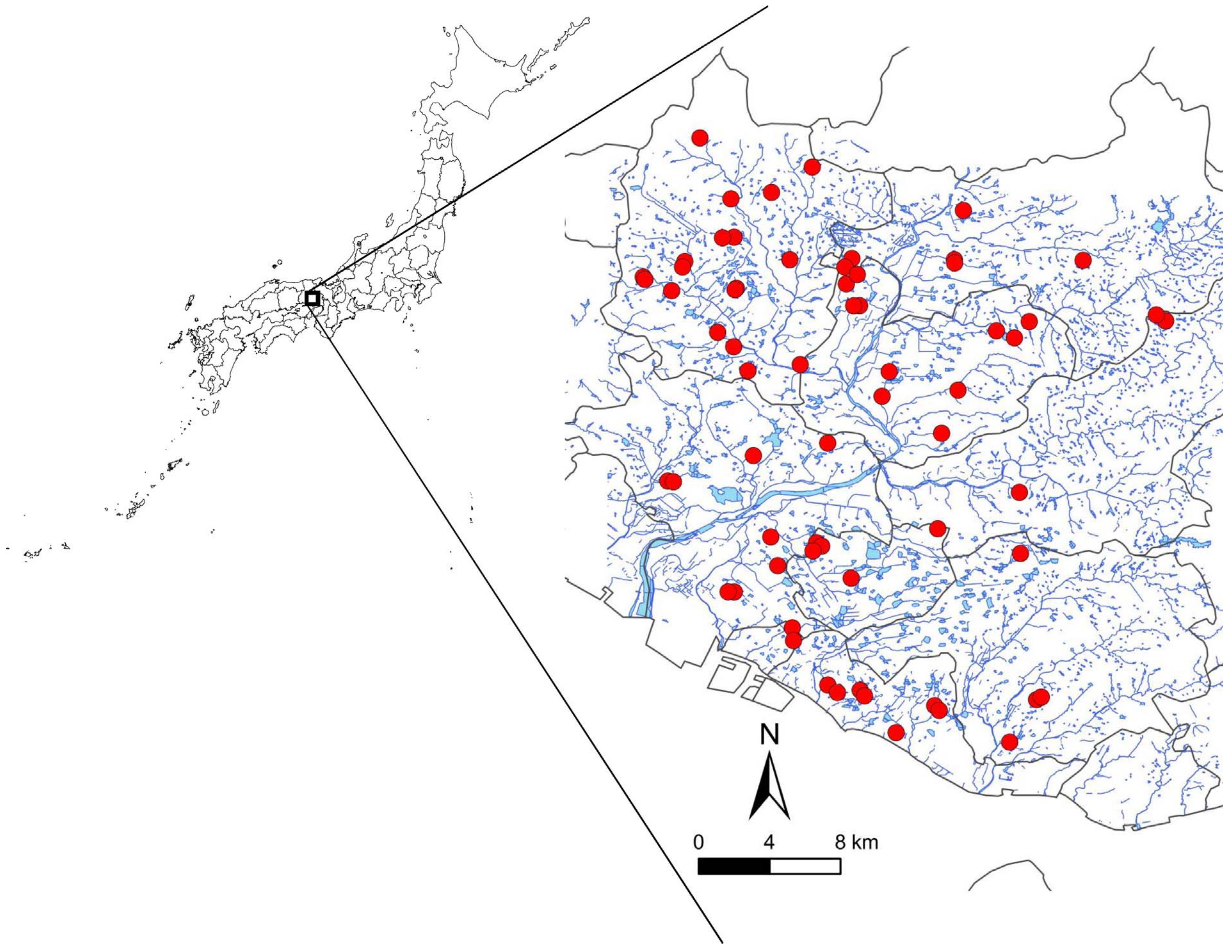

Fig. 1. Map of the 64 farm ponds in Hyogo Prefecture, Japan.

demand for food, these ponds serve as refuge habitats for aquatic and semi-aquatic wildlife that once inhabited natural floodplain wetlands. In practice, farm ponds contain many indigenous or endangered species that are absent from natural wetland habitats (Takamura, 2012). However, biodiversity in farm ponds is threatened because of increased demands for land consolidation and changes in management styles of ponds over time.

Farm ponds have alternative stable states characterised by different trophic states: a clear-water state and a turbid state (Declerck et al., 2006; Phillips et al., 2016). Previous studies have reported that changes from a clear-water state to a turbid state in shallow lakes or ponds are caused by various abiotic and biotic stresses. For example, non-point source pollution from farmland and urban areas is a major factor that enhances nutrient input into shallow lentic systems (Carpenter et al., 1998). Land-use changes, such as deforestation in the surrounding area and input of agrochemicals through agricultural intensification, have been reported to deteriorate water quality and reduce the species richness of aquatic plants in farm ponds (Akasaka et al., 2010). Ecosystem engineering via bioturbation activities by fish or macrophyte cutting and destruction by non-native crayfish are among the major factors that cause macrophyte reduction (Rodríguez et al., 2005; Matsuzaki et al., 2007; Scheffer and van Nes, 2007). Furthermore, fish predation on zooplankton can have positive effects on phytoplankton via trophic cascades (Vanni et al., 1997). In most cases, such abiotic and biotic stresses are associated with trophic state changes via increased concentration of phosphorus and/or nitrogen (Jeppesen et al., 1997; Declerck et al., 2006)

Although our understanding of how multi-taxonomic groups respond to eutrophication is growing (Menetrey et al., 2005; De Marco et al., 2014; Rosset et al., 2014; Wezel et al., 2014), most researchers have directly addressed the response of biological indicators along the gradient of eutrophication and have not considered the relative effects of local and landscape factors on multi-taxonomic diversity. Furthermore, studies reporting the relative effects of local and landscape stressors on farm pond biodiversity are often limited to a restricted set of taxonomic groups such as aquatic plants (Akasaka et al., 2010).

Using a database of 64 farm ponds with different land uses in western Japan (Takamura, 2011), we investigated the effects of surrounding landscape components, modern pond management practices, fish abundance, and other environmental variables on the trophic state of farm ponds to identify the major stressors of trophic state changes in such ponds. We hypothesised that local and landscape-level land uses, fish abundance, and the occurrence of invasive crayfish are significant stressors of trophic state changes. We subsequently documented the influence of changes in the trophic state on the taxonomic richness of phytoplankton, aquatic plants, zooplankton, macroinvertebrates, fish, and adult odonates in farm ponds. Given that aquatic plants provide refuge as well as foraging and/or spawning sites for many animals, and play vital roles in maintaining the clear-water state through various ecosystem functions (Jeppesen, 1998), we hypothesised that the taxonomic richness of aquatic plants and animals is positively associated with the clear-water state, while that of phytoplankton is negatively associated with such a state due to their counteracting association with aquatic plants (Phillips et al., 2016). However, we expect that responses of taxonomic groups along the gradient of trophic states may be weak when the effects of other local and landscape stressors are simultaneously considered.