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Paddy management for potential conservation of endangered Itasenpara bitterling via zooplankton abundance

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ABSTRACT

In recent decades, the decline of biodiversity due to land-use changes in agricultural landscapes has become a central issue in ecology. Paddy management practices support animal diversity in agricultural landscapes. Using an endangered fish (the Itasenpara bitterling) inhabiting rivers connected to paddy fields as its subject, this study investigated two hypotheses: first, paddy field management affects the spatial distribution of Itasenpara bitterling in the adjacent river, and second, zooplankton and warm water supplied by paddy fields to the adjacent river are the primary factors influencing bitterling abundance. To model habitat suitability for the juvenile Itasenpara bitterling, rivers around paddy fields were examined using geographical information system tools and field survey methods in conjunction with a generalized linear model. The supply of zooplankton from paddy fields to the adjoining river positively contributed to juvenile Itasenpara bitterling abundance. This finding suggests that paddy management practices contribute to zooplankton abundance, and thus increase habitat suitability for juvenile Itasenpara bitterling.

1. Introduction

The conservation of semi-natural ecosystems such as agro-ecosystems is crucial to the ongoing maintenance of biodiversity (Tilman et al., 2001; Foley et al., 2005), especially because agricultural lands occupy approximately 40% of all terrestrial areas worldwide (Ramankutty and Foley, 1999). Agro-ecosystems harbor unique biodiversity compared with natural ecosystems. However, semi-natural landscapes have experienced major land-use changes in recent decades, contributing to the loss of biodiversity, a central issue to biological conservation in recent years (Krebs et al., 1999; Tilman et al., 2001; Benton et al., 2003; Billeter et al., 2008). Thus, in recent decades research has increasingly recognized the value of traditional agricultural habitats (Tscharntke et al., 2005; Knop et al., 2006; Kleijn et al., 2011). As many endangered species inhabit traditionally managed agricultural landscapes, integrative conservation efforts that balance biodiversity with productive agricultural systems are especially important (Pimentel et al., 1992; Bengtsson et al., 2003; Tscharntke et al., 2005; Bennett et al., 2006).

Paddies in particular provide habitats for numerous aquatic organisms (Kobori and Primack, 2003; Washitani, 2008; Kadoya et al., 2009; Kato et al., 2010). The Ramsar Convention has defined paddy fields as wetlands, a term also recognized by at least 114 countries worldwide at the Convention of Parties in 2008 (http://www.ramsar.org/document/resolution-x31-enhancing-biodiversity-in-rice-paddies-as-wetland-systems). According to the Food and Agricultural Organization of the United Nations, paddy fields in Asia account for 90% of the world's rice production. Floodplains are threatened ecosystems, as more than 90% of floodplains in North America and Europe have been modified for cultivation (Tockner and Stanford, 2002). Thus, global efforts have been made, especially in Asia, to restore the integrity of river floodplains (Zerbe and Thevs, 2011). Rice cultivation has a substantial impact on the biodiversity of floodplains (Elphick and Oring, 1998; Armitage et al., 2003; Washitani, 2008) and Japan has a long history of rice cultivation (more than 2500 years; Fujiwara, 1998). Paddy fields managed through traditional agricultural systems (i.e., a dual-purpose channel, with paddy fields connected to the channel and ponds) have functioned as secondary floodplain habitats for endangered Cyprinidae (Suzuki et al., 2008; Onikura et al., 2009). However, there has been no report that such paddy fields affect the spatial distribution of fish in the adjoining rivers.

The Itasenpara bitterling *Acheilognathus longipinnis* is a freshwater fish that engages in an unusual spawning symbiosis with freshwater mussels in autumn. The hatched larvae live in the mussels for about

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seven months, after which the juveniles swim up from the mussels in June and mature in the following autumn (Kitamura et al., 2009; Nishio et al., 2012, 2015). The Itasenpara bitterling is a typical plankton-feeding cyprinid that is endemic to Japan. This species was designated as a natural monument of Japan in 1974 and nationally recognized as being scientifically important. Also, the species was listed as critically endangered in the Red List of the Ministry of the Environment of Japan in 2014 and as vulnerable in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species in 2017. The natural habitat of the Itasenpara bitterling is floodplain water (Kitanishi et al., 2012, 2013; Nishio et al., 2015, 2017). However, these fish are currently distributed in only three regions of Japan (the Toyama, Osaka, and Nobi plains) owing to the disappearance of floodplains (Nishio et al., 2012, 2015; Yamazaki et al., 2014). In the Toyama plain, these fish are currently only found in two small river systems (the Moo and Busshouji Rivers). Traditional agricultural systems (i.e., water control via dual-purpose channels) have alternatively functioned as floodplain habitats via water level fluctuation for Itasenpara bitterling and freshwater mussels as a spawning substratum in the Moo River (Nishio et al., 2015, 2016, 2017), where ~1000 Itasenpara juveniles were observed in a 300 m section from May to June 2007 (Himi City, 2008). On the other hand, in the Busshouji River with newer agricultural systems (i.e., water control via separate irrigation and drainage channels), fewer than 40 juvenile Itasenpara bitterling were found in a 1.6 km section from May to June 2007 (Himi City, 2008).

This study clarified the relationship between endangered Itasenpara bitterling abundance in rivers (its natural habitat) and the connected paddy fields in order to develop a model that explained the relationship between bitterling distribution and other factors. Understanding the potential roles of local habitat conditions in the current distribution of the Itasenpara bitterling may help in identifying feasible approaches to the restoration of degraded bitterling habitat in floodplains. This study was hypothesized that hydrological connectivity directly impacts juvenile Itasenpara distribution, as paddy fields can mediate the habitat quality of adjoining rivers. The objectives were to examine (i) whether the water management strategies employed in rice cultivation affect the spatial distribution of the Itasenpara bitterling in the adjacent rivers and (ii) whether the primary factors affecting the spatial distribution of the Itasenpara bitterling are zooplankton and warm temperatures supplied by the paddy fields to adjoining rivers. To investigate these two research questions, Itasenpara bitterling distribution was predicted using geographic information system (GIS) tools and field survey methods in conjunction with a generalized linear model (GLM) to assess the importance of landscape-scale factors.

2. Methods

2.1. Study area

This study was conducted in the Moo River system, which comprises a low-gradient river that flows into Toyama Bay, Japan (Fig. 1; Supporting information Appendix S1), along with a small-scale catchment area of about 9 km^2. The Moo River system is approximately 10 km long, 5–10 m wide, 10 m above sea level, and has an average riverbed gradient of 0.2%. The Moo River system has three tributaries: the Moo (in this study, segments S1, S2, S3, and S4); Hounoki (S5, S6, and S7); and Nakayachi (S8 and S9) rivers. About 36% of the catchment area around this river is used in rice cultivation, and usage of the river system in particular as a dual-purpose-channel for rice cultivation has been substantially maintained even in recent years. Water levels are controlled artificially based on the irrigation needs of paddy fields. During the irrigation season (April to June), the water gates are closed, maintaining a water depth of approximately 1 m for rice cultivation and creating a lentic environment in the channel. Water circulates between the paddy fields and the Moo River system, with warm water, abundant in zooplankton from the fields, draining into the river system. The riverbed is comprised of sand with some mud and clay deposits, while most of the riverbanks remain in their natural condition. Emergent plants, including the common reed *Phragmites australis* and Manchurian wild rice, are abundant. Several bitterling species, including *A. longipinnis*, the southern red tabira bitterling *A. tabira jordani*, the slender bitterling *Tanakia lanceolata*, and the Chinese rose bitterling *Rhodeus ocellatus ocellatus*, inhabit the study site (Nishio et al., 2015).

2.2. Survey site and field sampling

This study divided the river system into segments based on the following criteria: i) water gates prevent the migration of water and aquatic organisms (S3, S4, S6, S7, and S9); ii) the environment is sectioned by a water gate and the confluence of tributaries (S2, S5, and S8); and iii) the confluence of the Moo and Hounoki rivers greatly alters the environment (S1). In this study, these nine segments were considered independent of one another (Fig. 1).

To characterize the Itasenpara bitterling's habitat within these segments of the Moo River system, this study divided a 50 m stretch of each segment into eight reaches at equal intervals. At every 5 m, sampling spots were identified with suitable sites for two 0.5-by-0.5-m quadrats on the right and left bank of each reach. This sampling design generated 176 quadrats along each segment. In June 2010, in each quadrat, it was noted whether Itasenpara bitterling were present or absent, and the water depth (WD), riverbank material (RM), sediment material (SM), current velocity (CV), and vegetation cover area (CA) were measured to determine habitat suitability. The juvenile Itasenpara bitterling in each quadrat were captured using a dip net, as they swim close to the water surface in June. Two types of SM were identified and coded: sand (1) and clay (0). CA was estimated visually in each quadrat. The RM was coded as natural (1) or artificial (0).

2.3. Water temperature and zooplankton

Data on water temperature and zooplankton samples were collected from May to July 2012. A temperature data logger (Tidbit v2 UTBI-001; Onset Computer Corporation, Burne, MA, USA) was used to monitor water temperature at the lowest reach of each segment. Water temperature was measured every hour during the irrigation and non-irrigation seasons between May and July 2012. Water was collected at the surface and mid-water levels of eight reaches of each segment during the same period, and 100 mL were filtered through a 190-μm mesh net to estimate zooplankton abundance. Zooplankton was preserved in 5% formalin and then counted under a microscope (BX40; Olympus, Tokyo, Japan).

2.4. Environmental measurements using GIS

Environmental variables for each segment were measured directly or calculated using a GIS dataset, and the water catchment area associated with each segment was delineated. The ratio of paddy fields within the water catchment area (RPW), longitudinal gradient of the riverbed (LGR), and distance to the nearest artificial structure (DNR) were calculated using the GIS dataset. Polyline data for each segment were delineated from river centerline data provided by the National Land Numerical Information. Watershed delineation was conducted manually using Digital Map 25000 (Map Image). A 1:25,000 vegetation map from the 6th National Survey on the Natural Environment was used to estimate paddy field area. To calculate LGR, the elevation at both ends of each segment was extracted from the Digital Elevation Model (DEM) at a 10 m resolution, and the difference between the two values was divided by the segment length [LGR = (elevation at upstream end − elevation at downstream end)/segment length]. DEM data were compiled from the Fundamental Geospatial Data of Japan with an accuracy of 1:25,000. The DNR was defined as the minimum distance along the riverbank of each segment and calculated from point