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Influence of connectivity, habitat quality and invasive species on egg and larval distributions and local abundance of crucian carp in Japanese agricultural landscapes

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ABSTRACT

The quality of habitat at and around a spawning site, and the availability of movement between spawning and nonspawning habitats are likely to be important determinants for population persistence in a degraded and fragmented landscape. We assessed the influence of habitat connectivity, habitat quality and invasive species for distributions and local abundance of eggs and larvae of crucian carp (*Crassius auratus* complex, which is listed as "data deficient" on the Japanese Red List) in agricultural landscapes surrounding Lake Mikata, Japan, where drainage ditches and paddy fields are extensively utilised for spawning (lake or river shores are also used). We investigated the presence and abundance of eggs and larvae of crucian carp and habitat components at 146 sites across a range of presumed spawning habitats. Egg presence was affected strongly by connectivity to the lake (watercourse distance from the lake), and egg abundance was significantly influenced by both connectivity and habitat quality. In contrast, larval presence was primarily related to habitat quality. Larval abundance was influenced by connectivity and habitat quality, but the effect of connectivity was relatively low. Furthermore, larval abundance was negatively related to the presence of the invasive species red swamp crayfish (*Procambarus craki*) and bullfrog (*Rana catesbeiana*). Our findings indicate that connectivity, habitat quality and the presences of invasive species are crucial in determining suitable spawning and nursery habitats, but their relative importance may vary depending on egg and larval life stages. We suggest that restoring connectivity, improving habitat quality and removal of invasive species could be effective conservation strategies for the declining populations of crucian carp in agricultural landscapes.

1. Introduction

Habitat degradation and fragmentation are both seriously threatening biodiversity, such that habitat protection and restoration are integral elements of conservation and management (Kuussaari et al., 2009). Many freshwater organisms such as fishes and amphibians use multiple habitats to gain access to different resources required at the various individual life stages; therefore they are vulnerable to changes in the availability and quality of any or all of the required habitats (Riley et al., 2005; Parris, 2006; Lucas et al., 2009; Becker et al., 2010; Foldvik et al., 2010; Gorski et al., 2010). Because the reduction in connectivity between spawning and nonspawning habitats (including feeding habitats), and the loss or decrease in suitable spawning habitats can adversely affect population structure and persistence, characterising and prioritising suitable spawning and nursery habitats are essential to conservation planning in a degraded and fragmented landscape (Knapp et al., 1998; Fernandez et al., 2003; Parris, 2006; Isaak et al., 2007; Werner et al., 2007; Becker et al., 2010; Gorski et al., 2010). However, our understanding of the factors that determine suitable spawning and nursery habitat selections remains limited for a wide variety of aquatic organisms.

Rice paddies and the adjacent drainage ditches, which are temporary wetlands connected to permanent bodies of water such as rivers or lakes, provide suitable spawning and nursery habitats for various freshwater fishes, including crucian carp (*Carassius auratus* complex; Yamamoto et al., 2010) in the monsoonal region in Asia such as Japan (Katano et al., 2003; Khoa et al., 2005; Washitani, 2007; Suzuki et al., 2008; Kanao et al., 2009). The adults of crucian carp typically live in permanent bodies of water such as lakes, but during the rice-planting season, when paddies are fully

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irrigated, reproductive adults move into the shallow shores of rivers and lakes, and into paddy fields and drainage ditches to spawn. Crucian carp is a substrate spawner and scatters adhesive eggs over substrates such as aquatic macrophytes (Laurila et al., 1987; Katano and Hakoyama, 1997; Kanao et al., 2009). Therefore, the possibility of movement between spawning sites and nonspawning habitats as well as the quality of spawning habitats can strongly affect reproductive success.

In Japan, there is currently considerable concern over the declines in the population of crucian carp, which is commercially important for local fisheries (Suzuki et al., 2008; Kano et al., 2010). It is believed that habitat fragmentation and degradation due to improvements made to the paddy systems over the last 40 years with regard to increasing rice production are among the major reasons for the decline. Historically, paddy fields were connected to rivers by earth irrigation and drainage ditches, and the water level of the paddy fields is similar to that of the ditches, which allows crucian carp to migrate easily from rivers into these fields through the ditches. In modern irrigation systems, however, irrigation ditches are lined with pipes and separated from the drainage ditches, and water is drained from the fields into deep, U-shaped, concrete-sided ditches in which the water level is more than 70 cm below that of the rice fields (Lane and Fujioka, 1998; Katano et al., 2003; Washitani, 2007; Kano et al., 2010). Loss of spawning substrates, such as aquatic macrophytes, together with the effects of invasive species, such as bullfrogs (*Rana catesbeiana*) and red swamp crayfish (*Procambarus clarkii*), may also affect the quality of spawning habitat in agricultural landscapes. The aquatic habitat networks provided by paddy systems have been highly fragmented and degraded, but they remain of high conservation value, as they are the most species-rich habitat of aquatic species in Japan, and the drainage ditches contribute to the support and conservation of aquatic fauna (Washitani, 2007). To conserve crucian carp populations in altered agricultural landscapes, local and landscape determinants of suitable spawning and nursery habitats should be identified.

The aim of this study was to identify local and landscape variables determining the distribution and local abundance of the eggs and larvae of crucian carp. We focused on a population assemblage of crucian carp in agricultural landscapes in the basin of Lake Mikata (a component of the lake system designated as a Ramsar site) in Fukui Prefecture, Japan, because an aquatic network of many small rivers and drainage ditches connect to the lake that mutually differ in their biotic and abiotic features. Specifically, we examined whether the importance of connectivity (watercourse distance from the lake), habitat quality (water body type, bottom substrates and aquatic macrophytes), the effects of invasive species on the presence and local abundance of crucian carp. We also examined whether the importance of these factors differs depending on life stage, because different life stages can have different habitat requirements and dispersal ability (Lowe et al., 2004; Einum et al., 2006, 2008; Foldvik et al., 2010).

2. Materials and methods

2.1. The target aquatic network system and survey sites

Our investigation site was a part of the watershed of the Lake Mikata in Fukui Prefecture, Japan (Fig. 1, N35°56′68.18″, E135°88′25.83″). The lake is a part of the Mikata-goko lake system, which has been designated as a Ramsar site consisting of five bodies of brackish-freshwater. Lake Mikata is the only freshwater lake (eutrophic lake) in Mikata-goko and has an area of 3.45 km^2 with a maximum depth of approximately 2.5 m. In Lake Mikata, crucian carp is one of the most commercially important fish. However, the catch of crucian carp has been declining in Lake Mikata, especially since the late 1980s (Fig. 2).

We focused on the aquatic habitat network consisting of drainage ditches, rivers and lake in the watershed of Lake Mikata. At this study site, most of the paddy fields have already been converted to modern irrigation systems. Paddy fields are connected to the lake through rivers and drainage ditches, and drainage ditches are interconnected not only to each other, but also to rivers. Because there are 50–100 cm vertical gaps between the paddy fields and drainage ditches, crucian carp can utilise the drainage ditches, rivers and lakeshore as spawning sites, but they cannot migrate into

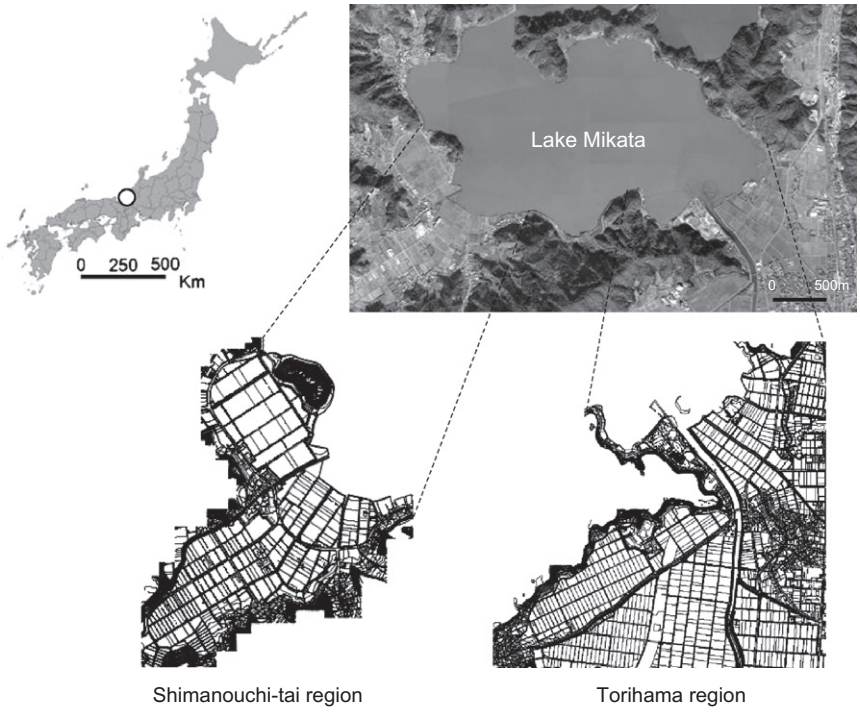

Fig. 1. The study watershed of Lake Mikata, which is part of a wetland of international importance as deemed by the Ramsar Convention, in Fukui Prefecure, Japan.