Biological Conservation 219 (2018) 96–104

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Hydrological effects of paddy improvement and abandonment on amphibian populations; long-term trends of the Japanese brown frog, *Rana japonica*

Noriko Kidera[a,b], Taku Kadoya[a], Hiroya Yamano[a], Noriko Takamura[a], Daiichi Ogano[b], Takashi Wakabayashi[b], Masato Takezawa[b], Masami Hasegawa[b,*]

[a] National Institute for Environmental Studies, Center for Environmental Biology and Ecosystems Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
[b] Faculty of Science, Toho University, Funabashi, Chiba 274-8510, Japan

ARTICLE INFO

Keywords:
Agricultural abandonment
Agricultural intensification
Long-term trend
Population decline
Rice fields
Satellite images

ABSTRACT

In rice fields, the cultivation area itself can play an essential role as a habitat for wetland organisms. Many previous studies showed negative impact of agricultural intensification and abandonment on biodiversity in wet farmland ecosystems. However, verification of the direct impact of aquatic environmental change by the paddy improvement and abandonment still remains. Here, we investigated the effects of the intensification and abandonment on the area of wet fields remaining in paddies during the fallow season, as well as the factors driving the population decline of the Japanese brown frog (*Rana japonica*), using data of long-term monitoring numbers of egg masses at multiple sites. To quantitatively estimate the spatial and temporal variation in saturated areas with water in the paddies where the frogs spawn in early spring, we used infrared bands of Landsat images. Both paddy improvements and abandonment have affected *R. japonica* populations through the reduction of wet areas in the fields. Furthermore, the frog's population size was positively associated with the area of surrounding forest. Our findings suggest that conservation in wet farmland requires appropriate water management inside the cultivation area as well as in other landscape elements that serve as secondary habitats.

1. Introduction

Land-use change is one of the main drivers of biodiversity loss (Baur et al., 2006; Flohre et al., 2011), and current trends of agricultural intensification and abandonment are having major negative impacts on biodiversity and ecosystems (Benton et al., 2003; Donald et al., 2006). Agricultural intensification (which includes mechanization, fertilizer use, agrochemical use, and intensive rotational cultivation) and abandonment have led to declines in farmland biodiversity as a result of the replacement of habitat structures that are heterogeneous in time and space with more homogeneous ones (Benton et al., 2003; Donald, 2004; Lenda et al., 2012; Moreira and Russo, 2007; Robinson and Sutherland, 2002), although the impact of farmland abandonment on biodiversity is not always negative (Queiroz et al., 2014). Previous studies have mainly addressed the impacts of agricultural intensification and abandonment on relatively limited taxa, such as plants, arthropods, and birds, and in regions such as Western Europe and North America, where most farmland is dry.

Rice fields, which are distributed mostly in Asia, are wet farmlands that play an important role of substitute habitat for many wetland species that depend primarily on natural temporary wetlands (Lawler, 2001). Paddy-dominated landscapes harbor various organisms and play important roles in maintain biodiversity (Katoh et al., 2009; Natuhara, 2013). Therefore, it is likely that the impacts of agricultural intensification and abandonment on biodiversity in paddies differ from the impacts on in dry arable fields. Intensive farming in rice fields usually involves the improvement of drainage and irrigation systems for water level management to promote machinery use (Katayama et al., 2015; Natuhara, 2013). Efficient modern systems help to drain the ground completely dry, whereas in traditional systems the field ground is saturated with water and shallow pools remain even after drainage and during the fallow season. Eventually, the ground desiccation causes the aquatic habitats to become unsuitable for many wetland species. Paddy abandonment can also induce aquatic environmental changes. When irrigation and continuous mowing cease, the field desiccation generally progresses. Subsequently, the vegetation types often change markedly, shifting to dry grassland and shrubs, although the vegetation changes vary with the topography and the management history before abandonment (Kusumoto et al., 2005; Ohkuro et al., 1996). Even when water pools remain in abandoned fields, the transition to dense and tall vegetation reduces the area of open water puddles.

Negative impacts of intensive farming on biodiversity in paddies

* Corresponding author at: Miyama 2-2-1, Faculty of Science, Toho University, Funabashi, Chiba 274-8510, Japan.
E-mail addresses: kidenon@gmail.com (N. Kidera), mhase@bio.sci.toho-u.ac.jp (M. Hasegawa).

https://doi.org/10.1016/j.biocon.2018.01.007
Received 26 January 2017; Received in revised form 12 December 2017; Accepted 5 January 2018
0006-3207/ © 2018 Published by Elsevier Ltd.

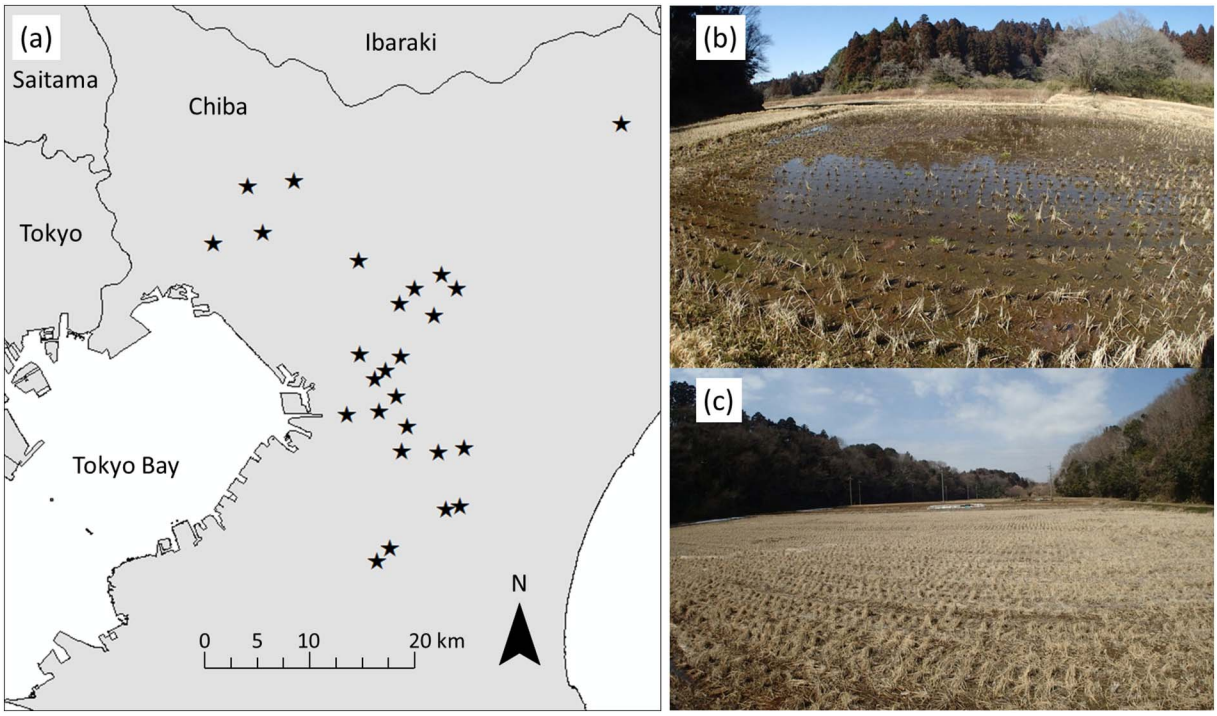

Fig. 1. Survey sites locations (a) and ground conditions of wet and dry paddies during the fallow season (b and c). Each star represents a site location. Photo (b) shows a wet field in a traditional paddy, and photo (c) shows dry fields after the installation of the modern water management systems.

have been well documented. Several studies have demonstrated that modern water management systems cause habitat destruction and population decline in freshwater fishes (Katano et al., 2003), arthropods (Kadoya et al., 2009; Nishihara et al., 2006; Takeda et al., 2006), amphibians (Fujioka and Lane, 1997; Naito et al., 2012), and birds (Lane and Fujioka, 1998). However, the effects of abandonment are still controversial. Some studies suggest that paddy abandonment causes biodiversity loss, including population decline in plants, arthropods, fishes, and amphibians (Kitano et al., 2003; Nakamura, 2011; Osada, 1978; Osawa et al., 2013), whereas others suggest that paddy abandonment provides habitat that might harbor threatened aquatic plant species and invertebrates (Ikegami et al., 2011; Nishihara et al., 2006; Osawa et al., 2013). To take proper mitigation measurements, researchers still need to assess the direct impacts of the changes of aquatic environments caused by farming intensification and abandonment on the population size of wetland organisms and their long-term trends.

Frogs are valuable indicators of such aquatic environmental changes in rice fields. Frogs depend chiefly on waterbodies in the early stage of the life cycle, whereas adults use both aquatic and terrestrial habitats (Wells, 2007). Moreover, frogs play a key role in structuring biological assemblages in rice fields. In Japan, many natural wetlands, such as floodplains and valley floors, have been converted to rice fields since the medieval era (Washitani, 2001). Consequently, for a variety of frogs, rice fields have traditionally served as aquatic habitats, including spawning sites (Hasegawa, 1998). Since the 1960s, however, Japanese rice fields have experienced intensification as part of farmland improvements (Katayama et al., 2015). Besides efficient water drainage, the paddy improvements have converted drainage ditches from shallow earthen ditches to deep concrete-lined ones (Katayama et al., 2015). These environmental changes could negatively affect many frogs through habitat degradation and split (Fujioka and Lane, 1997; Watabe, 2014). Moreover, the number of abandoned fields has been rapidly increasing since 1980s (Katayama et al., 2015). Because tall and dense vegetation develops in abandoned area, environmental changes by abandonment could not only negatively but also positively affect them through degradation of breeding habitat and/or increase of non-breeding habitats (e.g. as a feeding site and refugia). For proper conservation managements of organisms that require multiple habitats, it is essential to comprehensively understand impact of environmental changes in the current paddies not only on breeding habitat but also on secondary habitat (Miyashita et al., 2014; Naito, 2012).

Here, we focused on the long-term population trend of the Japanese brown frog which breeds in a wet paddy in early spring (Hasegawa, 1998). The saturated paddy with water from rain and groundwater during fallow season provides breeding sites for *R. japonica*. Because it sometimes freezes during the season, a sunny shallow pool without dense covered by tall grasses is a suitable for its early life stage (Kadowaki, 2002; Ogano et al., 2007). Therefore, the aquatic environmental changes in current paddies are likely to directly and strongly affect its breeding success. Furthermore, because *R. japonica* female lays a single egg mass per season (Maeda and Matsui, 1999), the number of egg masses is a good proxy of effective population size. Accordingly, long-term trends in egg mass number allow us to distinguish population declines resulting from environmental changes from natural fluctuations (Blaustein et al., 1994; Houlahan et al., 2000; Pechmann et al., 1991). To verify the impact of the hydrological changes caused by agricultural intensification and rice field abandonment on *R. japonica* populations, we assessed the effects of modern water management systems and abandonment on the area of wet fields in paddies in the non-flooded season (i.e., winter to early spring). We also used about 20 years of egg mass monitoring data from multiple sites to examine the factors driving the frog's population decline.

2. Methods

2.1. Monitoring of egg mass number of Rana japonica

For long-term monitoring, we set 26 sites in rice fields in northern Chiba Prefecture in central Honshu, Japan (Fig. 1). Rice is cultivated once a year in this region. The flooding season (including the intermittent flooding period) for rice cultivation is generally from late April to late July (Hasegawa, 1998). We set all of the survey sites in *yatsu* paddies; in *yatsu* landscapes, irrigated rice is cultivated in narrow, branching valleys and there are a variety of landscapes, including

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