THE IMPORTANCE OF CONSOLIDATED DRAINAGE CANALS AS A HABITAT FOR AQUATIC PLANTS

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The role of agriculture waterways as a habitat for aquatic plants after farmland consolidation has not been recognized. The goal of this study was to clarify how concrete agricultural waterways contribute to regional plant diversity and to elucidate factors that determine the distribution of aquatic plants in such waterways. We compared the aquatic flora in an irrigation canal, drainage canal, marsh, river, and rice field in a farming region in Northern Japan. The drainage canal had the highest ratio of unique species among the five habitats, and raised regional β-diversity. The analysis of environmental factors showed that aquatic plant communities are associated with water velocity less than 0.25 m/s during the irrigation period in the current waterway. The emergent and the free-floating plants were distributed throughout areas with high electrical conductivity (EC) and low dissolved oxygen (DO). The floating-leaved *Potamogeton* species were distributed throughout the main drainage canal, which was characterized by high DO and current. A specific habitat in which rare plant species dominated, characterized by the inflow of spring water, low current velocity, was established in some sections of the lateral drainage canal. It is concluded that consolidated drainage canals are extremely important for improving regional plant diversity. In addition, this study showed that various physical habitats promote aquatic plant diversity.

1 INTRODUCTION

Farmland consolidation is defined as improving irrigation and drainage facilities and expansion of paddy size for increase of agricultural productivity [1]. In Japan, farmland consolidation projects were institutionalized in Japan in 1963, and since then waterways have been concreted and large-scale land modifications have been made in many agriculture areas. As a result, we have lost many swamps and many of the riparian species that previously coexisted with humans in the seasonal agricultural environment [2,3]. Therefore, agricultural engineering works such as drainage canals therefore need to be designed to balance ecosystem functioning with improvement of farm productivity. In areas where farmland was consolidated earlier, 30 or 40 years have now passed; existing facilities are deteriorating and need to be updated. The environmental conditions favoring the growth of aquatic plants on farmland must be considered in the design or restoration of such facilities. Aquatic plants grow better in unlined soil waterways, but no study has yet examined the environment of concrete agricultural waterways after farmland consolidation. We think that concrete agricultural waterways after farmland consolidation may also have rich aquatic plant species diversity.

From the above perspective, here we studied how concrete waterways present after farmland consolidation contributed to regional plant diversity in a local agriculture area in North Japan. In addition, we clarified the environmental conditions that were important to the growth of aquatic plants in these waterways.

2 METHODS

2.1 Study site

The study site was located in the Ishikari lowland area of Hokkaido, which is Japan’s leading rice-farming district (Figure1). This area has been developed for rice farming for a long time: farmland consolidation was completed in the 1970s, right after the institutionalization of land consolidation. The farmland at the study site was consolidated about 40 years ago; existing facilities are deteriorating and need updating.

2.2 Field investigations

In this 550-ha farming region, we surveyed the aquatic flora in irrigation canals, drainage canals, a marsh, a river, and a rice field. We targeted emergent plants, submerged plants, floating-leaved plants, and free- floating plants, as defined by Kadono [4], as aquatic flora.

We surveyed species composition by placing a 1×1 m quadrat in 62 plots. In each quadrat, the coverage of each plant species was examined in 5% increments. Thirteen physical or chemical variables were examined. Water depth, mud depth, water temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), and current velocity were examined at the time of the community survey. We also recorded four waterway types (irrigation canals, main drainage canal, lateral drainage canal, unlined drainage canal), distance from the spring, and distance from the spillway. Adjacent to each picket point, in the middle of each waterway we measured water depth, mud depth, and current velocity by using a measuring pole and a current meter. These physical variables were measured three times, and the averaged values were used for further analysis. These field investigations were conducted in August to September 2014.

Figure1. Study site and canal network (2014)

2.3 Statistical analysis

TWINSPAN was used to classify the 62 plots into several plant community types by using species composition data. Canonical correspondence analysis [CCA; 5] was used to detect environmental gradients in the plant communities. Coverage of plant species was used as dependant variable and the 13 environmental variables were used as explanatory variables in this analysis. In addition, we created a classification tree to clarify the boundary of environmental variables for each plant community. The correlation analysis using Pearson's correlation corrected by the Bonferroni method was used to determine the relationship between species richness and the 13 environmental variables.

3 RESULT

3.1 Comparison of the aquatic flora

We identified 36 aquatic plant species. We found 11 species in the rice field, 24 in the swamp, 11 in the river, and 28 in the drainage canals (Table 1). We did not find aquatic plant species in the irrigation canals. Although most of the drainage canals were made of concrete, the percentage of species found there that were not found elsewhere was the highest, at 25%. Species that were found only in the drainage canals included *Sparganium simplex*, *Eleocharis acicularis* var. *longiseta*, *Potamogeton crispus*, and *Potamogeton cristatus*. In contrast, all 11 species found in the rice field were confirmed to occur in other landscape elements.

3.2 Habitat of the aquatic plant in the waterway

The CCA showed that communities of emergent plants and free-floating plants (*Lemna minor and Alisma canaliculatum*) were established in the unlined drainage canal and were characterized by high EC and low DO. A

Table 1. Aquatic plant species, number of species and the ratio of unique species to each landscape element (● limited 1 landscape element)

Life form	Species name	rice field	swamp	river	drainage canal	irrigation canal
Emergent plant	*Equisetum fluviatile*		○	○	○	
	Nuphar japonicum		○		○	
	Alisma canaliculatum	○	○		○	
	Alisma plantago-aquatica var. orientale	○	○	○	○	
	Sagittaria trifolia	○			○	
	Monochoria korsakowii	○	○		○	
	Iris pseudacorus		●			
	Phragmites australis	○	○	○	○	
	Torreyochloa viridis				●	
	Zizania latifolia		●			
	Sparganium erectum		○	○	○	
	Sparganium glomeratum				●	
	Typha latifolia	○	○	○	○	
	Eleocharis acicularis var. longiseta				●	
	Eleocharis mamillata var. cyclocarpa			●		
	Scirpus juncoides subsp. hotarui			○	○	
	Scirpus tabernaemontani		○	○		
	Scirpus triqueter				●	
	Scirpus yagara		●			
Free-floating plant	*Ceratophyllum demersum*		●			
	Utricularia vulgaris var. japonica		○		○	
	Lemna aoukikusa	○	○		○	
	Lemna minor	○	○	○	○	
	Spirodela polyrhiza	○	○		○	
Floating-leaved plant	*Nymphaea tetragona var. angusta*		●			
	Trapa japonica		●			
	Potamogeton cristatus				●	
	Potamogeton distinctus				●	
	Potamogeton natans		○		○	
	Potamogeton octandrus		○	○	○	
	Sparganium simplex				●	
Submerged plant	*Elatine triandra var. pedicellata*	○	○		○	
	Myriophyllum verticillatum				●	
	Callitriche verna	○	○		○	
	Potamogeton crispus				●	
	Potamogeton berchtoldii		○	○	○	
Number of species		11	24	11	28	0
Number of unique species		0	6	1	9	0
Unique species / all species		0	0.17	0.03	0.25	0

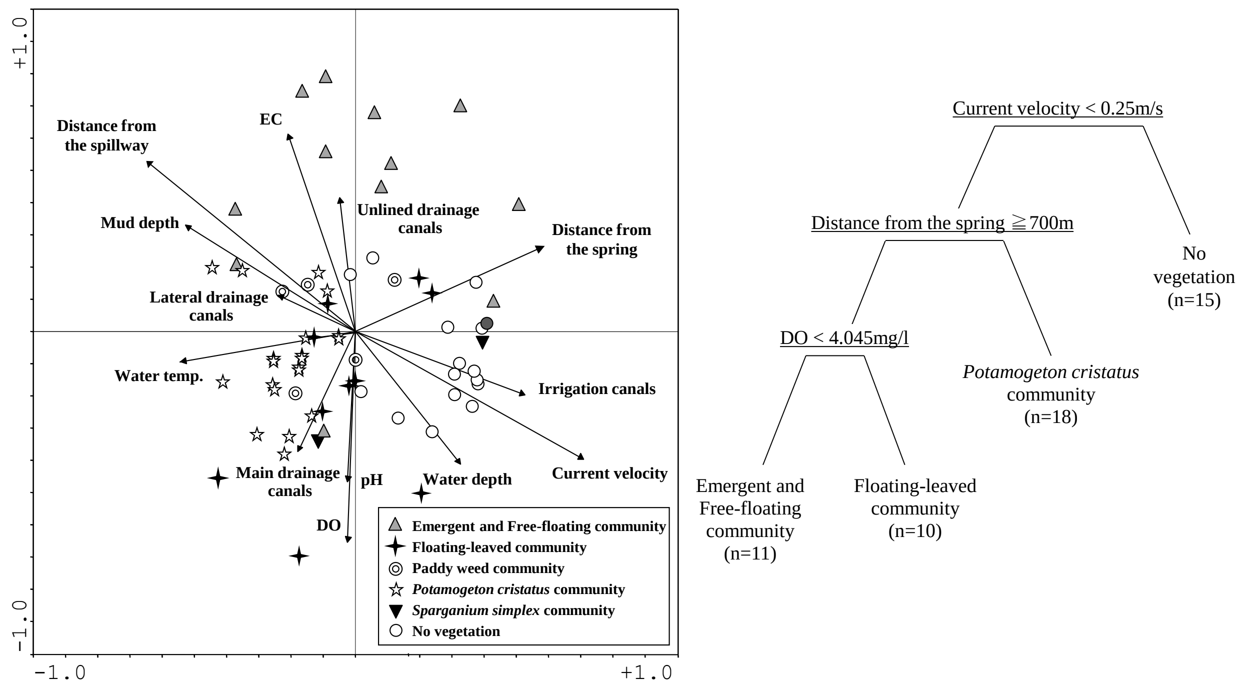

Figure2. CCA ordination diagram (left), and classification tree (right) using the data of 62 plots in drainage canal (Each plant community types classified using TWINSPAN).

floating-leaved plant community (*Potamogeton octandrus*) was established in the main drainage canal and was characterized by high DO and pH. The specific habitat in which the rare plant species (*P. cristatus*) dominated was characterized by spring water inflow and low current; this species was established in some sections of the lateral drainage canal. The classification tree showed that aquatic vegetation did not become established when the current velocity during the irrigation period exceeded 0.25 m/s (Figure 2). In all of the irrigation canals, aquatic plants were unable to settle on the bottom because the strong flow during the irrigation period carried away the mud required for the plants to settle. On the other hand, where the current velocity during the irrigation period was less than 0.25 m/s, mud was deposited in the drainage canal and vegetation became established. Most of the ingredients of the mud were silt. At a spillway where water fell into drainage from the irrigation canal, the current velocity exceeded 0.8 m/s. Only the *Sparganium* community became established, at a location about 20 m downstream from the spillway. The correlation analysis showed that number of species was negatively correlated with current velocity (r=-0.52) and water depth (r=-0.44) in each quadrat.

4 DISCUSSION

Many aquatic plant species not seen in other landscape elements grew in the drainage canals after land consolidation. Therefore, the concrete drainage canals likely functioned as major landscape elements to improve aquatic plant species diversity in the agricultural area. In particular, these drainage canals were the habitat of submerged plant communities, the populations of which had recently declined markedly in the floodplain. In addition, these drainage canals also had many common aquatic species with other landscape elements. Thus, the concrete drainage canals likely raised local β diversity in this study site, and also functioned as one of the refuge of the common aquatic species.

No aquatic plants grew in some sections of the *Sparganium simplex* community was established in the fast-flowing section downstream of the spillway. This shows that *Sparganium* was likely suited to this relatively fast flow because of its tape-like shape [4]. Many aquatic plant communities were established in areas of slow current. Plant communities also differed among different drainage types (main, lateral, unlined). The emergent and free-floating plants communities were present in the unlined canal, which were characterized by high EC and low DO. As the unlined canal was an environment that eutrophied and became anaerobic, many plants in these communities, which could grow in eutrophied and anaerobic conditions, were dominant. A floating-leaved community which was dominated by some *Potamogeton* species was present in the main drainage canals, which was characterized by high DO and pH. We think that much oxygen dissolved in the water by active photosynthesis of the floating-leaved plant mat, and water became alkaline by carbon dioxide being used by photosynthesis concurrently. The *P. cristatus* community was characterized by spring water inflow and low current. This is rare plant community with an extremely limited domestic distribution [4]. The aquatic plants which specifically appears in the spring water are known, this may be one of the community which specifically appears to spring water.

We found here that concrete drainage canals were important habitats for aquatic plant communities. Aquatic plant diversity in the drainage canals depended on the waterway type and on various current and oxygen conditions, inflow of spring water. Creation and conservation of places that offer a variety of physical environmental conditions is important. Existing facilities such as waterways need to be updated and restored to balance the securing of agricultural yields with maintenance of the diversity of plants and other organisms.

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