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# DEVELOPMENT OF FLORA IN RELATION TO WATER MANAGEMENT IN OBASUTE-OIKE IRRIGATION POND, JAPAN

Teruo Arase[1], Tetsuo Okano[1], Yoshiyuki Uchikawa[1] and Taizo Uchida[2]

[1]Faculty of Agriculture, Shinshu University, Japan; [2]Faculty of Engineering, Kyushu Sangyo University, Japan

**ABSTRACT:** In order to clarify the factors affecting the species diversity of plant communities around an irrigation pond, we surveyed Obaste-oike Irrigation Pond in Nagano Prefecture, Japan. The pond is comprised of three subdivided ponds, Kami-ike, Naka-ike, and Shimo-ike. Despite being adjacent to each other and connected by streams, the water levels in the three ponds differ. Five plant communities were studied, and one or two survey plots were selected in each community along each subdivided pond. A 32-$m^2$ quadrat was established in each plot of grassland, and a 400-$m^2$ quadrat was established in each plot of forest. The results of the distribution of species revealed that approximately 40% of the species were endemic to each subdivided pond in the terrestrial communities, whereas over 60% were endemic in the hydrophytic communities. To increase species diversity in irrigation ponds, especially in hyrdophytic communities, we suggest that dividing the ponds into several zones with distinct water levels and managing them in a sustainable manner is important.

*Keywords: Obaste-oike Irrigation Pond, Water Level, Plant Community, Species Diversity*

## 1. INTRODUCTION

Recently, irrigation ponds are expected to have various functions, such as ecological conservation, disaster damage prevention, and scenic health resorts [1]. In ecological conservation, it is desirable that ecosystems include numerous plants and animals with high species diversity. However, according to the species-area curve theory, the number of species generally increases and reaches a maximum as the area increases [2], [3]; it follows as a consequence that a small area may include a low number of species. Is there anything that can be done to increase species diversity around an irrigation pond besides increasing its area?

Irrigation ponds are artificial reservoirs that hold water, and in Japan, they are mainly connected with rice paddy fields. Water demands in downstream areas regulate the water level of irrigation ponds. For example, in rice paddy fields, fine adjustments are made to control the water level to suit the growth of rice. Thus, the water level of irrigation ponds fluctuates largely within a year compared with natural water bodies that maintain an almost constant water level [1].

To date, many reports on species diversity in irrigation ponds have focused on hydrophytic vegetation, but most underrate the influence of water level. For example, a study by Shimoda and Kagawa concentrated on conventional water quality analyses [4]. However, since the function of supplying water for agriculture is more important than all other irrigation pond functions, we should pay close attention to the impact that water use for agriculture or other human uses has on the ecosystem around irrigation ponds. Therefore, we decided to focus on the fluctuation of water levels rather than water quality since water levels are directly linked to the distinctiveness of irrigation ponds. A better understanding of the influence of water levels in irrigation ponds will facilitate comprehension of how plant communities develop, and also provide information on how to maintain and control irrigation ponds from the viewpoint of plant communities with high diversity.

We studied Obaste-oike Irrigation Pond (Figs. 1 to 2 and Table 1), which experiences large fluctuations in water level. The pond is comprised of three subdivided adjacent ponds (Kami-ike, Naka-ike, and Shimo-ike). Since both the spilled water (through a sluice gate) and the deep water (through a bottom sluice) are led into the adjacent subdivided ponds (Fig. 1), the three subdivided ponds are estimated to have little differences in water quality. On the contrary, large fluctuations in the water levels of the subdivided ponds occur because water is used from each pond in a pre-defined order (firstly from Shimo-ike, next from Naka-ike, and last from Kami-ike) owing to water shortage (Table 1) [5], [6]. Consequently, it is appropriate to assume that the fluctuation in water level would be larger in Shimo-ike than Naka-ike, and Naka-ike than Kami-ike.

As for hydrophytic plant communities in Obaste-oike Irrigation Pond, a previous study found that approximately 66% of the species surveyed were endemic to each subdivided pond

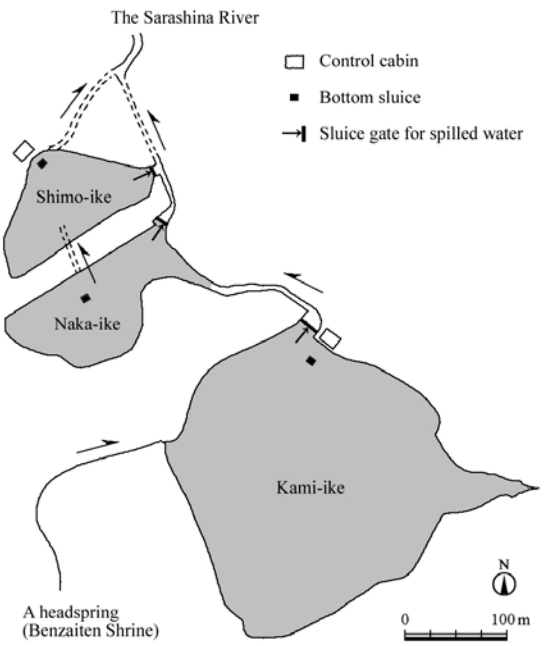


Fig. 1 The water system of Obaste-oike Irrigation Pond.

[5]. The low species similarity among the three subdivided ponds implies that the hydrophytic communities in each subdivided pond appear to have developed independently [5]. However, since the flora of the terrestrial plant communities surrounding the pond was not studied in the previous report [5], it cannot be confirmed whether water level fluctuations caused endemic hydrophytic flora to develop independently in each subdivided pond.

Thus, in the present study, we investigated both hydrophytic and terrestrial plant communities surrounding the subdivided ponds of Obaste-oike Irrigation Pond. By analyzing the species distribution among the three subdivided ponds, we aimed to gain information on the development of flora and the influence water level fluctuations. We also aimed to offer technical recommendations for maintaining and controlling irrigation ponds with high-diversity plant communities.

## 2. METHODS

### 2.1 Investigation Site

Obasute-oike is located at an elevation of 820 m in Chikuma Heights, Chikuma City, Nagano Prefecture, Japan. It irrigates the Obaste-tanada area, which contains famous terraced paddy fields with an area of about 820,000 $m^2$.

This pond was originally constructed in the Edo period (1600-1868), encouraging the use of water collected in a hollow formed by a landslide.

Table 1 Comparison of the three subdivided ponds of Obasute-oike Irrigation Pond.

| Items | Kami-ike | Naka-ike | Shimo-ike |
|---|---|---|---|
| Water reserves ($m^3$) | 191,500 | 28,900 | 40,000 |
| Maximum filling area ($m^2$) | 61,000 | 15,000 | 12,000 |
| Maximum water depth (m) | 5.1 | 2.8 | 8.1 |
| Order of water use | last | ⟷ | first |
| Frequency of sluice control | low | ⟷ | high |
| Fluctuation of water level | (small) | ⟷ | (large) |

Note: This information was previously tabulated by the authors [5].

Fig. 2 Vegetational views of the site. The top: Shimo-ike filled with water, the middle: Naka-ike during a draught, and the bottom: a mountain-side forest along Kami-ike.

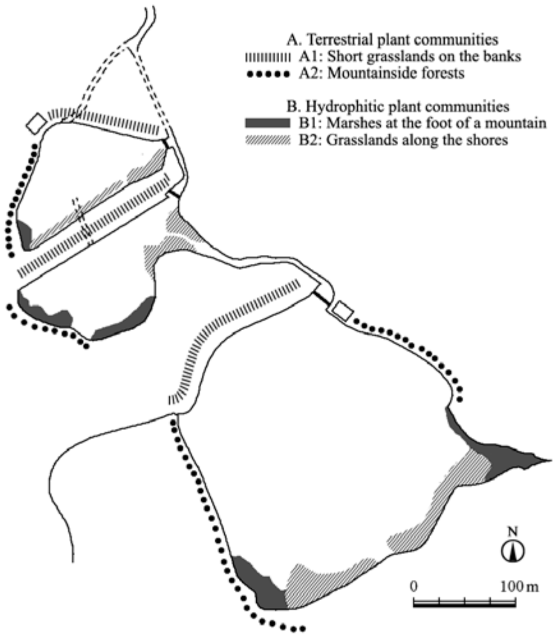


Fig. 3 Distribution of plant communities.

The banks were raised in the Taisho period (1912-1926), but water shortages were still so severe that irrigation disputes occasionally took place among villages. In 1946, Shimo-ike was added to help alleviate water shortages.

### 2.2 Vegetation Survey

The vegetation of the investigation site was classified into five plant communities (Fig. 3) as follows: A) terrestrial plant communities composed of A1) short grasslands on the banks, and A2) mountainside forests; and B) hydrophytic plant communities composed of B1) marshes at the foot of a mountain, B2) grasslands along the shores, and B3) the water area.

The sizes of the investigation plots were 32 $m^2$ (4 m × 8 m) for A1, B1, and B2, and 400 $m^2$ (20 m × 20 m) for A2. As for B3, we observed the whole water area from the shores and used a boat to create a list of the plant species present because of its sparse vegetation. Two investigation plots were established in each of A2, B1, and B2 in Kami-ike and Naka-ike. Only one investigation plot was established in each of the other plant communities because of their limited area.

Vegetation surveys of hydrophytic plant communities (B1, B2, and B3) were conducted in 2010, and those of terrestrial plant communities (A1 and A2) in 2014 and 2015. The plant coverage of each plant species was measured in the plots of A1, A2, B1, and B2. We employed the following classes of plant coverage in each plot for the field survey: +, the plant species covered less than 1% of the plot area; 1, the plant species covered from 1 to 9%; 2, the plant species covered from 10 to 24%; 3, the plant species covered from 25 to 49%; 4, the plant species covered from 50 to 74%; and 5, the plant species covered from 75 to 100%.

To determine the number and distribution of plant species, the plant coverage data were converted into presence or absence data (1 or 0, respectively), and categorized by subdivided pond. Species found in only one of the subdivided ponds were considered “endemic species”, while those found in two or three of the subdivided ponds were considered “common species”. The difference in the categorized totals among plant communities was tested using the $\chi^2$-test performed with a spreadsheet program (Microsoft Excel 2007).

## 3. RESULTS

### 3.1 Vegetation

#### 3.1.1 *Terrestrial plant communities*

Short grasslands on the banks (A1) along each subdivided pond were dominated by orchard grass (*Dactylis glomerata*) and tall fescue (*Festuca arundinacea*). This plant community seemed to be cut frequently.

In mountainside forests (A2) along each subdivided pond, the tree stratum was dominated by Japanese red cedar (*Cryptomeria japonica*) and deciduous broad-leaved trees such as Japanese chestnut (*Castanea crenata*), a species of willow (*Salix* sp.), and konara oak (*Quercus serrata*). The herbaceous stratum was dominated by ferns such as *Dryopteris crassirhizoma*, a bamboo grass (*Sasamorpha borealis*), and sedges such as *Carex stenostachys*.

#### 3.1.2 *Hydrophytic plant communities*

Marshes at the foot of a mountain (B1) were colonized by the common reed *(Phragmites australis*), but its coverage class ranged from + to 3 among plots. *Leersia japonica* and *Impatiens textori* were also found in each subdivided pond.

Grasslands along the shores (B2) were colonized by some emergent plants such as *Leersia japonica*, *Scirpus wichurae*, and *Scirpus triqueter*, but their coverage class ranged from + to 4 among plots.

In the water area (B3), only water chestnut (*Trapa japonica*) was observed to be a common species. Some submerged plants such as

*Potamogeton crispus* were present, but existed very sparsely in the plant community.

### 3.2 Number and Distribution of Plant Species

Table 2 shows the number and distribution of plant species in the three subdivided ponds of Obaste-oike Irrigation Pond. The number of species was different among plant communities; mountainside forests (A2) had the highest number of species at 159, whereas the water area (B3) had the least at 6. The grasslands of A1, B1, and B2 had 41, 92, and 58 species, respectively (Table 2).

In terrestrial plant communities (A1 and A2), the percentages of endemic and common species were nearly 40% and 60%, respectively. On the contrary, these percentages were reversed in hydrophytic communities (B1, B2, and B3) where the percentages of endemic and common species were less than 40% and over 60%, respectively (Table 2). A significant difference in the categorized totals was detected between terrestrial and hydrophytic communities ($\chi^2$-test, $p$<0.0001).

## 4. DISCUSSION

From the results of the percentages of endemic and common species, a reversal and a similarity were detected among the five plant communities in Obasute-oike Irrigation Pond. It is important to note that the majority of species in terrestrial plant communities (A1 and A2) were common species whereas endemic species were more prominent in hydrophytic plant communities (B1, B2, and B3). The percentages were relatively close between A1 and A2, and also among B1, B2, and B3, although the landscape and the total number of species were distinct in each plant community (Table 2).

The most intrinsic difference between the terrestrial and hydrophytic environment is whether ordinary water flooding occurs or not. Since the subdivided ponds are estimated to have little differences in water quality, it can be assumed that water level would be a significant factor in the regulation of plant communities. In terrestrial plant communities, relatively similar soil environments would allow many common species throughout the area. However, in hydrophytic plant communities, fluctuations in water level strongly increase the mortality of plants and influence their growth, which results in a flora with many endemic species in response to the microenvironment.

Based on the results of the present study, some technical recommendations can be made to maintain and control irrigation ponds with high-diversity plant communities. If the environment of a pond is homogeneous, the number of plant species will be limited by its area, as a consequence of the species-area curve theory [2], [3]. It seems difficult to increase species diversity in terrestrial plant communities because of the lack of regulating factors as substantial as water. However, in hydrophytic plant communities, dividing the area into several zones with different microenvironments (i.e. different water depths or flooding frequencies) is expected to increase species diversity beyond the capacity of its area, as demonstrated in the subdivided ponds of Obasute-oike Irrigation Pond. It is important to create a heterogeneous environment throughout the area,

Table 2 Number and distribution of plant species in the 3 subdivided ponds of Obaste-oike Irrigation Pond.

| Plant community | Endemic species | | | Common species | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | Kami-Ike | Naka-ike | Shimo-ike | Kami-ike Naka-ike | Naka-ike Shimo-ike | Kami-ike Shimo-ike | All the 3 ponds | |
| Terrestrial | | | | | | | | |
| A1 | 5 | 6 | 5 | 3 | 7 | 3 | 12 | 41 |
| % | 12.2 | 14.6 | 12.2 | 7.3 | 17.1 | 7.3 | 29.3 | |
| subtotal % | | | 39.0 | | | | 61.0 | 100.0 |
| A2 | 22 | 21 | 23 | 17 | 17 | 14 | 45 | 159 |
| % | 13.8 | 13.2 | 14.5 | 10.7 | 10.7 | 8.8 | 28.3 | |
| subtotal % | | | 41.5 | | | | 58.5 | 100.0 |
| Hydrophytic | | | | | | | | |
| B1 | 31 | 27 | 6 | 16 | 4 | 2 | 6 | 92 |
| % | 33.7 | 29.3 | 6.5 | 17.4 | 4.3 | 2.2 | 6.5 | |
| subtotal % | | | 69.6 | | | | 30.4 | 100.0 |
| B2 | 7 | 10 | 20 | 8 | 3 | 3 | 7 | 58 |
| % | 12.1 | 17.2 | 34.5 | 13.8 | 5.2 | 5.2 | 12.1 | |
| subtotal % | | | 63.8 | | | | 36.2 | 100.0 |
| B3 | 1 | 2 | 1 | 1 | 0 | 0 | 1 | 6 |
| % | 16.7 | 33.3 | 16.7 | 16.7 | 0.0 | 0.0 | 16.7 | |
| subtotal % | | | 66.7 | | | | 33.3 | 100.0 |

and to establish and maintain several zones of distinct microenvironments.

However, the water level in an irrigation pond can be maintained on the assumption that someone regulates it. In Obaste-oike Irrigation Pond, the most fundamental method of adjusting the water level is the indispensable water demand of continuing traditional rice cultivation in the downstream areas.

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**Corresponding Author: Teruo Arase**