Native and non-native frogs responded differently to modernization at Japanese paddy fields

Qothrun Izza¹, G Fujita¹ and T Miyashita¹

¹Department of Ecosystem Studies, Graduate School of Agriculture and Life Sciences, the University of Tokyo, Japan

E-mail: tmiya@es.a.u-tokyo.ac.jp

Abstract. Rice farming modernizations, especially changes in the irrigation system, have been accused as one of the reasons of frog population decline in Japan. Here, we examined responses of native frog, Daruma pond frog (Pelophylax porosus porosus) and non-native frog, Rice frog (Fejervarya kawamurai) population to the modernization in Japanese paddy field. We tested the following two hypotheses: 1) native frog’s density will be lower in the modernized paddy field, and 2) non-native frog density will not be affected by modernization. After two periods of field studies (2017 and 2018), we found that native frog’s density is indeed lower in modernized paddy fields, and the non-native frog’s density is lower in the non-modernized sites. Presumably, changes of shallow soil ditches to concrete ditches in modernized paddy fields act as a death trap for Daruma pond frog. Ditch depth and the distance from forest also significantly affecting the density of Daruma pond frog. On the other hand, the population of Rice frog did not show any negative response to the modernizations. The non-native frog population remained stable because they may have high fecundity.

1. Introduction
Paddy dominated landscapes are a substitute for natural wetlands and harbor high species diversity, with approximately 5000 species recorded [1]. However, this ecosystem threatened by changes in rice farming activity in the last several decades [2]. Agricultural activities changed to a modern one. These modernizations include the use of chemicals, changes of irrigation systems, for example consolidation and deepening ditches, and larger fields [3]. A recent global study showed up to 30% of species richness and species abundance lost due to agricultural expansion, and 7-13% lost due to agricultural intensification or modernization [4]. This proves that agricultural development and modernization are one the largest threat to biodiversity.

The agricultural modernization is one of the leading cause of frog population decline in Japan because certain frog species in Japan inhabit rice field [5]. The population density of several native frogs such as Nagoya daruma frog (Pelophylax porosus brevipodus), Tokyo daruma frog (Pelophylax porosus porosus), and Japanese brown frog (Rana japonica) are reported to be declining as modernization in paddy field continues. Contrary to the native frog decline, the population density of rice frogs (Fejervarya kawamurai) said to remain high within its native range [6]. This species also rapidly spreading from its native range in western to north-eastern part of Honshu island, Japan [7].
The population of non-native Rice frog (*Fejervarya kawamurai*) seems to be unaffected by modernizations in paddy fields. But, there is a lack of information about this persisted population; whether the density is high in non-modernized fields or it is also high in modernized fields, or how their population can persist in the first place. Many studies have been focused on finding out reasons why the native frogs' population is declining in Japan. There is no study that compare the density of native frogs and non-native frogs in relation to the paddy fields modernization.

Here, we compared the population density of native frog, Tokyo daruma frog (*Pelophylax porosus porosus*) and non-native frog, Rice frog (*Fejervarya kawamurai*) between modernized and non-modernized paddy fields in Chiba, Japan. This comparison is a basic need for further assessments for native frog’s conservation planning. Considering that the anthropogenic driven environmental changes are unavoidable, finding out why certain species can persist while others can’t is necessary, to be a controlling factor.

2. Method

2.1. Study sites

There are two types of study sites; modernized and non-modernized sites. Modernized sites contain 208 modernized paddy fields, and non-modernized site contain 70 conventional paddy fields. Study sites are located in two areas; Mefuki and Konotori, Noda City, Chiba prefecture, Japan (figure 1). We chose these sites because it is the northern edge of non-native Rice frogs’ range in Japan [8].

![Figure 1. Study sites in Noda city, Chiba Prefecture, Japan. Modernized site is a large agricultural area with intensive farming activity. The fields in the modernized area was used every time of the year. The non-modernized site consists of fields with environmentally friendly farming activities. The fields were cultivated once a year.](image)

The modernized paddy fields all have concrete ditches, underground water pipe and pump, and large paddy field size. There is limited vegetation in the surrounding area, and the main source of water is a nearby big river called Tone river. Meanwhile, all non-modernized paddy fields have a soil-based ditches which canalize water from underground water spring or creeks to paddy fields, and out to drainage soil-based ditches. The non-modernized paddy fields are smaller than the modernized ones, and the area is surrounded by small forests.

2.2. Field surveys

The field survey was conducted from July to September 2017 and from May to September 2018, once a week at each site, in sunny and cloudy days. Survey unit is the levee in all paddy fields available at each site. Frog data were collected using the visual encounter survey method (walking in each levee to record frog and environmental data). Data recorded were number and size (Snout Vent Length; SVL) of juvenile and adult frog. Environmental factors recorded were: the levee length, vegetation height, and coverage of the levee, the ditches conditions (distance from paddy field, type, depth, water availability, and vegetation covering the ditch), and levee distance from the nearest forest.

2.3. Statistical analysis

2.3.1. Frog density comparison between two sites. The frog density difference between the modernized and non-modernized paddy fields in each year was compared using repeated measure one-way ANOVA tests for unequal sample sizes, with the significant level fixed at 0.01. Due to multiple comparisons (repeated tests) used in these analyses, P-value was adjusted using Bonferroni correction method [9].
2.3.2. Factors affecting the frog’s density. I used generalized linear mixed models (GLMM) to examine factors affecting the density of Daruma pond frog and Rice frog following the principle of model selection using AIC (Akaike’s Information Criteria). I used the lme4 package in R ver. 3.4.2 (R Core Team, 2016). The maximum density of frog recorded from each levee (maximum density from all survey date on each levee) was used as the response variable. I used four independent explanatory variables as fixed effects; 1) Water coverage of the levee, 2) Vegetation height of the levee, 3) Ditch depth, and 4) Distance of levee to the nearest forest. Besides these three variables as fixed effects, two additional variables, Ditch type (concrete or soil) and PADDY ID (IDs of each paddy) were included as random effects to control effects from confounding factors and pseudo-replications. The Poisson distribution was used for the error distribution.

3. Result

3.1. Frog density comparison between modernized and non-modernized paddy fields

There was a significant difference in the density of native and non-native frog between modernized and non-modernized sites. The density of Daruma pond frog was certainly lower in the modernized paddy fields compared to the non-modernized paddy fields on 2017 ($P \leq 0.0001$, differ by 0.019 on average). In contrast, the density of Rice frog was higher the modernized paddy fields ($P \leq 0.0001$, differ by 0.289 on average). The same pattern was seen in 2018. The density of Daruma pond frog was lower in the modernized paddy fields compared to the non-modernized ones ($P \leq 0.0001$, differ by 0.014 on average) and the density of Rice frog was higher the modernized paddy fields ($P \leq 0.0001$, differ by 0.192 on average).

![Figure 2](image.png)

**Figure 2.** The differences of Daruma pond frogs and Rice frogs between two sites in 2017 and 2018. Black dots showed the density of frog in modernized sites, and the red dots showed the density of frog in the non-modernized sites

3.2. Factors affecting the density of frogs

| Year | Daruma pond frog | Rice frog |
|------|------------------|-----------|
| 2017 | 1 Ditch depth + distance from forest
2 Ditch depth + distance from forest + vegetation height
3 Ditch depth + distance from forest + water coverage | 1 Vegetation height + water coverage + ditch depth
2 Vegetation height + water coverage + ditch depth + distance from forest |
| 2018 | 1 Ditch depth + distance from forest + water coverage | 1 Vegetation height + water coverage
2 |
We separated models based on frog species and sampling years. Table 1 showed the best models of each frog species at each year. We can see from the models, the density of Daruma pond frog was affected significantly by the ditch depth and distance from the forest. Both ditch depth and distance from forest have a significant negative effect on the density of Daruma pond frog, meaning that the density of Daruma pond frog decreased as the ditch depth and paddy field distance from forest increased. Other factors, water coverage, and vegetation height do not significantly affect the density of Daruma pond frog.

On the other hand, the ditch depth and distance from the forest were not a prominent factor in the best models for Rice frog. The density of Rice frog was not affected significantly by the ditch depth and distance from forest. The density of Rice frog was more influenced by the water coverage and vegetation height. Water coverage had a significant positive effect on the density of Rice frogs, and vegetation height had a negative effect on the density of Rice frog.

4. Discussion
The density of Daruma pond frog is certainly lower in the modernized paddy fields compared to the non-modernized paddy fields (Figure 2). Ditch depth and distance from the forest showed a significant effect on the density of Daruma pond frog. Ditch depth here also represented the consolidation of ditches. Soil ditches are usually shallower than the concrete one. So generally, the best explanation is that the most significant factor was not only the ditches depth, but the type of irrigation ditches, which we did not use in the regression analysis because of technical problems (there are only two types of ditches, and those types represent the difference between sites, so there is a definite correlation).

Several studies showed that modernization in the irrigation system had caused population declines of certain frog species [10]. Several frogs use rice field as breeding sites, but they move to surrounding environment after reaching adult stage. Those species need habitat connections to move around. The modernization in irrigation systems changes shallow soil ditches to consolidated deep ones, interrupting that connection. So in summary, consolidated deep ditches are likely to act as traps for frogs that have no sucker-legs to help them climb the ditches [11].

Distance from the forest was also considered as a significant factor to explain the Daruma pond frog density. Daruma pond frog preferred paddy field near to the forest. In the ideal wetland ecosystem in Japan, flooded paddy fields are connected with various habitats, such as irrigation ponds, grasslands, or forests [12]. As explained before, several frogs use rice field as breeding sites, but they move to surrounding environment after reaching adult stage [13]. Adult frogs move to surround habitat for foraging, hibernating, or migrating [14]. For those activities, it is certain that forest availability around the paddy field is important.

Another potential factor that we did not assess in this study is the available wet areas around paddy fields. A long term study on Japanese brown frogs (Rana japonica) showed that both rice field intensification and abandonment affect the frog populations through reduction of wet areas in rice fields [15]. Japanese brown frogs breed in wet rice fields in early spring. The rice fields are mostly not irrigated yet, therefore during this fallow season the frogs depend on water puddles formed from groundwater or rain. However, rice field intensifications decreased the wet area during fallow season and therefore interrupting the breeding of Japanese brown frog.

The wet area availability might also have a great impact on Daruma pond frogs because, during planting season, the paddy fields in Japan will be drained at some period around mid-summer. In Japan, rice farming activities begin in early spring. For instance, rice fields are usually flooded in early to mid-April, and the rice seedlings are planted in early to mid-May in the central part of Japan. Water in the rice field then drained for 7-14 days in mid-June to enhance the growth of rice plants [16]. In the mid-season drainage period when water is limited in paddy fields, Daruma pond frog must depend on wet
area around the paddy to survive. Unfortunately, we can’t provide information about relationship of wet area and Daruma pond frog density in this study. However, wet areas might also closely relate to forest as forest can store and provide underground water.

Then, how Rice frog density remained high in the modernized paddy fields and did not negatively affected by concrete ditches or distance from forest? Rice frog might spend all their life in paddy fields without moving to surrounding areas [8, 17]. Therefore, forest availability is not the most significant factor affecting the frog’s density. As for ditches, Rice frog is also considered as a frog with no sucker legs. They can also be trapped in the deep concrete ditches. Our best explanation is that the density of this frog is much higher than other frogs, so the impact of ditches is not significantly affecting the population. *Fejervarya kawamurai* may have fast life-history traits (such as high fecundity, rapid growth, and maturation) [18] that enable them to produce a large number of offspring.

The potential of a species to multiply rapidly is advantageous in environments that are short-lived, allowing the organism to colonize new habitat quickly and exploit new resources [19]. This kind of species has life cycle properties that are favored by natural selection in such condition; production of a large number of offspring and earlier in the life cycle [20]. *Fejervarya kawamurai* might be an example of those species. Female of *Fejervarya kawamurai* lay multiple clutches of eggs, and their tadpole metamorphoses quickly [21]. The ability of *Fejervarya kawamurai* to reproduce effectively may support the survival of this species under agricultural modernization because the loss of density (presumably because of concrete ditches) covered quickly by rapid population growth, and the short larval period is also beneficial against mid-summer drainage in paddy fields. Further research on detailed mechanism of how this non-native frogs can persist in modernized paddy field is needed.

5. References

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