# CAN THE SPAWN OF JAPANESE BROWN FROGS (*Rana japonica*, Ranidae) BE A LOCAL ENVIRONMENTAL INDEX TO EVALUATE ENVIRONMENTALLY FRIENDLY RICE PADDIES?

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**ABSTRACT:** Since the 1950s, rice cultivation in Japan has remarkably changed owing to paddy field consolidation for improved irrigation and drainage practices. However, consolidated paddies negatively affected the biodiversity in the agricultural landscapes because of the disjunction between forests and paddies and differences in the land grading level between paddies and concrete waterways. However, recently, the biodiversity at the study site, i.e., Kosaji village, Shiga Prefecture, has started to recover, owing to the efforts of farmers who have been using environmentally friendly products to boost rural development. The farmers of this village have established waterways at the marginal edge of paddy fields that has helped maintain the water levels during winter, thereby providing a stable habitat for aquatic organisms. The primary habitat of the target species—the Japanese brown frog (hereafter, JBF; *Rana japonica* Boulenger, 1879; Ranidae) —is paddy fields and the surrounding forests. This study aimed to evaluate whether the presence of frog spawns can be used as an indicator of environmentally friendly rice cultivation. The habitat characteristics of JBF oviposition were analyzed in relation to the changes the in paddy fields cultivated using ecofriendly farming practices by spatial analyses. The number of JBF spawns was determined weekly in every paddy field in Kosaji village from February to March 2016. Moreover, the following indicators were monitored in each paddy field: the ratio of still water pool to the parcel of land, order in the line from the valley mouth, paddy size, and existence of marginal canal. Results of geographically weighted regression analyses showed that the environmentally friendly cultivation methods effectively maintained the habitat of JBFs via the first 3 above-mentioned variables. Furthermore, the marginal canals played an important role in raising wet ratio and providing water space in winter.

## 1. INTRODUCTION

Rice (*Oryza sativa*) has long been cultivated in paddy fields in most Asian countries. Since the introduction of rice cultivation from the Eurasian continent, rice paddies on alluvial plains have been the major landscape element in the mainland of Japan. With the expansion of rice cultivation, an appreciable area of alluvial plains has been converted to agricultural landscapes (Sato 2008). Although this change in land use might affect native wetland ecosystems, rice paddies provided alternative habitats for fauna such as aquatic insects, fish, and amphibians.

During the 1950s, the Japanese government introduced paddy field consolidation for improved irrigation and drainage practices to increase food production after World War II. The consolidated paddies led to a decrease in biodiversity in the agricultural landscapes because of a disjunction between forests and paddies and differences in the land grading level between paddies and concrete waterways. This consolidation also resulted in the elimination of some species, e.g., Kissing Loach (*Parabotia curta* Temminck and Schlegel, 1846), from the agricultural landscapes. However, recently, the biodiversity in the Japanese rural area has started to recover owing to the efforts of farmers who have been using environmentally friendly products to boost rural development (e.g. Nakanishi and Ide 2014). For instance, farmers in Kosaji village, Shiga Prefecture, have collaborated to establish water space at the marginal edge of the paddy fields (hereafter, marginal canals) and ensured that water levels are maintained during winter (hereafter, flooded paddies in winter) to provide stable habitats for aquatic organisms.

Although environmentally friendly agriculture (EFA) has been expanding, there are few methods or indices to evaluate farmers' activities. Previously reported indices are not feasible for local use. The existing indices are developed by researchers who are not familiar with local agricultural practices and agriculture-related culture, and thus are not applicable for use by the locals. Thus, not universal, but local environmental indices need to be developed such that they can be selected, implemented, and developed upon by the farmers.

Some aquatic organisms thriving in paddy fields can be used as indices to determine the influences of farming activities on their habitat. In this study, we discuss whether the habitat characteristics of a frog species, Japanese brown frogs (*Rana japonica* Boulenger, 1879), satisfy the conditions of a local environmental index by using spatial analyses, i.e., geographical information system application. For this purpose, we used a transdisciplinary approach, which requires the involvement of persons from outside academia into the research process to integrate the best available knowledge, reconcile values and preferences, as well as create ownership for the solutions to problems (Lang *et al.* 2012). Such approaches have proved useful for sustainable science. For example, in many environmental conservation programs, local people play considerably important roles such as encouragement for land-use change (Asano 2015) and recipients of influences of environmental changes. In the case of rural environmental issues, farmers can act as non-academia persons in such a transdisciplinary approach.

In this study, we used a repeated interview method and conducted discussions with farmers to focus on local environmental issues and determine what activities can help overcome these challenges. Our analysis suggested that water management in winter is a concern for farmers, and the farming activities alter the habitats for organisms living in or close to paddies. Therefore, in this study, we aimed to determine the correlation between agricultural activities and fitness or increasing and decreasing of indices for species in the Kosaji Village from the aspects of ecological science (**Fig. 1**).

## 2. STUDY AREA

### 2.1 Geography

Kosaji Village (34°945′–34°921′N, 136°200′–136°241′E) is located in the southeast part of Shiga Prefecture, Japan (**Fig.2**). The village includes the Yasu River watershed, which is the largest river watershed that enters the Lake Biwa water basin. The geology of Kosaji Village can be attributed to Lake Koka, which is an ancient lake of L. Biwa and is present since 2.5 million years in Kosaji and adjacent villages. Diatomous earth in Kosaji has been denudated by water flow and forms many branched valleys at the slope of hills. Rice cultivation was started on these branched valleys.

Gentle hills are a source of farmyard compost and provide a terrestrial habitat for amphibians. In 2016, 8 frog species (Anura: *Rana japonica*, *R. porosa brevipoda*, *R. nigromaculatus*, *R. rugosa*, *R. catesbeiana*, *Fejervarya kawamurai*, *Hyla japonica*, and *Rhacophorus schlegelii*) and 1 species of salamander (Caudata: *Hynobius nebulosus*) were recorded, and 3 endangered species were found (Shiga Prefecture 2016). Amphibians can be considered as one of the characteristics of Kosaji landscape and land-use history.

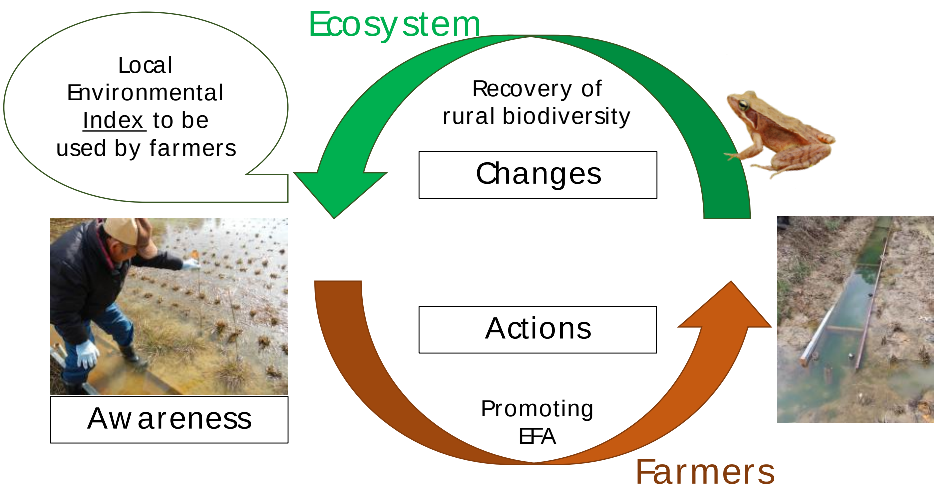


**Fig.1** Hypothesis of socio-eco-cycling model driven by a local environmental index

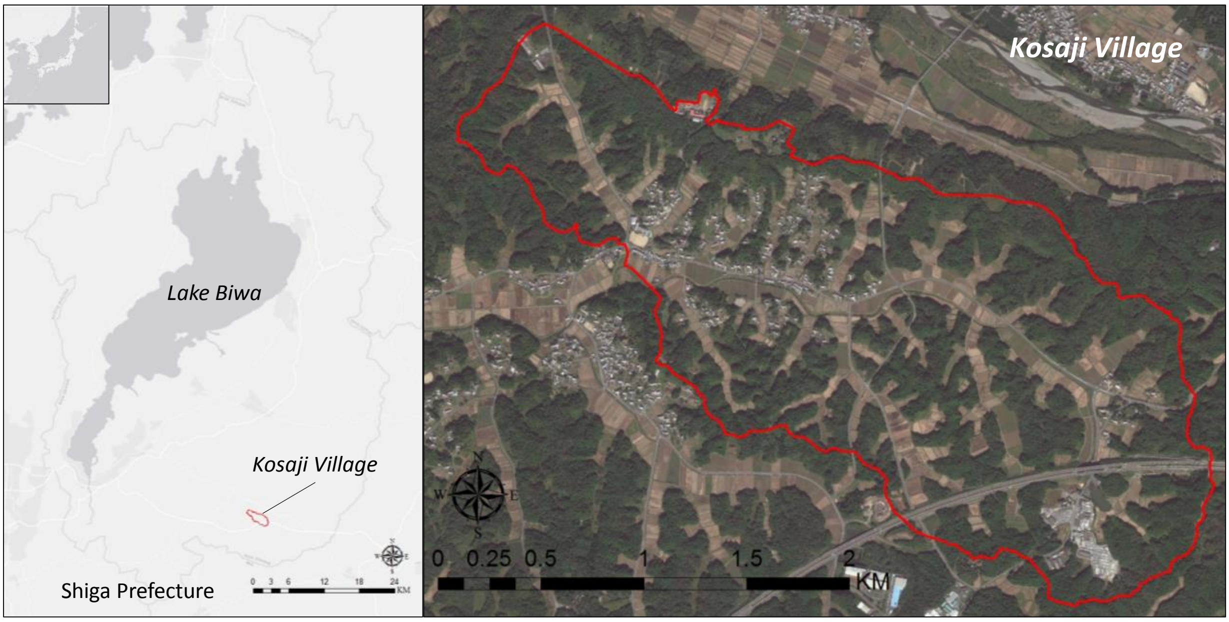


**Fig.2** Study area

**2.2 Agriculture in Kosaji**

Rice cultivation, especially sticky-rice products, is widespread in Kosaji (LBM 2011); sticky rice cultivated in Kosaji have been presented to the Imperial court. In Kosaji, rice has been mainly cultivated in wet fields; the diatomous earth used for cultivating rice does not dry easily, and the paddies remain flooded even in winter (Asano *et al.* 2016).

Randomly sized paddies that were traditionally grown on natural valleys are becoming rare since the 1950s. Consolidation of paddies has led to the introduction of agricultural machinery such as tillers, farming tractors, and combine harvesters to increase the efficiency of rice production. Paddy consolidation converted not only the shape of paddies but also irrigation and drainage systems leading to wastewater separation or drainage, which can efficiently dry up paddies (Naito *et al.* 2012).

Rice production improved remarkably after paddy consolidation; however, habitat diversity and continuity in the rural landscape such as between levees and *Satoyama* forests, waterways, and rice fields, and from upper rice terrace to downstream, decreased gradually (Osawa and Katsuno 2006; Naito 2012; Naito *et al.* 2012; Naito *et al.* 2013; Ju *et al*. 2016). JBF habitat was also remarkably affected by the disconnection of canals (Watabe *et al*. 2012) and drying up of paddies in winter (Uchiyama 2013).

In 1999, farmers recognized such degradations of wildlife habitats and continued existence of endangered species in rice paddies and encouraged EFA by setting up waterways at the marginal edge of paddies to maintain the water level during winter. EFA has increased over the last 15 years, and the number of farmers using this technique is also increasing. Integrated pest management (IPM) has also become widespread among farmers to reduce chemical pesticide usage. Rice cultivated using IPM or EFA strategies has become popular among consumers even though it is costlier than the rice cultivated using modernized practices (Govindasamy and Italia 1998). Flooded paddy in winter is an option of EFA; it has been proposed and assisted by the local government since February 2016. Furthermore, some paddies remained involuntarily flooded because the drainage system declined. JBF chose such flooded paddies as oviposition sites.

**3. MATERIAL AND METHODS**

JBF (*Rana japonica* Boulenger, 1879, Ranidae, Anura) is endemic to Japan and is distributed in most of the large Japanese islands except Hokkaido. Their body size ranges from 35 to 67 mm, and females are larger than males. Their body color is red-brown and varies across individuals and turns more brilliantly during the breeding period, which begins during early spring in the main islands, including Shiga Prefecture (Uchiyama 2013). JBF lives in terrestrial places close to water, such as levees of rice paddies and forest edges and hibernates during winter in the forests behind the paddies (Osawa and Katsuno 2007).

JBF breeds at the waterfront around the edge of *Satoyama* forests; hence, rice paddies are often selected for mating and laying spawns (**Fig. 3**). A JBF female lays one egg mass during one breeding season (Marunouchi *et al*. 2002; Matsushima and Kawata 2005). Temporary rain pools or other ephemeral water bodies such as still water in rice paddies and marshes are selected as oviposition sites (Wells 1977; Iwai *et al.* 2007), because predators such as fish


**Fig.3** Japanese Brown Frog and the method for marking up spawns;
JBF male (**3-1**), a pair JBF observed in the inside-paddy waterway at night (**3-2**),
a farmer marking JBF spawns by using bamboo stems (**3-3**), and a marked JBF spawn laid 2days ago (**3-4**)

or aquatic insects are less active in temporary pools (Skelly 1997).

JBF can be described a keystone species in the food web because they function as prey for higher-order animals such as snakes and raptorial birds, as well as a predator for lower-order animals such as insects (Mizuno and Hashimoto 2013).

### 3.2 Field survey

JBF spawn surveys were conducted from 1 February to 31 March in 2016 by us and the members of Kosaji Environmental Conservation Association (KECA). This survey period was selected for 2 reasons: (1) a member of KECA founded a frog spawn in his paddy on 31 January and informed us and (2) the subsidy for flooded paddy in winter obligates recipient farmers to maintain the water level for more than 2 months from 1 February. Newly added JBF spawns were not observed after March 25. Each spawn was marked with a bamboo stem to count accurately their number and prevent flushing out (**Fig. 3-3**, **Fig.3-4**) Participants can use this method after a short demonstration, wherein they are instructed to attach a piece of tape that includes the observation date (**Fig. 3-3**).
Paddy conditions were recorded by researchers when counting spawns to analyze the factors responsible for selecting the oviposition site: ***(a)*** the ratio of still water pool to the parcel of each paddy (photographs and GPS data were used for the calculation); ***(b)*** the order from valley mouth (**Fig.4**); ***(c)*** paddy size determined from the paddy management map developed by the KECA; and ***(d)*** existence of marginal canals (**Fig.5**). The order from valley mouth was considered as the integrated explanatory variable for the distance from urban land use and difference of habitat quality depending on the distance from the valley mouth. The behavior of JBF was used to determine the order or distance from the valley mouth and used as an appropriate variable. When JBF adults hibernating in forests during winter gather in rice paddies from each hibernating position, they need to head down the hill close to the paddies. This is similar to the manner in which rainwater flows down. When each paddy is in line with the terrace and even size, the individual watershed area for the upper rice paddy is greater than that for other paddies (**Fig.4**). Thus, the population of JBF in the upper paddy (***A3*** in **Fig.4**) is larger than the others when the JBF population density is constant across the entire hill.

### 3.3 Analyses

In this study, geographically weighted regression (GWR) analysis was used to investigate the factors responsible for the choice of oviposition site and the relationship between significant factors. The number of spawns in each paddy was used as an objective variable (**Fig.6**) and the ratio of still water pool to the parcel of each paddy, the order from the valley mouth, and paddy size were used as explanatory variables (**Fig.7**).

ArcGIS 10.3.1 and spatial statistical tools were used for the analysis.

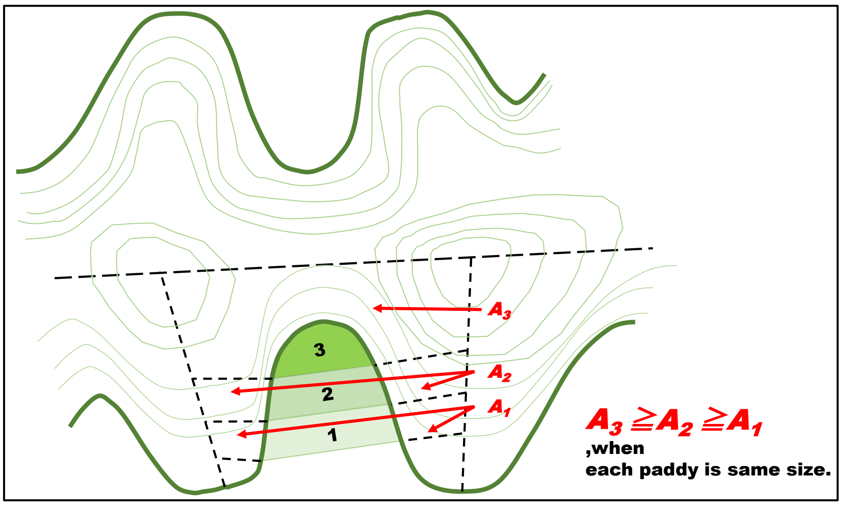


**Fig.4** Concept and occasion of explanatory variable; Order from valley-mouth

## 4. RESULTS

### 4.1 Results of field survey

JBF spawns showed scattered distribution with some hotspots, which are marked with dark brown color in **Figure 6**. Few hotspots were located in the urbanized area, such as along concrete roads or close to residence areas.

In all, 1,788 spawns of JBF were counted; the spawns were confirmed to be not belonging to *Rana ornativentris* Werner, 1903, which is a related species of JBF and is known distributing in Shiga Prefecture. JBF spawns were laid at marginal canals (**Fig.5**); inside –but on the edge– of flooded paddies (levels 3–4 of the variable “wet ratio” shown in **Fig.7**); and in water pools caused by wheel tracks of combine harvesters (level 1 of variable “wet ratio”), especially when most of the area of the parcel was without water.

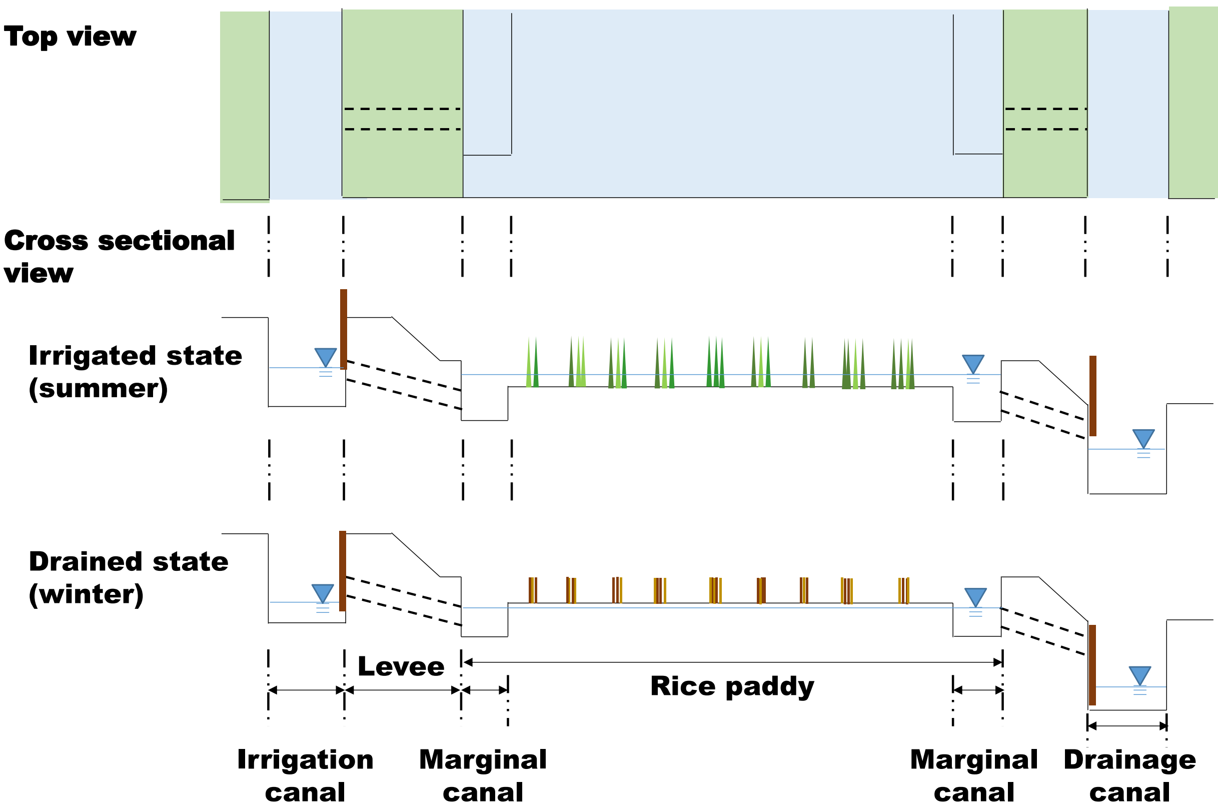


**Fig.5** Top and cross-sectional views of a rice paddy with marginal canals

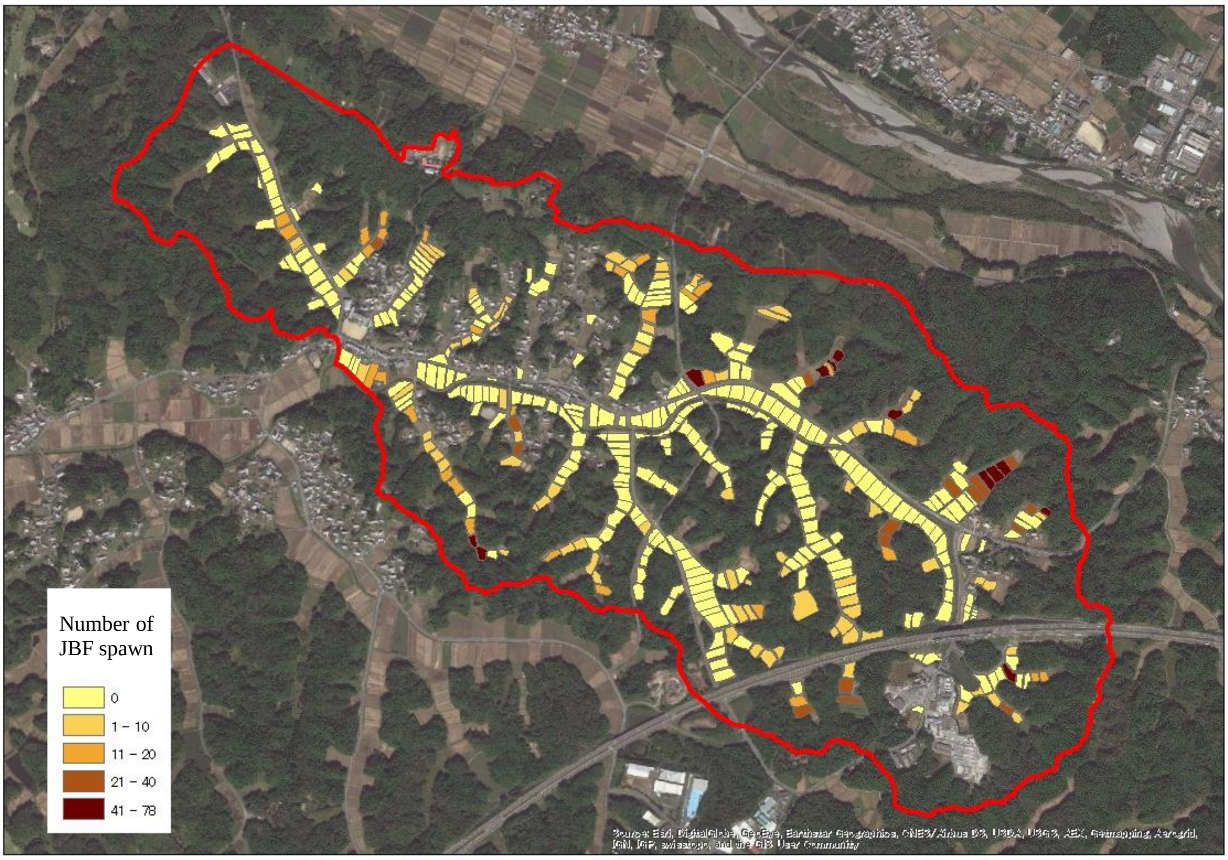


**Fig.6** Distribution of JBF spawns

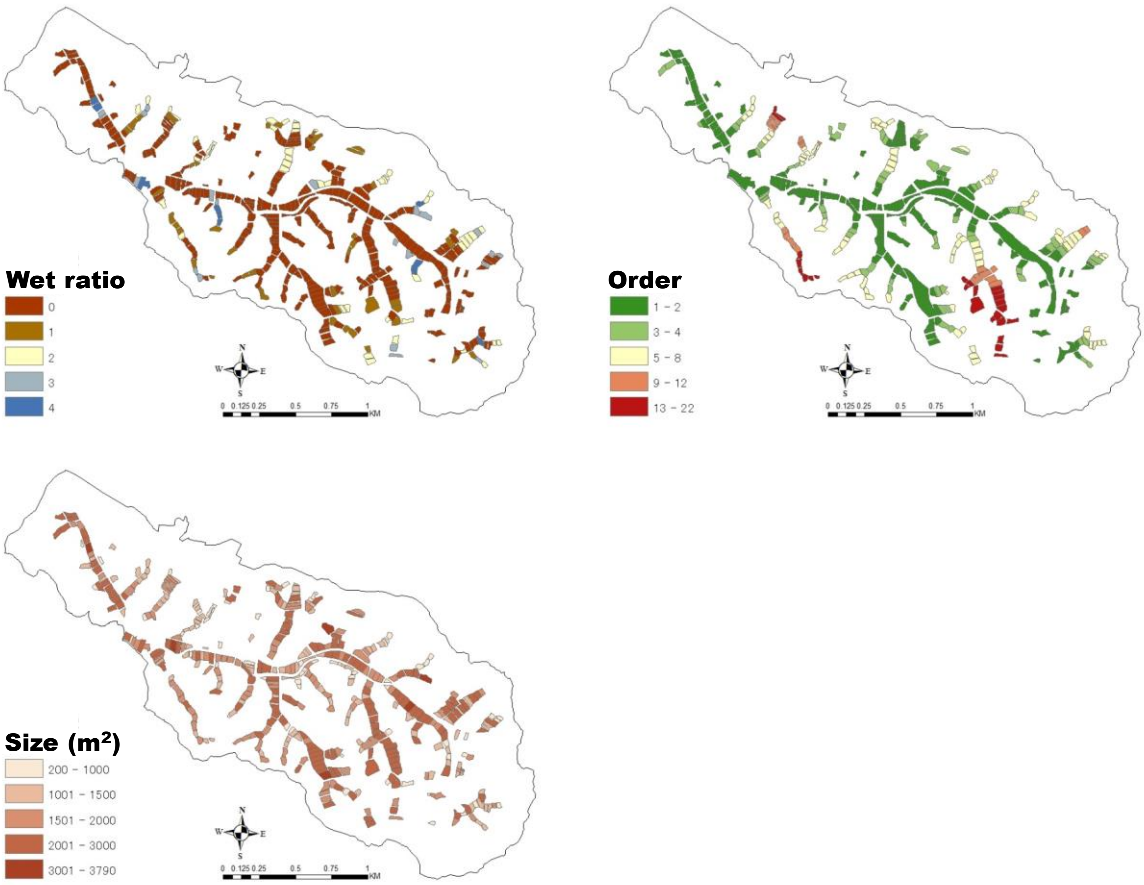


**Fig.7** Explanatory variables

### 4.2 Results of Analyses

The efficacy of the variables was investigated using ordinary least squares (OLS) method; the 3 explanatory variables were found to be effective (N = 414; AICc: 2,963.37; $R^2$ adjusted: 0.459; Koenker's $p < 10^{E-9}$).

The GWR model was found to be better than the OLS model (AICc: 2,757.10; $R^2$ adjusted: 0.698). The coefficient of explanatory variables and standard residues are shown in **Figure 8**. The spatial autocorrelation analysis of standard residues of GWR was conducted to investigate whether the 3 explanatory variables accounted for the distribution of the objective variable. The results suggested that Moran **I** value was 0.017664; Z score, 0.807033; and *p*-value, 0.419647, indicating that the standard residues of GWR were randomly distributed and that the explanatory variables were effective in determining the distribution of spawns.

## 5. DISCUSSION & CONCLUSION

### 5.1 Factors of JBF oviposition site choosing

Comparison of coefficients of explanatory variables generally suggested that the wet ratio and order to the valley mouth had positive impacts, and the paddy size had slight effect on the spawn number (**Fig.8**).

The wet ratio is an important key compared to the order variables that are less variable; however, the wet ratio can be improved by using better water management practices. And such changes of water management practices require less efforts to farmers compared with changing paddy size of order to valley mouth.

### 5.2 Relationship with EFA

Flooded paddy in winter, one of the EFA options, facilitates oviposition of JBF. JBF adults have been found to avoid laying spawns at pools where tadpoles hatch early (Crump 1991). The higher the number of pools in the same habitat, the more is the number of spawns in the same valley or in Kosaji.

Marginal canals, which is another option of EFA, was also related with the wet ratio. An association exits between paddies without the marginal canals (**Fig.9**) and level 0 of wet ratio (**Fig.7**).

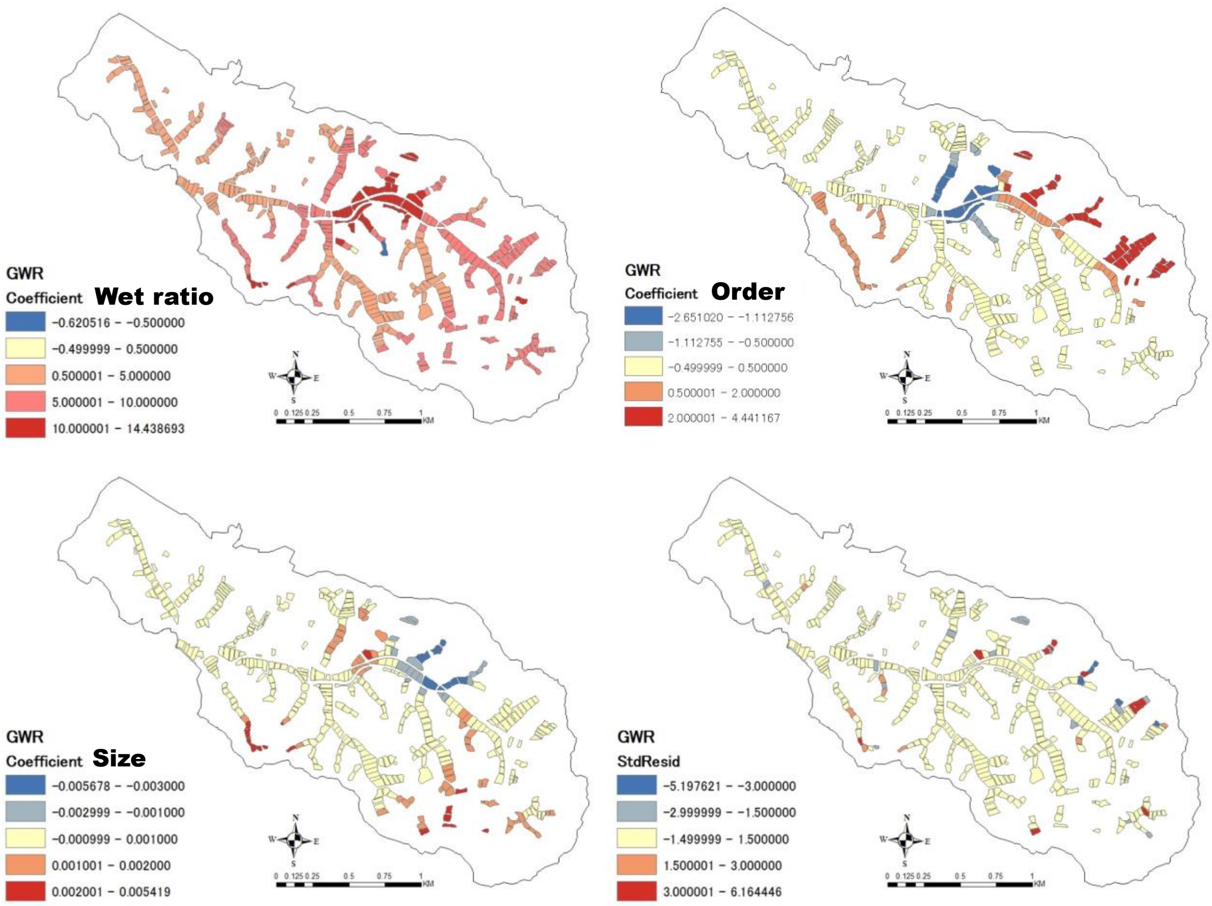


**Fig.8** Coefficients and Standard Residues of GWR Model

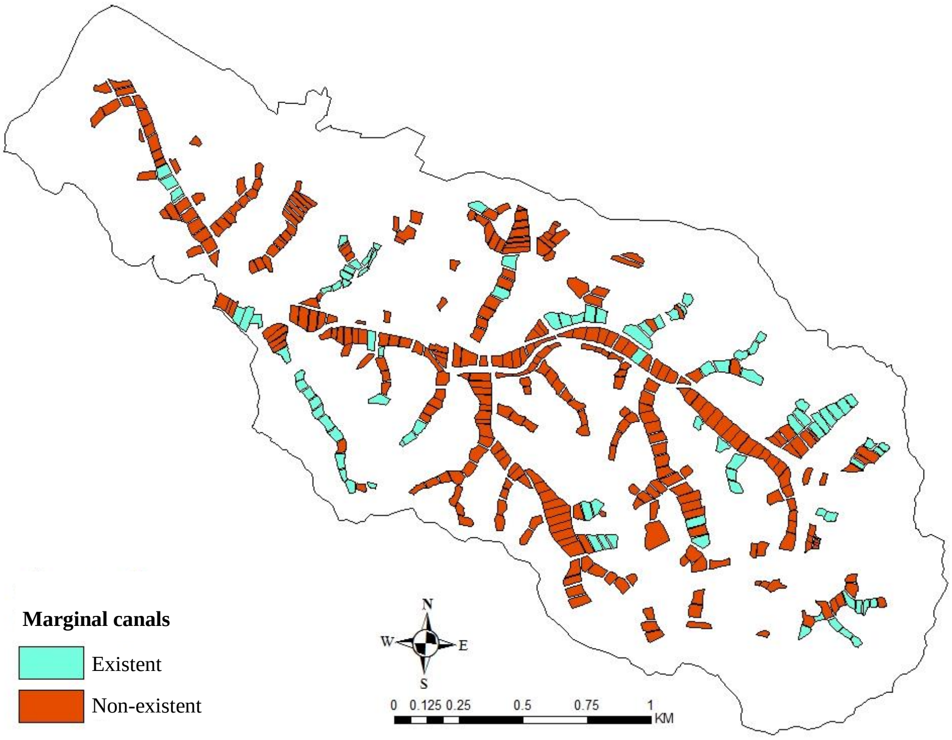


**Fig.9** Distribution of Marginal canals

### 5.3 A local environmental index

In this study, water management was found to have a greater impact on the number of JBF spawns compared to the fixed features. An important local environmental index is that there is some proof of there is evidence of frogs visiting paddy fields. JBF spawns are sufficiently large and can be easily recognized in water during winter. However, JBF spawns can be used as indicators of water management only in winter, but cannot indicate other seasonal parameters.

The KECA has initiated work to identify another local environmental index for summer 3 months after the JBF spawn survey. Their target species is 2 firefly species (*Luciola cruciata* and *Luciola lateralis*), and KECA members identified 2 relative species and developed an observation map, which is established in the JBF spawn survey. They are assimilating spatial analysis to investigate whether candidate species for environmental indices reflect the differences of micro-environment. Thus, the transdisciplinary approach was useful in developing a local environmental index.

## 6. ACKNOWLEDGMENTS

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